Effect of Live High – Train Low Altitude Training on Hemoglobin Mass and Sea Level Endurance Performance

Experiences with Swiss World Class Endurance Athletes

Jon Peter Wehrlin, PhD
Head Endurance Group, Section for Elite Sport
Swiss Federal Institute of Sports, Magglingen, Switzerland
Swiss Federal Institute of Sports Magglingen
Endurance Physiology Group, Section for Elite Sport

Anna Hauser, MSc, 100%. PhD Student

Thomas Steiner PhD, 100%. XC Skiing, Triathlon

Thomas Maier, MSc ETH 100%. MTB, Biathlon.

Severin Trösch, MSc ETH, 100%. Athletics, XC Skiing, Triathlon

Beat Müller BSc EHSM, DTLG, 60%. MTB, Biathlon Coach
Swiss Cycling.

Neu: Raphael Faiss, PhD, 100%. Cycling.

Jon Peter Wehrlin PhD, 100%. Head Group
Swiss Federal Institute of Sport, (University of Applied Sciences), Magglingen

=> Section for Elite Sport
(Collaboration with Swiss Olympic Association)

Performance diagnosis

Elite Sport

Research & Development

Teaching
- Bachelor
- Master Elite Sport (Since 2008)
- Coaches Education
- Sport medicine education
Contents:

1) Origin of Altitude Training: Live High – Train High

2) Live High – Train Low Altitude Training: Effects on Hemoglobin Mass and Sea Level Performance

3) Individual Hemoglobin Mass Responses

4) Examples: Experiences with Swiss National Team Athletes
1) Origin of Altitude Training: Live High – Train High
Olympic Games 1968 in Mexico City (Altitude 2300m)
Results of the Olympic Games 1968 in Mexico City

Live High – Train High

Preparing for Competitions at Altitude

Days at altitude

Change in VO$_{2\text{max}}$ (%) with acclimatization

-33%

LTHH

Saltin 1966; LTHH; 2300m; Olympic endurance athletes; n = 13
Pugh 1967; LTHH; 2270m; Runners; n = 6
Faulkner et al. 1967; LTHH; 2300m; Swimmers; n = 15
Faulkner et al. 1968; LTHH; 2300m; Runners; n = 5
Adams et al. 1975; Group I; LTHH 2300m; Runners; n = 6
Adams et al. 1975; Group II; LTHH; 2300m; Runners; n = 6
Jensen et al. 1993; LTHH; 1822m; Rowers; n = 9
Saltin 1997; LTHH; 2200m; XC-skiers; n = 12
Schuler et al. 2007; LHTL; 2344m; Cyclists; n = 8

Federal Office of Sport, Magglingen, Switzerland
Jon Peter Wehrlin, PhD, Section for Elite Sport
Live High – Train High

Preparing for Competitions at Sea Level

Living high - Training high

Advantage

Disadvantage

"red cell volume"

Reduced absolute training intensity
Live High – Train High

Reduced Absolute Training Intensity at Altitude

Wehrlin & Hallén, Eur J Appl Physiol, 2006

- 7.2% per 1000m
2) Live High – Train Low Altitude Training:

Concept and Background Information
Live High – Train Low

Preparation for Competitions at Sea Level

Advantage

"red cell volume"

Disadvantage

Reduced Intensity

“Living high-training low”: effect of moderate-altitude acclimatization with low-altitude training on performance

BENJAMIN D. LEVINE1 AND JAMES STRAY-GUNDERSEN2
1Institute for Exercise and Environmental Medicine, Presbyterian Hospital of Dallas 75231; and
2Baylor/The University of Texas Southwestern Sports Science Research Center,
The University of Texas Southwestern Medical Center, Dallas, Texas 75235

Levine & Stray-Gundersen, J Appl Physiol, 1997

Federal Office of Sport, Magglingen, Switzerland
Jon Peter Wehrlin, PhD, Section for Elite Sport
Live High – Train Low

