Endurance Seminar, Hypoxia Training Pajulahti November 2021

Altitude training before competition - models and use of intermittent hypoxia

Martin Burtscher: University Innsbruck, Austria

Start: OLYMPICS IN MEXICO CITY 1968

Mexico City 1968 - Munich 1972

2300 m | 520 m

	100m	**10.000m**	**Marathon**
1968	9.9	29:27.4	**2:20:26**
1972	10.14	27:38.4	**2:12:19**

Performance changes: Why?

No health risk!

HYPOXIA (ALTITUDE) EFFECTS
Continuous Exposure

Performance decline (aerobic)

Cardio-respiratory stress

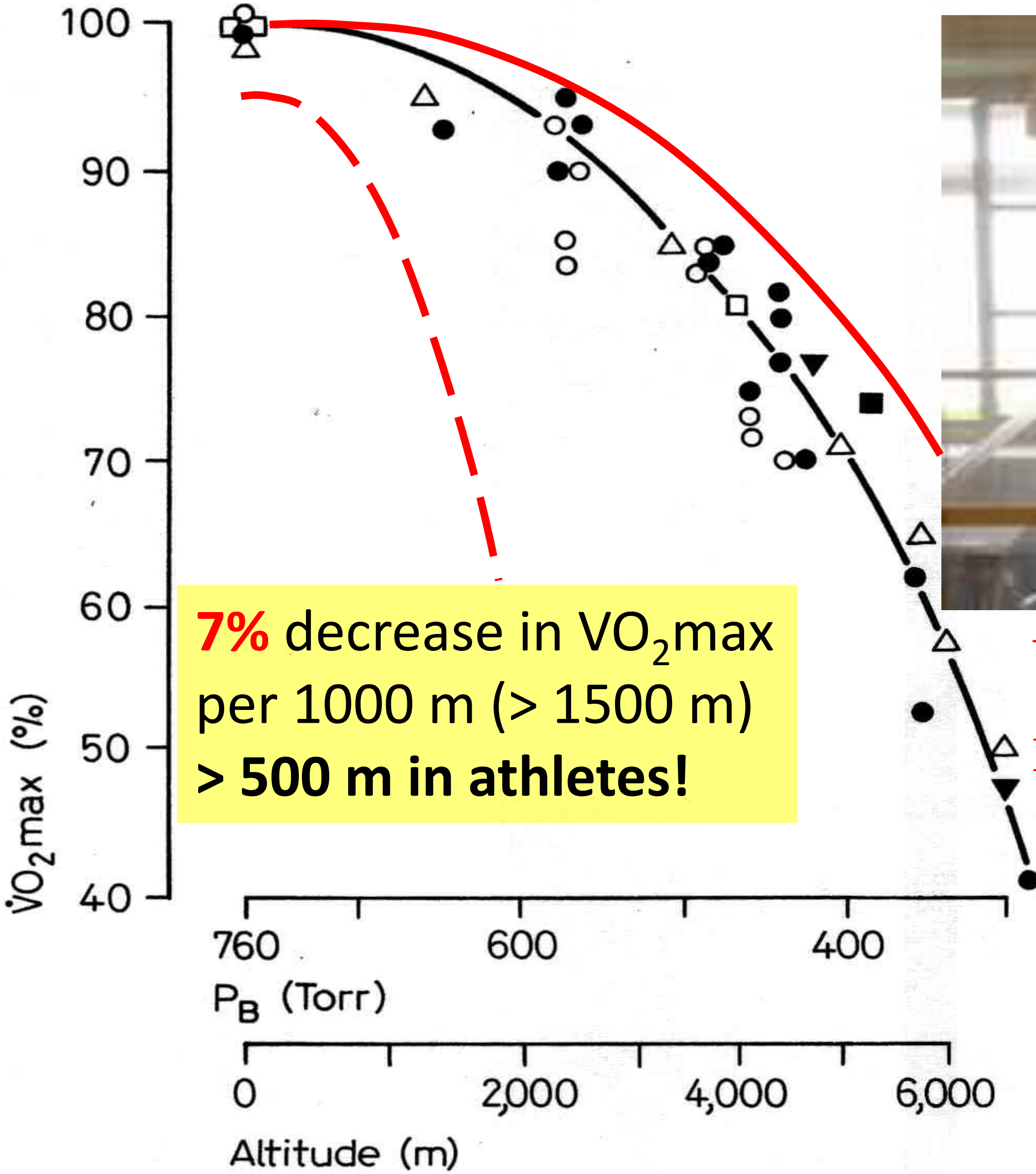
Exercise (in)tolerance

Adaptations

Hyperventilation
Hemoconcentration

Erythropoiesis

VO_2max decline with increasing altitude

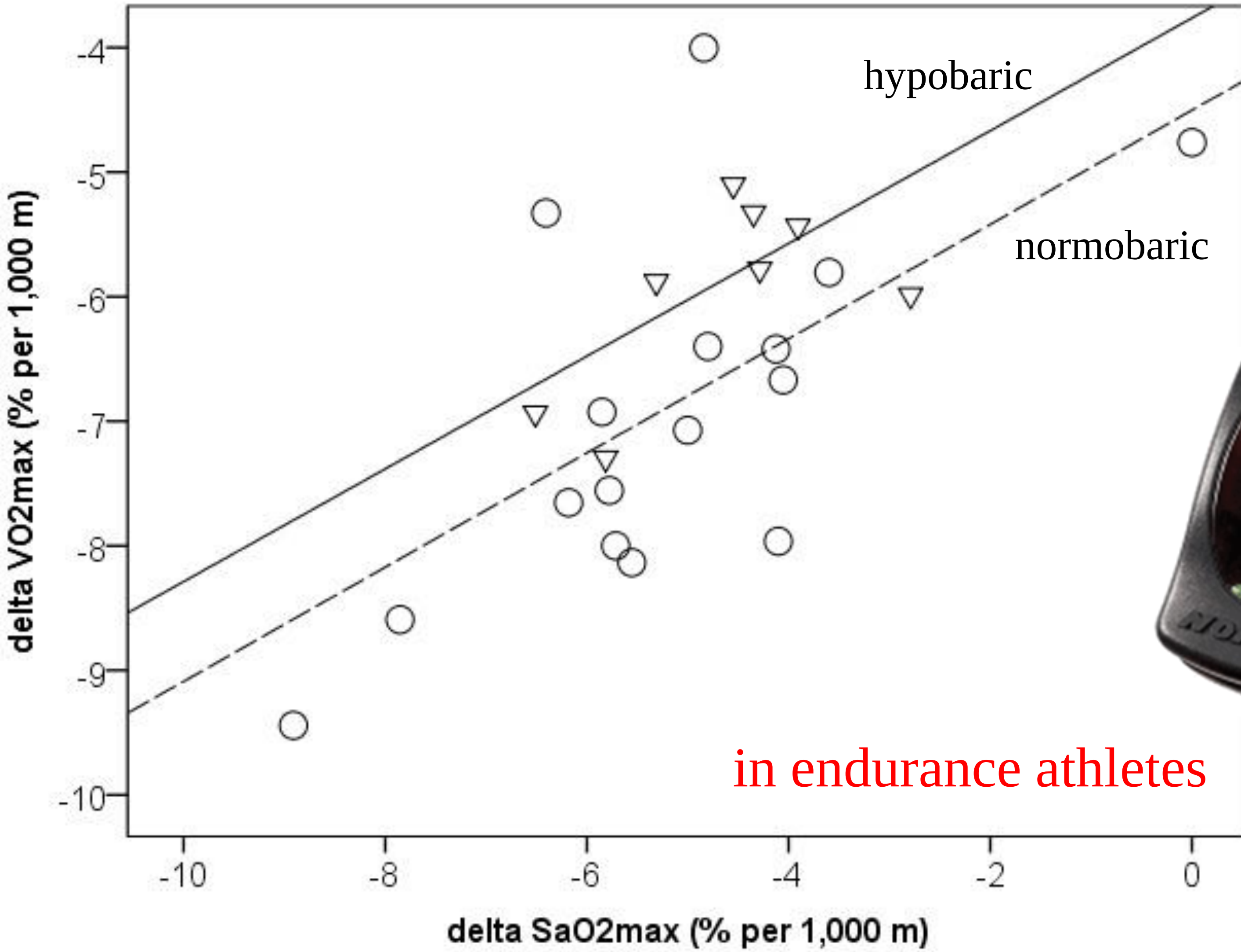


7% decrease in VO_2max per 1000 m (> 1500 m)
> 500 m in athletes!

