Effect of endurance training and altitude training on hemoglobin mass and performance

A Swiss perspective

Jon Peter Wehrlin, PhD

Head Endurance Department, Section for Elite Sport
Swiss Federal Institute of Sports, Magglingen, Switzerland
Thank you for the invitation!

(https://pajulahti.com/)
Swiss Federal Institute of Sport, Magglingen, Switzerland (950m above sea level)
Swiss Federal Institute of Sport Magglingen

Section for Elite Sport (Staff = 60)

- Sport Physiology Group (Endurance Sports)
- Sport Physiology Group (Team Sports)
- Sport Physiology Group (Force Sports)
- Training Science
- Sport Psychology
- Sports Medicine
- Sports Physiotherapy
Swiss Federal Institute of Sports: Section for Elite Sport

Elite Sports

Services

Research & Development

Education

Swiss Federal Institute of Sports
- Master elite sports
- Bachelor course
- Coaches education
- SGSM etc.
Section for Elite Sport Laboratories

- Exercise Physiology Laboratory (Endurance Physiology)
- Cross-Country Skiing Laboratory (Endurance Physiology)
- Mountainbike Laboratory (Endurance Physiology)
- Hemoglobin mass / Blood volume Laboratory (Endurance Physiology)
Section for Elite Sport Laboratories

Heat & Humidity Laboratory (Endurance Physiology)

Track Cycling Laboratory (Endurance Physiology)

Muscle Power Laboratory (Strength Physiology; Alpine Skiing, Ski jump, Snowboard etc.)
Research & Development

Applied Research

Goal: Answer applied research questions (ideally from the athletes and coaches) to improve performance….

Mountainbike: What is faster 26 or 29inch wheel?

Track cycling: Which helmet is the best for my athlete?

Effect of precooling on performance in the Tokyo heat?

Can my athlete profite from altitude training?
Effect of endurance training and altitude training on hemoglobin mass and performance

- A Swiss perspective

Jon Peter Wehrlin, PhD

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Endurance sport: VO$_{2 \text{max}}$ - Important limiting factors

- **Ventilation & Lung diffusion capacity**
- **Heart capacity**
- **Oxygen transport capacity**
- **Muscle capacity**

Endurance sport: VO\textsubscript{2max} - Limiting factor oxygen transport capacity

Hemoglobin molecule: Transport of oxygen
Developing performance diagnostic services: Cross-country skiing

Performance

Relevant Constructs (General)
- Psychological Factors
- Technical Performance
- Physical Performance
- Tactical Performance
- Material (Skis/Wax)

Critical Success Factors (Sport Specific)
- Prolonged high skating velocity

Key Performance Indicator (KPI)
- High $\dot{V}O_{2\text{max}}$ (> 80 mL·kg$^{-1}$·min$^{-1}$)

Important Factors
- Hemoglobin mass / Blood volume
$VO_{2\text{max}}$ - Limiting factor oxygen transport capacity: Hemoglobin mass

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

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

Importance of the hemoglobin mass: Blood doping
Importance of the hemoglobin mass:

=> Blood doping with rhEPO

*Lundby et al., J Physiol, 2007*
Importance of the hemoglobin mass:

=> Problem: Blood doping with low volume autologous blood transfusion

135ml red blood cells

Nordic World Ski Championships 2019: Max Hauke (Austria)
Key Questions for elite endurance athletes, coaches & scientists
Key Questions for elite endurance athletes and coaches

0) Introduction: Hemoglobin concentration vs hemoglobin mass

1) Does hemoglobin mass increase with endurance training?
   - Training camp (Peaking and Tapering)
   - Training Season
   - Several years endurance training

2) Can hemoglobin mass be used as a «talent marker» for endurance sports?
   - Differences in hemoglobin mass between adolescent and elite athletes
   - Long term development in hemoglobin mass in adolescent athletes
   - Prediction of hemoglobin mass at elite age based on hemoglobin mass at age 16? Who did it?
   - Minimal hemoglobin mass need for elite endurance athletes?

3) Does hemoglobin mass increase with live high-train low (LHTL) altitude training?
   - „Hypoxic dose“?
   - „Individual response“?
   - Can hypoxic tents be used?
   - How long is hemoglobin mass increased after the altitude training?

4) Does a small increase in hemoglobin mass increase endurance performance?
   - Effect of low volume autologous blood doping on performance (increase like LHTL training)

5) Does LHTL increase endurance performance? What are important limiting factors?

6) A Swiss perspective – How do we support athletes and coaches?

7) Conclusions
0) Introduction: Hemoglobin concentration (g/dl) vs hemoglobin mass (g)
Introduction: Hemoglobin concentration (g/dl) vs hemoglobin mass (g)

**Hemoglobin (Hb; g/dl)**
- Mean value ca. 15g/dl / (critical value 17g/dl)
- Red color in red blood cells, Binds the oxygen

**Hematocrit (Hct; %)**
- Percent red blood cells
- Men ca. 45%
  (Critical value men 50%)
Introduction: Hemoglobin concentration (g/dl) vs hemoglobin mass (g)

Problem: We do not know how the absolute values are!
Introduction: Hemoglobin concentration (g/dl) vs hemoglobin mass (g)

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

Important factors:
- Position: (horizontal = ↓ vs vertical = Hct ↑)
- Hydratation status (low = Hct ↑; high ↓)
- Training (acute = Hct ↑; after = Hct ↓)
- Altitude: (acute = Hct ↑)
- Heat: (acute = Hct ↑; chronic ↓)
Introduction: Hemoglobin concentration (g/dl) vs hemoglobin mass (g)

Effect of drinking one liter of saline solution on hematocrit value

Introduction: Hemoglobin concentration (g/dl) vs hemoglobin mass (g)

=> Effect of a ten days cycling competition on hematocrit value (identical with Hb g/dl)

Introduction: Hemoglobin concentration (g/dl) vs hemoglobin mass (g)

=> Important to measure absolute values!