Preparing for Competitions at Sea Level

Levine & Stray-Gundersen, J Appl Physiol, 1997
Live High – Train Low

Preparation for Competitions at Sea Level

Living high - Training low

Advantage

"red cell volume"

Disadvantage

Reduced Intensity
Live High – Train Low

Blood – Concentration Measures

**Hematocrit (Hct; %)**
- Percent red blood cells
- Men ca. 45%
- (Critical value men 50%)

**Hemoglobin (Hb; g/dl)**
- Mean value ca. 15g/dl / 17g/dl
- Red color in red blood cells, Binds the oxygen
Problem: We do not know how the absolute values are!
Live High – Train Low

Blood

Hb (g/dl) and Hct (%): Effects of changes in plasma volume

Important factors:
- Position: (horizontal = ↓ vs vertical = Hct ↑)
- Hydration status (low = Hct ↑; high ↓)
- Training (acute = Hct ↑; after = Hct ↓)
- Altitude: (acute = Hct ↑)
- Heat: (acute = Hct ↑; chronic ↓)
Live High – Train Low

Blood – Absolute values

Blood volume: 8000 ml

Hemoglobin mass: 1256 g

Red cell volume: 3520 ml

Plasma volume: 4480 ml
Live High – Train Low

Blood

=> Total amount of hemoglobin in g

CO-rebreathing method (100 years):
- Revived by Fogh-Andersen et al. (1990) and Thomsen et al. (1991) and is now frequently used in Sports Science and Sports Medicine:
  - with minor modifications (Prommer & Schmidt 2007)

Meta-Analysis about Error Measurement for blood volume parameters (Gore et al. 2005):
=> CO-rebreathing-method has the lowest error
Endurance sport: VO$_{2\text{max}}$ - Possible limiting factors

Lung diffusion capacity

Heart capacity

Oxygen transport capacity

Muscle capacity

Live High – Train Low

Blood

Schmidt & Prommer  Exerc Sport Sci Rev, 2010
Endurance Sport: Blood Doping

….can move you from 30th place to the podium…

Importance of the hemoglobin mass: Blood doping

Switzerland

Gedopter Thomas Frei erklärt, wie er die Kontrolleure jeweils täuschte

Spain

Neue Testergebnisse bringen Contador in Erklärungsnot

USA

Denmark

…..etc.
Increase in Red Cell Volume (Hemoglobin mass) with rhEPO Doping

Lundby et al., J Physiol, 2007
Live High – Train Low

Blood

![Graph showing increase in Hb mass for different conditions]

Schmidt & Prommer Exerc Sport Sci Rev, 2010
2) Live High – Train Low Altitude Training:

Effects on Hemoglobin Mass and Sea Level Performance

Key Question I for Elite Endurance Athletes:

How should I plan LHTL that hemoglobin mass increases?
Live High – Train Low

Blood

### Live High – Train Low

**Blood – Situation when we started 10 years ago**

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Altitude</th>
<th>Duration</th>
<th>Duration (h)</th>
<th>Technique</th>
<th>Result RCM / Hbmass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levine et al.</td>
<td>1991</td>
<td>2500</td>
<td>4 weeks</td>
<td>616</td>
<td>EB</td>
<td>↑ BV</td>
</tr>
<tr>
<td>Stray Gundersen et al.</td>
<td>1992</td>
<td>2500</td>
<td>4 weeks</td>
<td>616</td>
<td>EB</td>
<td>↑</td>
</tr>
<tr>
<td>Harper et al.</td>
<td>1995</td>
<td>2500</td>
<td>4 weeks</td>
<td>672</td>
<td>EB</td>
<td>↑</td>
</tr>
<tr>
<td>Levine et al.</td>
<td>1997</td>
<td>2500</td>
<td>4 weeks</td>
<td>616</td>
<td>EB</td>
<td>↑</td>
</tr>
<tr>
<td>Svedenhag at al.</td>
<td>1997</td>
<td>1900</td>
<td>4 weeks</td>
<td>720</td>
<td>I</td>
<td>→</td>
</tr>
<tr>
<td>Klausen et al.</td>
<td>1992</td>
<td>2000</td>
<td>6 days</td>
<td>144</td>
<td>CO</td>
<td>→</td>
</tr>
<tr>
<td>Friedmann et al.</td>
<td>1996</td>
<td>1800</td>
<td>3 weeks</td>
<td>504</td>
<td>CO</td>
<td>→</td>
</tr>
<tr>
<td>Telford et al.</td>
<td>1996</td>
<td>1760</td>
<td>4 weeks</td>
<td>672</td>
<td>CO</td>
<td>→</td>
</tr>
<tr>
<td>Gore et al.</td>
<td>1998</td>
<td>2690</td>
<td>4 weeks</td>
<td>744</td>
<td>CO</td>
<td>→</td>
</tr>
<tr>
<td>Ashenden et al.</td>
<td>1999</td>
<td>2650</td>
<td>12 days</td>
<td>207</td>
<td>CO</td>
<td>→</td>
</tr>
<tr>
<td>Ashenden et al.</td>
<td>1999</td>
<td>2650</td>
<td>2 weeks</td>
<td>108</td>
<td>CO</td>
<td>→</td>
</tr>
<tr>
<td>Ashenden et al.</td>
<td>2001</td>
<td>3000</td>
<td>4 weeks</td>
<td>207</td>
<td>CO</td>
<td>→</td>
</tr>
<tr>
<td>Dehnert et al.</td>
<td>2002</td>
<td>1956</td>
<td>2 weeks</td>
<td>182</td>
<td>CO</td>
<td>→</td>
</tr>
</tbody>
</table>

Adapted from Ashenden et al. 1999, Eur J Appl Physiol, 80:479-484
LHTL with CO Rebreathing and high enough hypoxic dose

**Live High – Train Low – Studies with CO Rebreathing Method**

<table>
<thead>
<tr>
<th>Change in Hb mass / RCV (%)</th>
<th>Time in hypoxia (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4</td>
<td>0</td>
</tr>
<tr>
<td>-2</td>
<td>100</td>
</tr>
<tr>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
</tr>
<tr>
<td>4</td>
<td>400</td>
</tr>
<tr>
<td>6</td>
<td>500</td>
</tr>
<tr>
<td>8</td>
<td>600</td>
</tr>
<tr>
<td>10</td>
<td>700</td>
</tr>
<tr>
<td>12</td>
<td>800</td>
</tr>
<tr>
<td>14</td>
<td>900</td>
</tr>
<tr>
<td>16</td>
<td>1000</td>
</tr>
<tr>
<td>18</td>
<td>1100</td>
</tr>
<tr>
<td>20</td>
<td>1200</td>
</tr>
<tr>
<td>22</td>
<td>1300</td>
</tr>
<tr>
<td>24</td>
<td>1400</td>
</tr>
<tr>
<td>26</td>
<td>1500</td>
</tr>
<tr>
<td>28</td>
<td>1600</td>
</tr>
<tr>
<td>30</td>
<td>1700</td>
</tr>
</tbody>
</table>