VO_2 max = maximal aerobic power

mod. Cerretelli, 1980

VO_2max decline related to changes in SaO_2



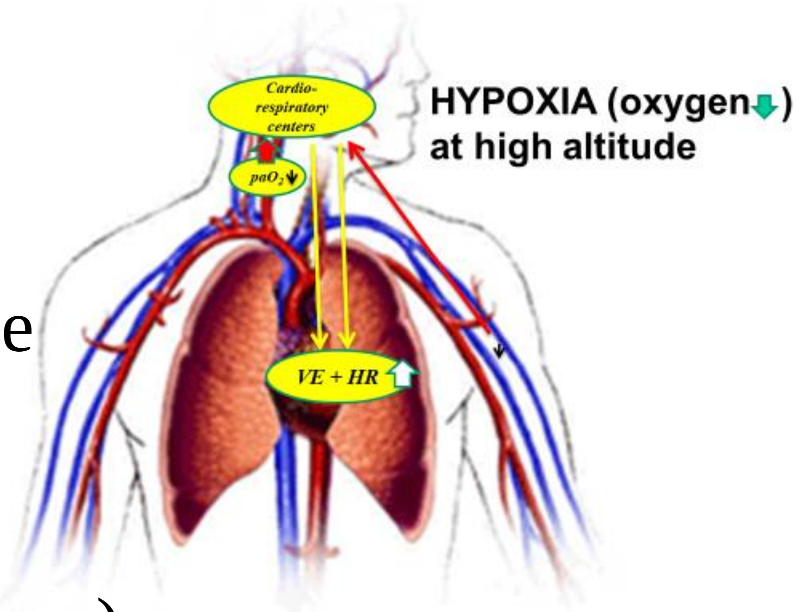
Oxygen delivery to working muscles:
Cardiac output x Hemoglobin x SaO_2

Treml et al., 2020

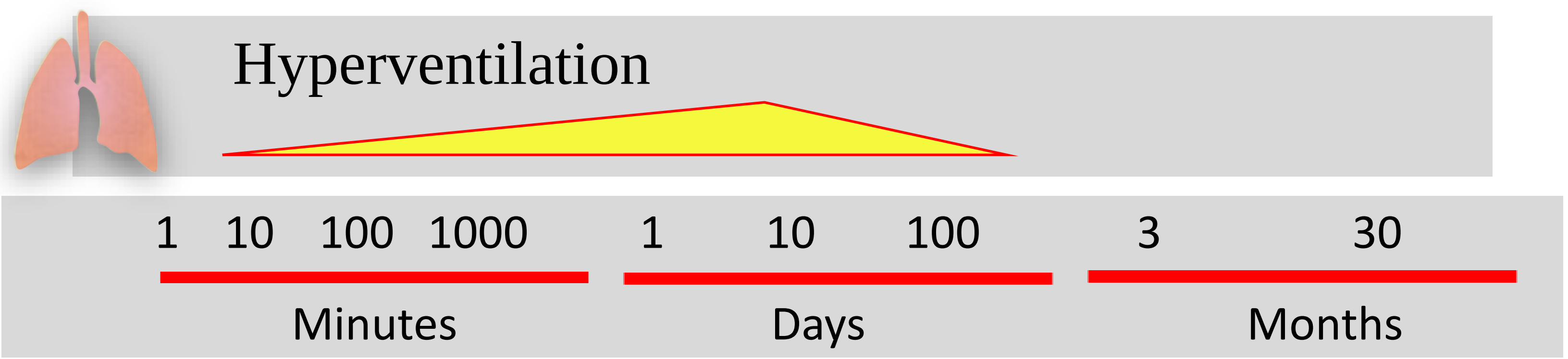
Physiological responses to high-altitude exposure