Blood volume:
8000 ml

Hemoglobin mass:
1256 g

Red cell volume:
3520 ml

Plasma volume:
4480 ml
Introduction: Hemoglobin concentration (g/dl) vs hemoglobin mass (g)

=> Relation to VO$_{2\text{max}}$

Schmidt & Prommer  Exerc Sport Sci Rev, 2010
Introduction: Hemoglobin concentration (g/dl) vs hemoglobin mass (g)

Measurement of hemoglobin mass

- 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

<table>
<thead>
<tr>
<th>Hb\text{mass}</th>
<th>RCV</th>
<th>PV</th>
<th>BV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>1.37%</td>
<td>1.89%</td>
<td>2.62%</td>
</tr>
<tr>
<td>R</td>
<td>0.991</td>
<td>0.981</td>
<td>0.968</td>
</tr>
<tr>
<td>Range</td>
<td>822-1264 g</td>
<td>2161-3456 ml</td>
<td>3185 – 5740 ml</td>
</tr>
</tbody>
</table>

Values from our Laboratory, (n=17)
Introduction: Hemoglobin concentration (g/dl) vs hemoglobin mass (g)

=> Measurement of hemoglobin mass

CO-rebreathing
Key Questions for elite endurance athletes and coaches

1) Does hemoglobin mass increase with endurance training?
   - Training camp (Peaking and Tapering)
   - Training season
   - Several years endurance training
1) Does hemoglobin mass increase with normal training?

Key question:
Effect of „training“ or „talent“?

1) Does hemoglobin mass increase with normal training?

=> Changes during a training camp

1) Does hemoglobin mass increase with normal training?

=> Changes with a peaking and tapering period

Wehrlin et al., 1. World Congress of Triathlon, Alicante, Spain 2011
1) Does hemoglobin mass increase with normal training?

=> Changes during a training season


⇒ Garvican et al. measured Hb mass in 10 elite Cyclists during 2-10 months:
CV was 3.3% (Range 2.4.4%)
1) Does hemoglobin mass increase with normal training?

=> Changes with several years of training

1) Does hemoglobin mass increase with normal training?

=> Several years of endurance training

⇒ Observation in routine hemoglobin mass measurement:
    Elite athletes show no big changes in hemoglobin mass with normal training

⇒ Possible to use it as “talent identification marker” in adolescence?
Key Questions for elite endurance athletes, coaches and scientists

2) Can hemoglobin mass be used as a «talent marker» for endurance sports?
   - Differences in hemoglobin mass between adolescent and elite athletes?
   - Long term development in hemoglobin mass in adolescent athletes
   - Prediction of hemoglobin mass at elite age based on hemoglobin mass at age 16? Who did it?
   - Minimal hemoglobin mass needed for elite endurance athletes?
2) Can hemoglobin mass be used as a «talent marker» for endurance sports?

=> Differences in hemoglobin mass between adolescent and elite national team athletes?
2) Can hemoglobin mass be used as a «talent marker» for endurance sports?

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=> Differences in hemoglobin mass between adolescent and elite athletes?
2) Can hemoglobin mass be used as a «talent marker» for endurance sports?

Differences in hemoglobin mass between adolescent and elite athletes?

«Golden age» between 16 and 21 to increase hemoglobin mass with endurance training?

2) Can hemoglobin mass be used as a «talent marker» for endurance sports?

Longitudinal study over 3 years

2) Can hemoglobin mass be used as a «talent marker» for endurance sports?

=> Long term development of hemoglobin mass in adolescent athletes?

Effect of Endurance Training on Hemoglobin Mass and \( \dot{V}O_2\text{max} \) in Male Adolescent Athletes

THOMAS STEINER, THOMAS MAIER, and JON PETER WEHR LIN

Section for Elite Sport, Swiss Federal Institute of Sport, Magglingen, SWITZERLAND