Hemoglobin mass + 1% per 100h at 2300-2500m

- Laitinen et al. 1995 (Abstract only; n=7 Runners; LHTL; Simulated altitude: 2500m; 20-28 days; CG)
- Svedenhag et al. 1997 (n=7 XC-skiers; LHTH; Real altitude: 1900m; 30 days; EB)
- Levine et al. 1997 (n=13 Runners; LHHT; Real altitude: 2500m; 28 days; CG; EB)
- Levine et al. 1997 (n=13 Runners; LHTL; Real altitude: 2500m; 28 days; CG; EB)
- Gore et al. 1998 (n=8 Cyclists; LHHT; Real altitude: 2690m; 31 days; CO)
- Rusko et al. 1999 (Abstract only; n=10 XC-Skiers/Triathletes; LHTL; Simulated altitude: 2500m; 25 days; CG; CO)
- Ashenden et al. 1999b (n=7 Runners; LHTL; Simulated altitude: 2650m; 12 days; CG; CO)
- Ashenden et al. 1999a (n=6 Cyclists/Triathletes/XC-skiers; LHTL; Simulated altitude: 3000m; 23 days; CG; CO)
- Dehnert et al. 2002 (n=11 Triathletes; LHHT; Real altitude: 1956m; 14 days; CG; CO)
- Saunders et al. 2004 (n=10 Runners; LHTL; Simulated altitude: 2000-31000m; 20 days; CG; CO)
- Friedmann et al. 2005 (n=16 Junior swimmers; LHHT; Real altitude: 2100-2300m; 21 days; CO)
- Heinicke et al. 2005 (n=10 Biathletes; LHHT; Real altitude: 2050; 21 days; CO)
- Brugniaux et al. 2006 (n=5; LHHT; Simulated altitude: 2500-3000m/1200m; 18 days; CG; CO)
- Robach et al. 2006 (n=9 Swimmers; LHTL; Simulated altitude: 2500-3000m/1200m; 13 days; CG; CO)
- Robach et al. 2006 (n=6 XC-skiers; LHTL; Simulated altitude: 2500-3500m/1200m; 18 days; CG; CO)
- Wehrlin & Marti 2006 (n=2 Runners; LHTL; Real altitude: 2456/1800m; 26 days; CO)
- Wehrlin et al. 2006 (n=10 Orienteers; LHTL; Real altitude: 2456m/1800m/1000m; 23 days; CG; CO)
- Neya et al. 2007 (n=10 runners; LHTL; Simulated altitude: 3000m; 29 days; CO)
- Pottgiesser et al. 2008 (n=7 Cyclists; LHHT; Real altitude: 1616m; 21 days; CO)
- Saunders et al. 2009 (n=9 Runners; LHHT; Simulated altitude: 2860m; 46 days; CO)
- Wehrlin et al. 2009 (Submitted; n=7; Cross-country skiers; LHHT; Real altitude: 2590m; 21 days; CG)
- Clark et al. 2010 (n=12 cyclists; LHTL; Simulated altitude: 3000m)
=> In summary, natural LHTL currently provides the best protocol for enhancing endurance performance in elite and subelite athletes

*Bonetti & Hopkins, Sea level Exercise performance following adaptation to Hypoxia, Sports Med, 2009*
3) Is performance after LHTL altitude training increased?

=> Keep in Mind:

Millet et al., Sports Med, 2010 (modified after Reiss)
3) Individual Hemoglobin Mass Responses

Key Question II for Elite Endurance Athletes:

Did MY Hemoglobin Mass increased with my LHTL Regimen?
Individual Hemoglobin Mass Responses

Statistical Significance vs. Practical Relevance

Hemoglobin mass (g)

Pre Altitude

Post Altitude

Original

Original

+ 4%
Individual Hemoglobin Mass Responses

Hemoglobin mass (g)

Pre Altitude

Post Altitude

Original

Measured

Original

+ 4%

+ 0%
Individual Hemoglobin Mass Responses

![Graph showing hemoglobin mass responses before and after altitude change]

- Hemoglobin mass (g)
- + 0%
- Pre Altitude
- Post Altitude

Federal Office of Sport, Magglingen, Switzerland
Jon Peter Wehrlin, PhD, Section for Elite Sport
Individual Hemoglobin Mass Responses

Hemoglobin mass (g)

Pre Altitude          Post Altitude

Original               Original

Measured              Measured

+ 4%                  + 0%

Original

Measured

+ 4%
Double Hemoglobin Mass Measurements

3 weeks at 1800m (St. Moritz)

+ 2.2%

Hemoglobin mass (g)