Hyperventilation

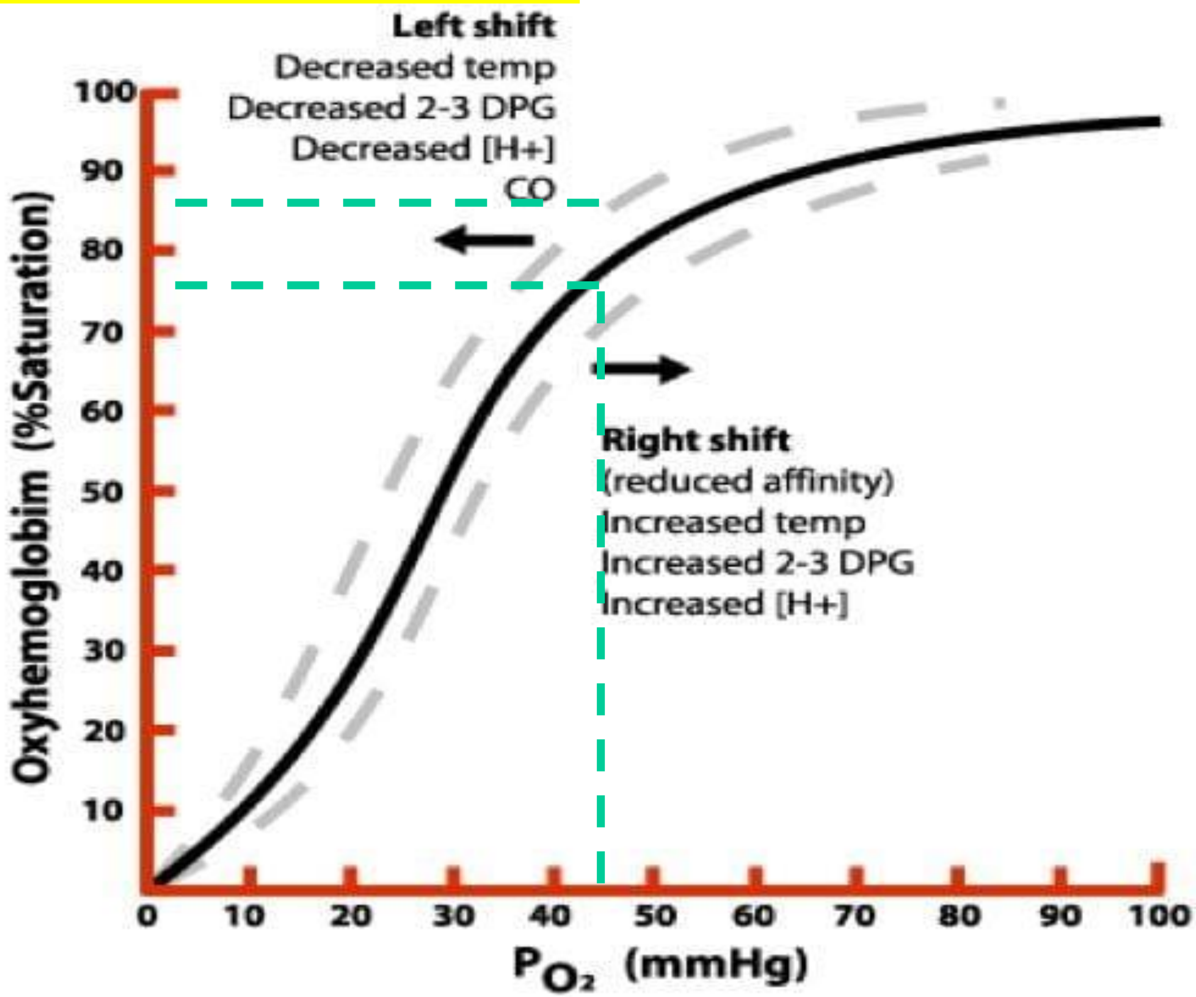
Alveolar and arterial pO_2
and **SaO_2** improve
Alveolar and arterial pCO_2 decrease



Alkalosis + diuresis (bicarbonate loss)