ABSTRACT

STEINER, T. T. MAIER, and J. P. WEHR LIN; Effect of Endurance Training on Hemoglobin Mass and \( \dot{V}O_2\text{max} \) in Male Adolescent Athletes. Med. Sci. Sports Exerc., Vol. 51, No. 5, pp. 912-919, 2019. Purpose: It is unknown, whether endurance training stimulates hemoglobin mass (Hbmass) and maximal oxygen uptake (\( \dot{V}O_2\text{max} \)) increases during late adolescence. Therefore, this study assessed the influence of endurance training on \( Hb_{\text{mass}} \), blood volume parameters, and \( \dot{V}O_2\text{max} \) in endurance athletes and control subjects from age 16 to 19 yr. Methods: Hemoglobin mass, blood volume parameters, \( \dot{V}O_2\text{max} \), and anthropometric parameters were measured in male elite endurance athletes from age 16 to 19 yr in 6-month intervals (\( n = 10 \)), as well as in age-matched male controls (\( n = 12 \)). Results: Neither the level of \( Hb_{\text{mass}} \) per lean body mass (LBM) (\( P = 0.80 \)) nor the development of \( Hb_{\text{mass}} \) during the 3 yr (\( P = 0.97 \)) differed between athletes and controls. \( Hb_{\text{mass}} \) at age 16 yr was 13.24 ± 0.89 g kg\(^{-1}\) LBM and increased by 0.74 ± 0.58 g kg\(^{-1}\) LBM (\( P = 0.01 \)) from age 16 to 19 yr. There was a high correlation between \( Hb_{\text{mass}} \) at age 16 and 19 yr (\( r = 0.77, P = 0.001 \)). Plasma volume, blood volume, and \( \dot{V}O_2\text{max} \) were higher in athletes compared to controls (\( P < 0.05 \)). Blood volume and \( \dot{V}O_2\text{max} \) increased with age (\( P < 0.01 \), similarly in both groups). Conclusion: Endurance training volumes do not explain individual differences in \( Hb_{\text{mass}} \) levels nor \( Hb_{\text{mass}} \) and \( \dot{V}O_2\text{max} \) development in the age period from 16 to 19 yr. The higher \( \dot{V}O_2\text{max} \) levels of athletes may be partially explained by training-induced higher plasma and blood volumes, as well as other training adaptations. Since \( Hb_{\text{mass}} \) at age 16 yr varies substantially and the development of \( Hb_{\text{mass}} \) in late adolescence is comparably small and not influenced by endurance training, \( Hb_{\text{mass}} \) at age 16 yr is an important predictor for \( Hb_{\text{mass}} \) at adult age and possibly for the aptitude for high-level endurance performance. Key Words: BLOOD VOLUME, CO-REBREATHTHOUGH, AEROBIC CAPACITY, ADOLESCENTS, MATURATION, TALENT IDENTIFICATION

2) Can hemoglobin mass be used as a «talent marker» for endurance sports?

=> Long term development of hemoglobin mass in adolescent athletes?

Project with same athletes and controls over 3 years (age 16 to age 19):

- **Xc-skiers / Triathletes**: Top 15 National Season-Ranking at study start (no National Team at this age)
- **Control subjects**: < 2 h of endurance training per week or < 3 h of team sports training.

- Blood samples
- Anthropometry (incl. assessment of biological age at study start)
- VO$_{2\text{max}}$-Test
- CO-rebreathing (for Hb$_{\text{tot}}$)

Training log book from T1 to T7
2) Can hemoglobin mass be used as a «talent marker» for endurance sports?

=> Long term development of hemoglobin mass in adolescent athletes?

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=> Long term development of hemoglobin mass in adolescent athletes?

2) Can hemoglobin mass be used as a «talent marker» for endurance sports?

=> Minimal hemoglobin mass needed for elite endurance athletes?

Men: National team: > 14g/kg bodyweight
     World class: > 15g-16g/kg bodyweight

Women: National team: > 12g/kg bodyweight
     World class: > 13-14g/kg bodyweight

High prediction of hemoglobin mass at 20 already at age 16!
2) Can hemoglobin mass be used as a «talent marker» for endurance sports?

=> Minimal hemoglobin mass needed for elite endurance athletes?

<table>
<thead>
<tr>
<th></th>
<th>National team:</th>
<th>World class:</th>
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<tbody>
<tr>
<td>Men</td>
<td>&gt; 14g/kg bodyweight</td>
<td>&gt; 15g-16g/kg bodyweight</td>
</tr>
<tr>
<td>Women</td>
<td>&gt; 12g/kg bodyweight</td>
<td>&gt; 13-14g/kg bodyweight</td>
</tr>
</tbody>
</table>

However, we do not systematically use Hbmass for Talent identification – we do not have enough talents!

=> High prediction of hemoglobin mass at at 20 already at age 16!
Key Questions for elite endurance athletes, coaches and scientists

3) Does hemoglobin mass increase with altitude training (LHTL)?
- „Hypoxic dose“?
- Can hypoxic tents be used?
- „Individual response“?
- How long is hemoglobin mass increased after the altitude training?
Key Questions for elite endurance athletes, coaches and scientists

3) Does hemoglobin mass increase with altitude training (LHTL)?
   - „Hypoxic dose“?
3) Does hemoglobin mass increase with altitude training (LHTL)? What's the plan?

- Low Oxygen
  \( P_{O_2} \downarrow \)
- Arterial hypoxemia
  \( S_a O_2 \downarrow \)
- Hemoglobin mass ↑
- Erythropoesis ↑
- Aerobic performance ↑
  \( VO_{2max} \)
- \( O_2 \) transport capacity of the blood ↑

Levine & Stray-Gundersen, 2005
3) Does hemoglobin mass increase with altitude training (LHTL)?

Altitude/ Hypoxic training

- LH + TH
  - Natural/Terrestrial
  - Hypobaric hypoxia (HH)
  - \( F_{O_2} = 20.9\% \)
  - \( P_e < 760 \text{ mmHg} \)

- LH + TL
  - Nitrogen dilution
  - Oxygen filtration
  - Normobaric hypoxia (NH)
  - \( F_{O_2} < 20.9\% \)
  - \( P_e = 760 \text{ mmHg} \)

- LHTLH
  - Supplemental Oxygen

- LL + TH
  - IHE
  - CHT
  - IHT
  - RSH
  - IHIT

= ?≠

- \( P_{O_2} < 150 \text{ mmHg} \)

LH = live high; TH = train high; TL = train low; LL = live low; LHTLH = live high-train low and high; IHE = intermittent hypoxic exposure; CHT = continuous hypoxic training; IHT = intermittent hypoxic training; RSH = repeated sprint training in hypoxia; IHIT = intermittent hypoxic exposure during interval training.