Pre Altitude  Post Altitude

Measurement I  Measurement II  Measurement I  Measurement II
Individual Hemoglobin Mass Response (LHTL)

Hauser et al. (In Preparation)

Anna Hauser
PhD Student
Magglingen – Lausanne
4) Examples: Experiences with Swiss National Team Athletes
Example: Experiences with Swiss National Team Athletes

2010  LHTL Altitude Training „Best Practice“

2011  Individual Adaptations

2012  London Olympic Games
Example: Experiences with Swiss National Team Athletes

World Cup / C1
- World Cup Houffalize 1./2.5.2010
- World Cup Offenburg 22./23.5.2010
- World Cup/C1 Chambéry 6.6.2010
- C1 Engelberg 20.6.2010
- World Cup C1 5./6.6.10

European Championships Haifa
7.7. - 11.7.2010
23-28 days after LHTL

LHTL Bernina Hospiz
25.5 - 13.6.2010

Weeks after LHTL
1 2 3

Control group
- Full Test 18.5.2010
- Full Test 15.6.2010
- Full Test 24.6.2010
- Full Test 1.7.2010

Altitude group
- Full Test 17.5.2010
- Full Test 14.6.2010
- Full Test 25.6.2010
- Full Test 2.7.2010

Target I
- European Championships Haifa
7.7. - 11.7.2010
23-28 days after LHTL

Target II
- C2 Flims?
3.7.2010

Example:
Experiences with Swiss National Team Athletes

Federal Office of Sport, Magglingen, Switzerland
Jon Peter Wehrlin, PhD, Section for Elite Sport
Example: Experiences with Swiss National Team Athletes

Performance: Capacity Test with Self selected Speed

+3.3%
(unpublished Data)
Example: Experiences with Swiss National Team Athletes

Viktor Röthlin
Swiss Marathon
Example: Experiences with Swiss National Team Athletes

Example: Experiences with Swiss National Team Athletes

Table 1  Haematological variables before and after 26 days of living high and training low in two world class runners

<table>
<thead>
<tr>
<th></th>
<th>5000 m runner</th>
<th></th>
<th>Marathon runner</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>% change</td>
<td>Before</td>
</tr>
<tr>
<td>Packed cell volume</td>
<td>0.388</td>
<td>0.386</td>
<td>-0.5</td>
<td>0.427</td>
</tr>
<tr>
<td>Haemoglobin (g/l)</td>
<td>132</td>
<td>133</td>
<td>-0.8</td>
<td>156</td>
</tr>
<tr>
<td>Haemoglobin mass (g)</td>
<td>878</td>
<td>945</td>
<td>+7.6</td>
<td>952</td>
</tr>
<tr>
<td>Erythrocyte volume (ml)</td>
<td>2581</td>
<td>2742</td>
<td>+6.3</td>
<td>2605</td>
</tr>
<tr>
<td>Plasma volume (ml)</td>
<td>4728</td>
<td>5064</td>
<td>+5.8</td>
<td>4099</td>
</tr>
<tr>
<td>Blood volume (ml)</td>
<td>7309</td>
<td>7807</td>
<td>+6.8</td>
<td>6704</td>
</tr>
</tbody>
</table>

Example: Experiences with Swiss National Team Athletes

Live high (2456m) and train "low" (1800m) for 26 days
Living and Training at Altitude (2000-2500 m) in Kenya
Beijing 2008
6. Place
=>prepared with LHTL altitude training
2010: 1. Place, European Championships Barcelona

Live at 2307m
Train at 1800m
Train at 400m

Live at 2307m
Train at 1800m
Train at 400m

Marathon at the European Championships
Barcelona (Spain)
Thank’s for your attention!
Prix de Quervin 2014

Congratulations to Raphael Faiss!

Congratulations to Grégoire Millet!

Thanks for excellent collaboration!
Panorama of altitude training strategies

Altitude/Hypoxic Training

LHTH

LHTL

LHTLH

LLTH

IHE

IHT

IHIT