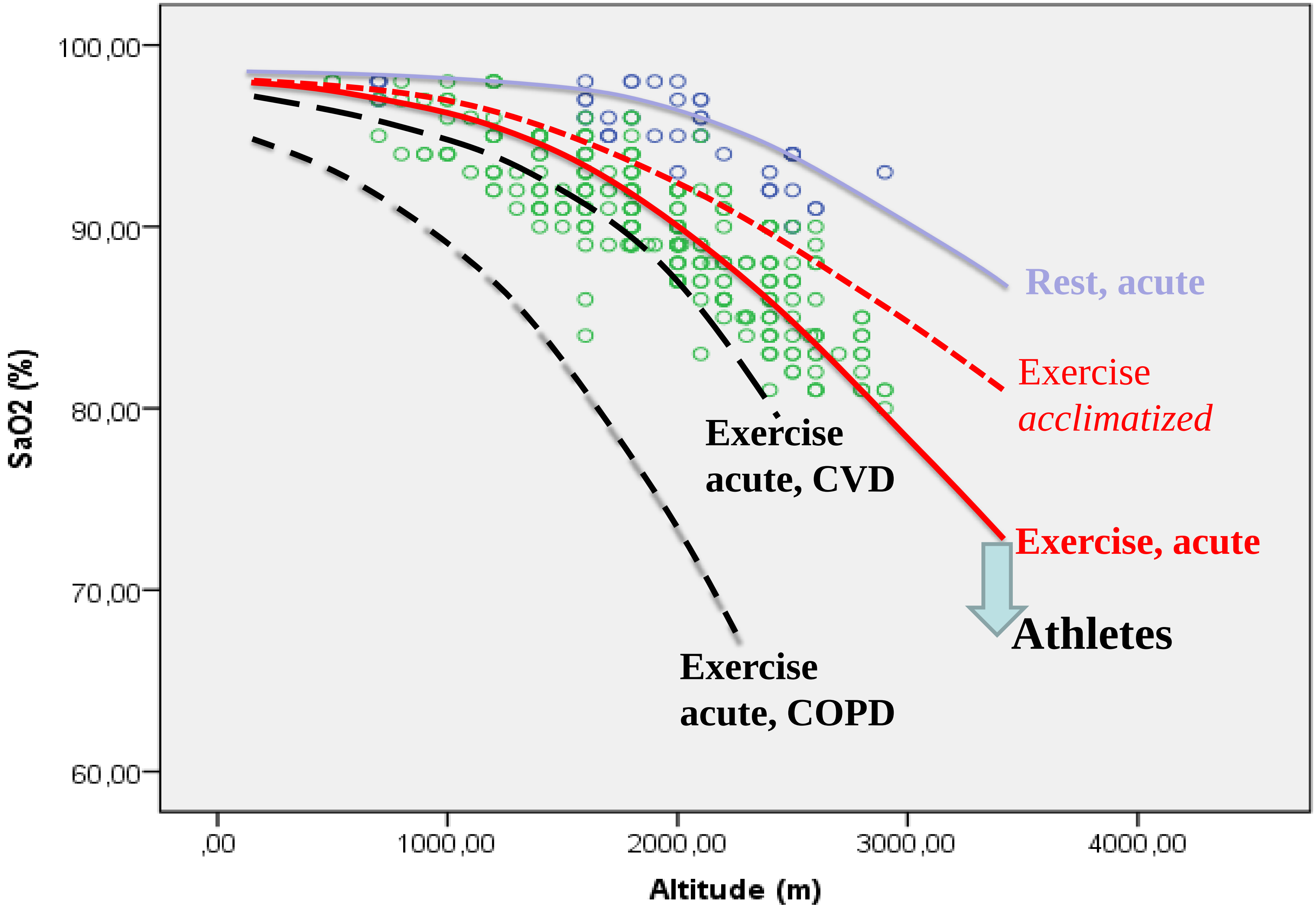


Hyperventilation/Alkalosis



AnaesthesiaUK

SaO_2 decline differs depending on conditions



Acute HYPOXIA

Plasma Volume decreases

↓

Stroke volume decreases → Heart rate increases

Hemoconcentration → Hb increases

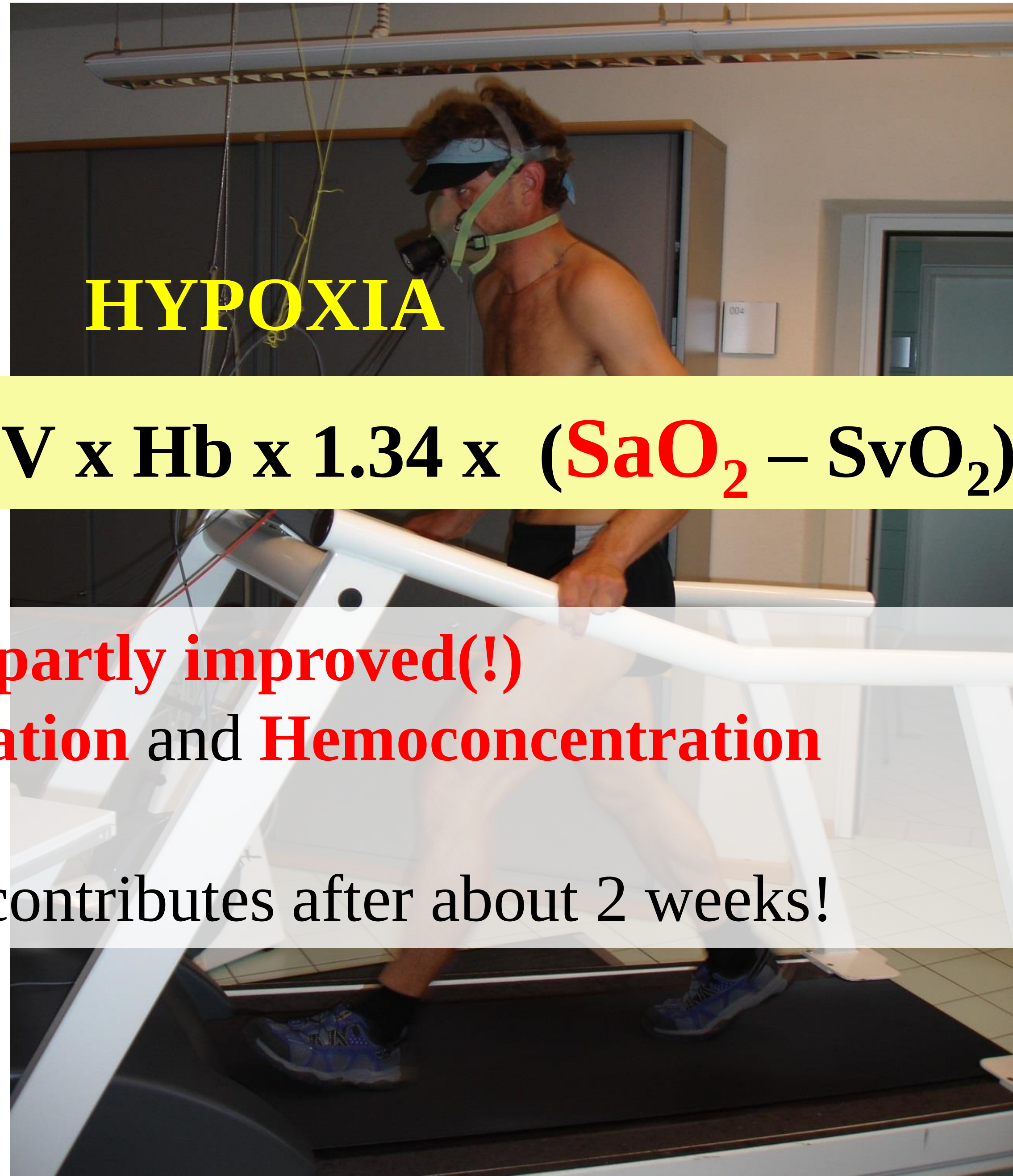
$$VO_2 = HR \times SV \times Hb \times 1.34 \times (SaO_2 - SvO_2)$$

Hypoxia (-)

Hyperventilation/Alkalosis (+)

Plasma volume ↓ Hemoglobin concentration ↑

Net effects of HYPOXIA on VO_2 (submax)



Initially decreased!

$$VO_2 = HR \times SV \times Hb \times 1.34 \times (SaO_2 - SvO_2)$$

After several days partly improved(!)
due to **Hyperventilation** and **Hemoconcentration**

→ **Erythropoiesis** contributes after about 2 weeks!