Wilber 2007; Millet et al. 2010 & 2013
3) Does hemoglobin mass increase with altitude training (LHTL)? Hypoxic dose?
3) Does hemoglobin mass increase with altitude training (LHTL)?  Hypoxic dose?

- Laitinen et al. 1995 (Abstract only; n=7 Runners; LHTL; Simulated altitude: 2500m; 20-28 days; CG)
- Svedenhag et al. 1997 (n=7 XC-skiiers; LHTH; Real altitude: 1900m; 30 days; EB)
- Levine et al. 1997 (n=13 Runners; LHTL; Real altitude: 2500m; 28 days; CG; EB)
- Gore et al. 1998 (n=8 Cyclists; LHTH; Real altitude: 2690m; 31 days; CO)
- Rusko et al. 1999 (Abstract only; n=10 XC-Skiiers/Triathletes; LHTL; Simulated altitude: 2500m; 25 days; CG; CO)
- Ashenden et al. 1999a (n=8 Cyclists; LHTL; Simulated altitude: 2650m; 12 days; CG; CO)
- Ashenden et al. 1999b (n=7 Runners; LHTL; Simulated altitude: 2650m; 12 days; CG; CO)
- Svedenhag et al. 1997 (n=7 XC-skiiers; LHTH; Simulated altitude: 3000m; 23 days; CG; CO)
- Dehnert et al. 2002 (n=11 Triathletes; LHTL; Real altitude: 1956m; 14 days; CG; CO)
- Friedmann et al. 2005 (n=16 Junior swimmers; LHTH; Real altitude: 2100-2300m; 21 days; CG)
- Haninice et al. 2005 (n=10 Biathletes; LHTH; Real altitude: 2500m; 21 days; CD)
- Brugniaux et al. 2006 (n=5; LHTL; 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)
- Wehrlin & Marti 2006 (n=2 Runners; LHTL; Real altitude: 2456/1800m; 26 days; CO)
- Robach et al. 2006 (n=6 XC-skiiers; LHTL; Simulated altitude: 2500-3500m/1200m; 13 days; CG; CO)
- Wehrlin et al. 2006 (n=10 Orienteers; LHTL; Real altitude: 2456/1800m/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; LHTH; Real altitude: 1816m; 21 days; CO)
- Saunders et al. 2009 (n=9 Runners; LHTL; Simulated altitude: 2860m; 46 days; CO)
- Wehrlin et al. 2009 (Submitted; n=7; Cross-country skiers; LHTL; Real altitude: 2590m; 21 days; CG)
- Clark et al. 2010 (n=12 cyclists; LHTL; Simulated altitude: 3000m)

**Change in Hb mass / RCV (%)**

**Time in hypoxia (hours)**

3) Does hemoglobin mass increase with altitude training (LHTL)? Hypoxic dose?


\[ y(\%) = \exp(1.07 \times 10^4 x - 1) \times 100 \]

\[ y(\%) = \exp(1.39 \times 10^4 x - 7.59 \times 10^4 x^2 - 1) \times 100 \]

+ 1 – 1.5% / 100 hours
(>2200m)
3) Does hemoglobin mass increase with altitude training (LHTL)? Hypoxic dose?

\[ r = 0.51 \]
\[ P = 0.03 \]

3) Does hemoglobin mass increase with altitude training (LHTL)? Hypoxic dose?

Schmidt W & Prommer N. Exercise and Sport Sciences Reviews, 2010, 68-75
Key Questions for elite endurance athletes, coaches and scientists

3) Does hemoglobin mass increase with altitude training (LHTL)?
   - Can altitude tents be used?
3) Does hemoglobin mass increase with altitude training (LHTL)?

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Individual response?!

Key Questions for elite endurance athletes, coaches and scientists

3) Does hemoglobin mass increase with altitude training (LHTL)?
   - „Individual response“?
3) Does hemoglobin mass increase with altitude training (LHTL)?

Individual response?

=> What is technical variation and what is a real physiological change?

Friedmann et al. 2005

Classic altitude training
- 3 weeks; 2100-2300 m
- 16 elite junior swimmers

What is the problem when I want to consult athletes individually?
Key Questions for elite endurance athletes, coaches and scientists

3) Does hemoglobin mass increase with altitude training (LHTL)?
   - „Individual response“?
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Individual response?

=> What is technical variation and what is a real physiological change?
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3) Does hemoglobin mass increase with altitude training (LHTL)?

Individual response?

Duplicate measures:
- Reduce error by a factor of $1/\sqrt{2}$ (30%) Hopkins, 2000
- Outliers can be identified!
- Within 6h
- Results are averaged

3) Does hemoglobin mass increase with altitude training (LHTL)?

Individual response?

=> What is technical variation and what is a real physiological change?
3) Does hemoglobin mass increase with altitude training (LHTL)?

Individual response?

3) Does hemoglobin mass increase with altitude training (LHTL)?

Individual response? (Can be different with each LHTL camp)


Slide adapted from Garvican (USOC IATS 2013 Conference)
3) Does hemoglobin mass increase with altitude training (LHTL)?

Individual response? (Can be different with each LHTL camp)

Example

2015: Live high-train low altitude training camp
400 hours at 2500m
=> Hemoglobin mass +5%

2016: Identical live high-train low altitude training camp
400 hours at 2500m
=> Hemoglobin mass +0.2%
3) Does hemoglobin mass increase with altitude training (LHTL)?

Individual response? (Can be different with each LHTL camp)

Slide adapted from Garvican (USOC IATS 2013 Conference)
Key Questions for elite endurance athletes, coaches and scientists

3) Does hemoglobin mass increase with altitude training (LHTL)?

   - How long is hemoglobin mass increased after the altitude training?
3) Is the increase in Hb_{mass} different between normobaric and hypobaric hypoxia?

=> How long is hemoglobin mass increased after altitude training?


Living altitude Kenyan Runners:
Before 2090m, then travelled to 340m asl.

- 5.5% Hemoglobin mass after 33 days
Key Questions for elite endurance athletes, coaches and scientists

4) Does a small increase in hemoglobin mass increase endurance performance?
   - Effect of low volume autologous blood doping on performance (increase like LHTL altitude training)
4) Does a small increase in hemoglobin mass increase performance (like with LHTL)?

=> Effect of a low-volume autologous blood transfusion?

**Abstract**

PURPOSE: This study tested the hypothesis that autologous blood transfusion (ABT) of ~50% of the red blood cells (RBC) from a standard 450-ml phlebotomy would increase mean power in a cycling time trial. In addition, the study investigated whether further ABT of RBC obtained from another 450-ml phlebotomy would increase repeated cycling sprint ability.

**METHODS:** In a randomized, double-blind, placebo-controlled crossover design (3-month wash-out), nine highly trained male subjects donated two 450-ml blood bags each (BT trial) or were sham phlebotomized (PLA trial). Four weeks later, a 650-kcal time trial (n = 7) was performed 3 d before and 2 h after receiving either ~50% (135 ml) of the RBC or a sham transfusion. On the following day, transfusion of RBC (235 ml) from the second donation or sham transfusion was completed. A 4 × 30-s all-out cycling sprint interspersed by 4 min of recovery was performed 6 d before and 3 d after the second ABT (n = 9).

**RESULTS:** The mean power was increased in time trials from before to after transfusion (P < 0.05) in BT (213 ± 35 vs 223 ± 38 W; mean ± SD) but not in PLA (223 ± 42 vs 224 ± 46 W). In contrast, the mean power output across the four 30-s sprint bouts remained similar in BT (639 ± 35 vs 644 ± 26 W) and PLA (638 ± 43 vs 639 ± 25 W).

**CONCLUSIONS:** ABT of only ~135 mL of RBC is sufficient to increase mean power in a 660 kcal cycling time trial by ~6% in highly trained men. In contrast, a combined high-volume transfusion of ~135 and ~235 mL of RBC does not alter 4 × 30-s all-out cycling performance interspersed with 4 min of recovery.

135ml RBC = 300ml Blood (Hct 45%)

Hct 45% = Hb 15g/dl

3dl Blood * 15g/dl = 45g Hemoglobin
4) Does a small increase in hemoglobin mass increase performance?

=> Effect of a low-volume autologous blood transfusion?

Schmidt W & Prommer N. Exercise and Sport Sciences Reviews, 2010, 68-75

Bejder et al. MSSE 2019
4) Does a small increase in hemoglobin mass increase performance (Like with LHTL)?

=> Effect of a low-volume autologous blood transfusion?

135ml RBC = 300ml Blood (Hct 45%)

Hct 45% = Hb 15g/dl

3dl Blood * 15g/dl = 45g Hemoglobin

If the Athlete has 1000g hemoglobin mass

=> 45g = 4.5% increase in Hemoglobin mass

=> Performance in time trial + 5%

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Time Trial Performance Is Sensitive to Low-Volume Autologous Blood Transfusion.

Beider J¹, Breunfeldt Andersen A¹, Solheim SA¹, Gybel-Bresk M², Recher NH², Johansson PH², Nordsborg NB¹

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PURPOSE: This study tested the hypothesis that autologous blood transfusion (ABT) of ~50% of the red blood cells (RBC) from a standard 450-ml phlebotomy would increase mean power in a cycling time trial. In addition, the study investigated whether further ABT of RBC obtained from another 450-ml phlebotomy would increase repeated cycling sprint ability.

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4) Does a small increase in hemoglobin mass increase performance?

=> Effect of a low-volume autologous blood transfusion?

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=> Effect of a low-volume autologous blood transfusion?


**Time Trial Performance Is Sensitive to Low-Volume Autologous Blood Transfusion.**

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**Author information**

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PURPOSE: This study tested the hypothesis that autologous blood transfusion (ABT) of ~50% of the red blood cells (RBC) from a standard 450-ml phlebotomy would increase mean power in a cycling time trial. In addition, the study investigated whether further ABT of RBC obtained from another 450-ml phlebotomy would increase repeated cycling sprint ability.

METHODS: In a randomized, double-blind, placebo-controlled crossover design (3-month wash-out), nine highly trained male subjects donated two 450-ml blood bags each (BT trial) or were sham phlebotomized (PLA trial). Four weeks later, a 650-kcal time trial (n = 7) was performed 3 d before and 2 h after receiving either ~50% (135 ml) of the RBC or a sham transfusion. On the following day, transfusion of RBC (235 ml) from the second donation or sham transfusion was completed. A 4 x 30-s all-out cycling sprint interspersed by 4 min of recovery was performed 6 d before and 3 d after the second ABT (n = 9).

RESULTS: The mean power was increased in time trials from before to after transfusion (P < 0.05) in BT (213 ± 35 vs 223 ± 38 W; mean ± SD) but not in PLA (223 ± 42 vs 224 ± 46 W). In contrast, the mean power output across the four 30-s sprint bouts remained similar in BT (639 ± 35 vs 644 ± 26 W) and PLA (638 ± 43 vs 639 ± 25 W).

**CONCLUSIONS:** ABT of only ~135 ml of RBC is sufficient to increase mean power in a 650-kcal cycling time trial by ~5% in highly trained men. In contrast, a combined high-volume transfusion of ~135 and ~235 ml of RBC does not alter 4 x 30-s all-out cycling performance interspersed with 4 min of recovery.

| 135ml RBC =300ml Blood (Hct 45%)                  |
| Hct 45% = Hb 15g/dl                             |
| 3dl Blood * 15g/dl = 45g Hemoglobin             |

*If the Athlete has 1000g hemoglobin mass*

⇒ 45g = 4.5% increase in Hemoglobin mass

⇒ Performance in time trial + 5%

Same amount as used as low volume autologous blood transfusion

**Nordic World Ski Championships 2019:**
Max Hauke (Austria)
Key Questions for elite endurance athletes, coaches and scientists

5) Does live high-train low (LHTL) altitude training increase endurance performance at sea level?

=> What are important limiting factors?
5) Does LHTL increase endurance performance?

Control all confounding factors (increase in Hb_{mass})!
5) Does LHTL increase endurance performance?

Individual response (Increase in Hb\textsubscript{mass})!

5) Does LHTL increase endurance performace?

Individual response (Increase in Hb<sub>mass</sub>!)

5) Does LHTL increase endurance performance at sea level?

Planning of training load and training intensity!

<table>
<thead>
<tr>
<th>Hypoxia</th>
<th>Normoxia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

## Hypoxic training model: to prepare a period of competitions at sea level

<table>
<thead>
<tr>
<th>Training load</th>
<th>Very high</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
<th>Very low</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
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<td>5</td>
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<td></td>
<td>1 to 15</td>
</tr>
</tbody>
</table>
5) Does LHTL increase endurance performance at sea level?

Planning of training load and training intensity!

<table>
<thead>
<tr>
<th>Training load</th>
<th>Hypoxic training model: to prepare a period of competitions at sea level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hypoxia</td>
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<tr>
<td></td>
<td>Normoxia</td>
</tr>
<tr>
<td>Very high</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Very low</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Training intensity</th>
<th>Int ≤ VT₁ strength training</th>
<th>Int ≤ VT₁ strength training</th>
<th>Int ≤ VT₂ Int ≤ VT₂ strength training</th>
<th>Int ≤ VT₁ strength training</th>
<th>Int ≤ VT₁ Int ≤ VT₂ Int ≤ MAP strength training</th>
<th>Int ≤ VT₁ Int ≤ VT₂ Int ≤ MAP strength training</th>
<th>Short recovery Int ≤ VT₁</th>
<th>Competition period at sea level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>2 to 3</td>
<td>1 to 15</td>
</tr>
</tbody>
</table>

Millet et al., Sports Med, 2010

21 days after LHTL
5) Does LHTL increase endurance performance?

Timing of posttest!
5) Does LHTL increase endurance performance at sea level?

 Timing of posttest!

Chapman RF, 2011
Key Questions for elite endurance athletes, coaches and scientists

5) Does live high-train low (LHTL) altitude training increase endurance performance?

=> Results of studies with elite athletes?
5) Does live high-train low (LHTL) altitude training increase endurance performance?

=> Results of studies with elite athletes?

LETTER TO THE EDITOR

“Live High-Train Low” Paradigm: Moving the Debate Forward

Millet G, Brocherie F.

=> it is very hard (impossible) to prove that a preparation with elite endurance athletes for an important competition at sea level is better to prepare with LHTL than sea level training!
5) Does live high-train low (LHTL) altitude training increase endurance performance?

=> Results of studies with elite athletes?

=> Impossible to prove – but not so important for elite sport athletes.

Subjects:
- World class elite endurance athletes (high n)
- Willing to perform best at pre- and posttest of a study and not at a competition
- «Responder» for hemoglobin mass increases with altitude training (genetic predisposition)

=> Successful increase in hemoglobin mass with LHTL (double measurements)

Study design / Method:
- Athletes are their own controls (individual responses)
- Cross over design over one year (same training period) (BUT Athletes will be one year older!)
- YES, Blinded for the treatment (LHTL or sea level) => Placebo Effect
- NOT Blinded for the treatment => Training has to be adjusted to altitude or sea level conditions
- High enough hypoxic dose (Individually different)?
- Optimal preparation for the pre- and posttests (Peaking and Tapering)
  => Time of best performance should be at the posttests (not at races of the athletes)
- Optimal timing of the pre- and posttests («best time man»)
- Optimal iron availability
- Optimal energy balance
- No negative effects (inflammation, illness, injury, overreaching, overtraining) during both periods
- Very precise and valid tests (hemoglobin mass) and performance
- etc.
Key Questions for elite endurance athletes, coaches and scientists

=> Does the elite athlete needs this perfect study to prove better performance?
Key Questions for elite endurance athletes, coaches and scientists

⇒ Does the elite athlete himself need this perfect study to prove better performance?

NO
5) Does live high-train low (LHTL) altitude training increase endurance performance?

=> Results of studies with elite athletes?

Schmidt W & Prommer N. Exercise and Sport Sciences Reviews, 2010, 68-75

Bejder et al. MSSE 2019
5) Does live high-train low (LHTL) altitude training increase endurance performance?

=> Results of studies with elite athletes?

Example:

2015: Live high-train low altitude training camp
400 hours at 2500m
=> Hemoglobin mass +5%

2016: Identical live high-train low altitude training camp
400 hours at 2500m
=> Hemoglobin mass +0.2%
Key Questions for elite endurance athletes, coaches and scientists

6) A Swiss perspective – How do we support athletes and coaches – Swiss Examples
6) A Swiss perspective – How do we supported athletes and coaches – Swiss Examples

a) Build a team: Athlete, Coach, Physician, Nutrician, Scientist.

b) Plan altitude training camp perfectly (timing in season, hypoxic dose, training, Nutrition, Recovery, Supplements (iron, vitamin b12, folic acid etc.) on individual base
c) Help with installation of altitude room at athlete's home (very easy with generators)
6) A Swiss perspective – How do we supported athletes and coaches – Swiss Examples

### Höhenberechnung

**Berechnung des FIO\(_2\) und des PIO\(_2\) nach Wohnhöhe und gewünschter simulierter Höhe**

<table>
<thead>
<tr>
<th>Ort</th>
<th>Wohnhöhe [m]</th>
<th>entspricht einem Luftdruck [mmHg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubigen</td>
<td>559</td>
<td>712</td>
</tr>
</tbody>
</table>

Auf Meereshöhe haben wir einen FIO\(_2\) von 20,93 %, ein Luftdruck von 760 mmHg und ein PIO\(_2\) von 149 mmHg.

### Berechnung der simulierten Höhe anhand der Generatoreinstellung

<table>
<thead>
<tr>
<th>Generator-einstellung</th>
<th>FIO(_2) [%]</th>
<th>PIO(_2) [mmHg]</th>
<th>Simulierte Höhe [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>20.7</td>
<td>137.6</td>
<td>600</td>
</tr>
<tr>
<td>1</td>
<td>20.3</td>
<td>134.9</td>
<td>590</td>
</tr>
<tr>
<td>1.5</td>
<td>19.9</td>
<td>132.3</td>
<td>590</td>
</tr>
<tr>
<td>2</td>
<td>19.5</td>
<td>129.6</td>
<td>590</td>
</tr>
<tr>
<td>2.5</td>
<td>19.1</td>
<td>127.0</td>
<td>590</td>
</tr>
<tr>
<td>3</td>
<td>18.7</td>
<td>124.3</td>
<td>590</td>
</tr>
<tr>
<td>3.5</td>
<td>18.3</td>
<td>121.6</td>
<td>590</td>
</tr>
<tr>
<td>4</td>
<td>17.9</td>
<td>118.0</td>
<td>590</td>
</tr>
<tr>
<td>4.5</td>
<td>17.5</td>
<td>116.3</td>
<td>590</td>
</tr>
<tr>
<td>5</td>
<td>17.1</td>
<td>113.7</td>
<td>590</td>
</tr>
<tr>
<td>6.5</td>
<td>16.7</td>
<td>111.0</td>
<td>590</td>
</tr>
<tr>
<td>6</td>
<td>16.3</td>
<td>108.8</td>
<td>590</td>
</tr>
<tr>
<td>6.5</td>
<td>15.9</td>
<td>105.7</td>
<td>2600</td>
</tr>
</tbody>
</table>

---

Empfohlene Einstellung
d) Plan double measurement of hemoglobin mass

### Informationen Höhentraining

<table>
<thead>
<tr>
<th>Ort</th>
<th>Schnalstal</th>
<th>Höhe [m]</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Höhentage [d]</td>
<td>18</td>
<td>Höhestunden [h]</td>
<td>281</td>
</tr>
</tbody>
</table>

Bemerkungen: LHTL

### Blutdaten (Mittelwerte aus Doppelmes sung)

<table>
<thead>
<tr>
<th></th>
<th>Vor Höhentraining</th>
<th>Nach Höhentraining</th>
<th>Veränderung (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>absolute Hämoglobinmasse [g]</td>
<td>761</td>
<td>788</td>
<td>+ 3.5 %</td>
</tr>
<tr>
<td>relative Hämoglobinmasse [g/kg]</td>
<td>11.8</td>
<td>12.2</td>
<td>+ 4 %</td>
</tr>
<tr>
<td>absolutes Blutvolumen [ml]</td>
<td>6336</td>
<td>6229</td>
<td>- 1.7 %</td>
</tr>
<tr>
<td>relativer Blutvolumen [ml/kg]</td>
<td>97.9</td>
<td>96.7</td>
<td>- 1.2 %</td>
</tr>
<tr>
<td>absolutes Plasmavolumen [ml]</td>
<td>4082</td>
<td>3877</td>
<td>- 5 %</td>
</tr>
<tr>
<td>relativer Plasmavolumen [ml/kg]</td>
<td>53.1</td>
<td>60.2</td>
<td>- 4.6 %</td>
</tr>
</tbody>
</table>
e) Control everything during the altitude training period

- Training and training quality
- Hours at altitude (hypoxic dose)
- Sleep and sleep quality
- Profile of Mood State
- Body weight
- Rest heart rate
- Oxygen saturation during sleep
- Overall state of the athlete ++, +, +/-, -, --
- Competition after the LHTL camp (14 – 24 days after)
- etc.

f) Evaluate the altitude training camp in the team (4 weeks after)

- How was it?
- What did work, what did not work, why?
- What could we improve/change (hypoxic dose etc.)
- Does the athlete coach want to do it again
Key Questions for elite endurance athletes, coaches and scientists

6) A Swiss perspective – How do we supported athletes and coaches – Swiss Examples
=> Statistical significance versus practical relevance?

Viktor Röthlin
Swiss Marathon Runner
=> Competition preparation at Muottas Muragl 2456m) (Engadin, Switzerland)
### 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>

A Swiss perspective – How do we supported athletes and coaches – Swiss Examples

- Live high (2456m) and train "low" (1800m) for 26 days
- Zürich Marathon 2:11:05
- WC Paris Marathon 2:11:14
- 5000m 13:52:69
- 5000m 13:35:50
- WC Paris 5000m Final 13:26:06
- WC Paris 5000m Qualification 13:36:54
- 5000m 13:12:16

Three months before LHTL
Day 1 before LHTL
Day 1 after LHTL
Day 14 after LHTL
Day 25 - 29 after LHTL
Beijing 2008

6. Place

=> prepared with LHTL altitude training
6) A Swiss perspective – How do we supported athletes and coaches – Swiss Examples

2010: 1. Place, European Championships Barcelona

- Live at 2307m
- Train at 1800m
- Train at 400m a

Marathon at the European Championships
Barcelona (Spain)
A Swiss perspective – How do we supported athletes and coaches – Swiss Examples
Key Questions for elite endurance athletes, coaches and scientists

6) A Swiss perspective – How do we support athletes and coaches – Swiss Examples
6) A Swiss perspective – How do we supported athletes and coaches – Swiss Examples

2010  Altitude Training „Best Practice“

2011  Individual Adaptations

2012  Olympic Games London
A Swiss perspective – How do we supported athletes and coaches – Swiss Examples

6)
A Swiss perspective – How do we supported athletes and coaches – Swiss Examples

Performance:
Capacity test with Self selected Speed

AG: 6023m => 6221m (+3.3%)

CG: 5244m => 5406m (+3.1%)

Typical «study» with elite athletes
6) A Swiss perspective – How do we supported athletes and coaches – Swiss Examples
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6) A Swiss perspective – How do we supported athletes and coaches – Swiss Examples

Judo: Preparation for a hard training period:

LHTL: Live high – train low

HTP: Hard training period

OS: Olympic games
A Swiss perspective – How do we support athletes and coaches – Swiss Examples

swisski

Swiss Cycling

Swiss Athletics

Triathlon

Swiss Swimming

Swiss Rowing
Everybody ok?
Key Questions for elite endurance athletes, coaches and scientists

6) Conclusions
Conclusion:
Key Questions for elite endurance athletes, coaches and scientists

1) Does hemoglobin mass increase with endurance training?
   - Training camp (Peaking and Tapering): No
   - Training Season: No
   - Several years endurance training: No

2) Can hemoglobin mass be used as a «talent marker» for endurance sports?
   - Differences in hemoglobin mass between adolescent and elite athletes => Yes
   - Long term development in hemoglobin mass in adolescent athletes =>Yes
   - Prediction of hemoglobin mass at elite age based on hemoglobin mass at age 16? Who did it?
     => Those with already high hemoglobin mass at age 16
   - Minimal hemoglobin mass need for elite endurance athletes?
     => 14g/kg males; 12g/kg females (national level)
     => 15-16g/kg males; 13-14g/kg females (world class level)
Conclusion:
Key Questions for elite endurance athletes, coaches and scientists

3) Does hemoglobin mass increase with altitude training (LHTL)?
   - „Hypoxic dose“? 400 hours at 2500m
   - „Individual response“? Yes, the increase ranges between 0% and 10%
   - Can hypoxic tents be used? Yes, similar response in hemoglobin mass increase
   - How long is hemoglobin mass increased after the altitude training? 4 (- 6) weeks

4) Does a small increase in hemoglobin mass increase endurance performance?
   - Effect of low volume autologous blood doping on performance

   Yes, a small amount of hemoglobin mass (like we reach with altitude training (5%)) increases endurance performance (time trial)
Conclusion:
Key Questions for elite endurance athletes, coaches and scientists

5) Does LHLT altitude training increase endurance performance?

We think yes, scientifically it is very hard to prove (but also, that it does not work). Most studies showed increased performance. Elite sport does not need the perfect study, due to individual different adaptations, every athlete has to try him-/herself.

(For competitions at altitude, you have to prepare with altitude (Olympics Beijing 2022))

6) A Swiss perspective – How do we support athletes and coaches?

Since 15 years, we support Swiss national team endurance athletes mostly on an individual base.

However, it is not a magical tool, it is all about hard work.
Thanks for your attention!

Questions?
Thank you for the invitation!

Kiitos kutsusta!

And all the best for you and your athletes!