Net effects of Hypoxia on VO_2 (maximal)

Initially decreased!

$$VO_2 = HR \times SV \times Hb \times 1.34 \times (SaO_2 - SvO_2)$$

Remains decreased (!)

as HRmax(⬇)cannot compensate for the decrease in SV

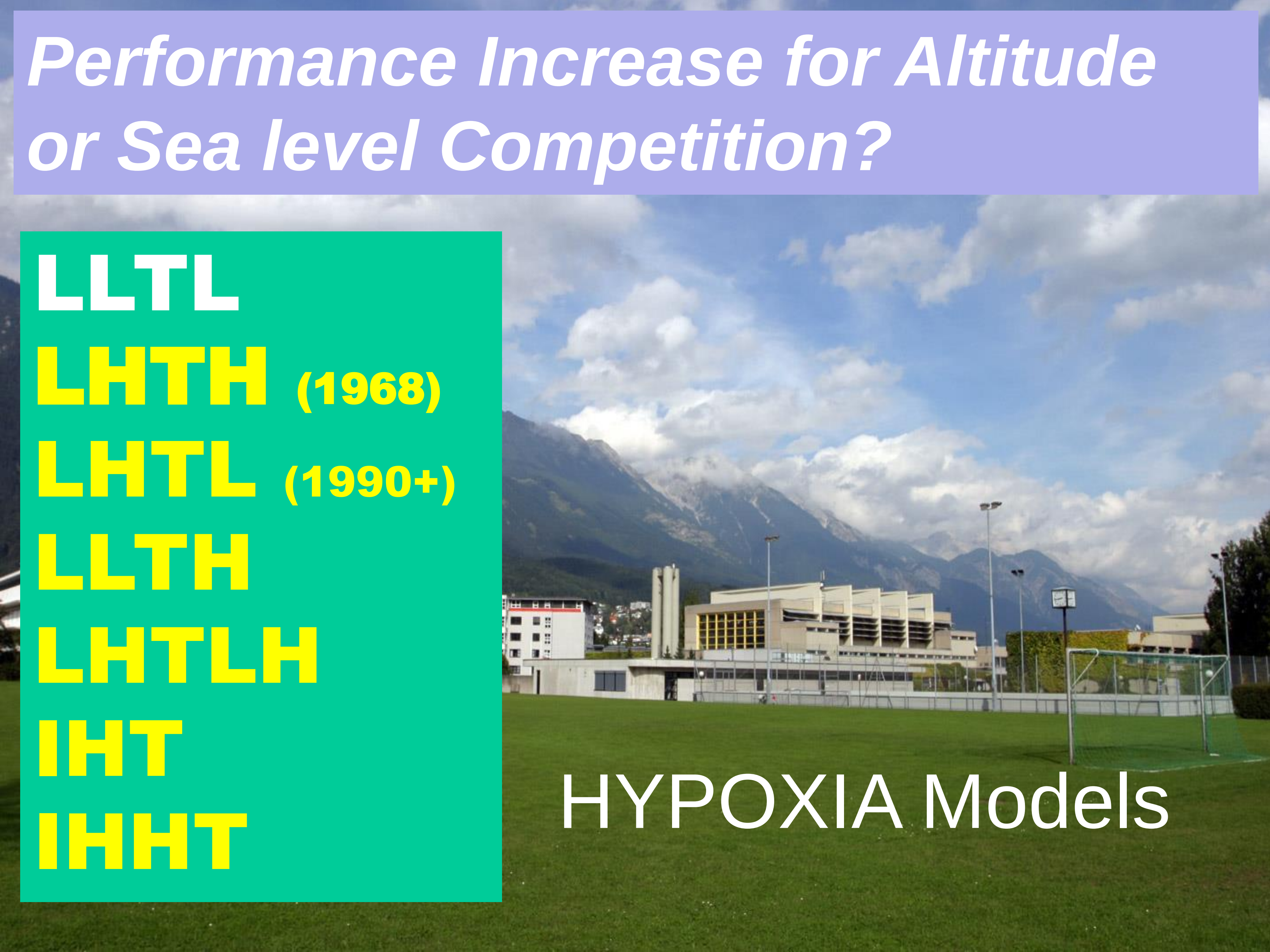
Additionally: unfavorable blood redistribution may occur

Training and Living in Hypoxia/at Altitu

Increase of arterial oxygen content
(Hb x SaO_2) → may improve SL performance
but: Reduced skeletal muscle stimulus!

Live High and Train Low (intensive)
to improve Sea Level Performance

Performance Increase for Altitude or Sea level Competition?



LLTL
LHTH (1968)
LHTL (1990+)
LLTH
LHTLH
IHT
IHHT

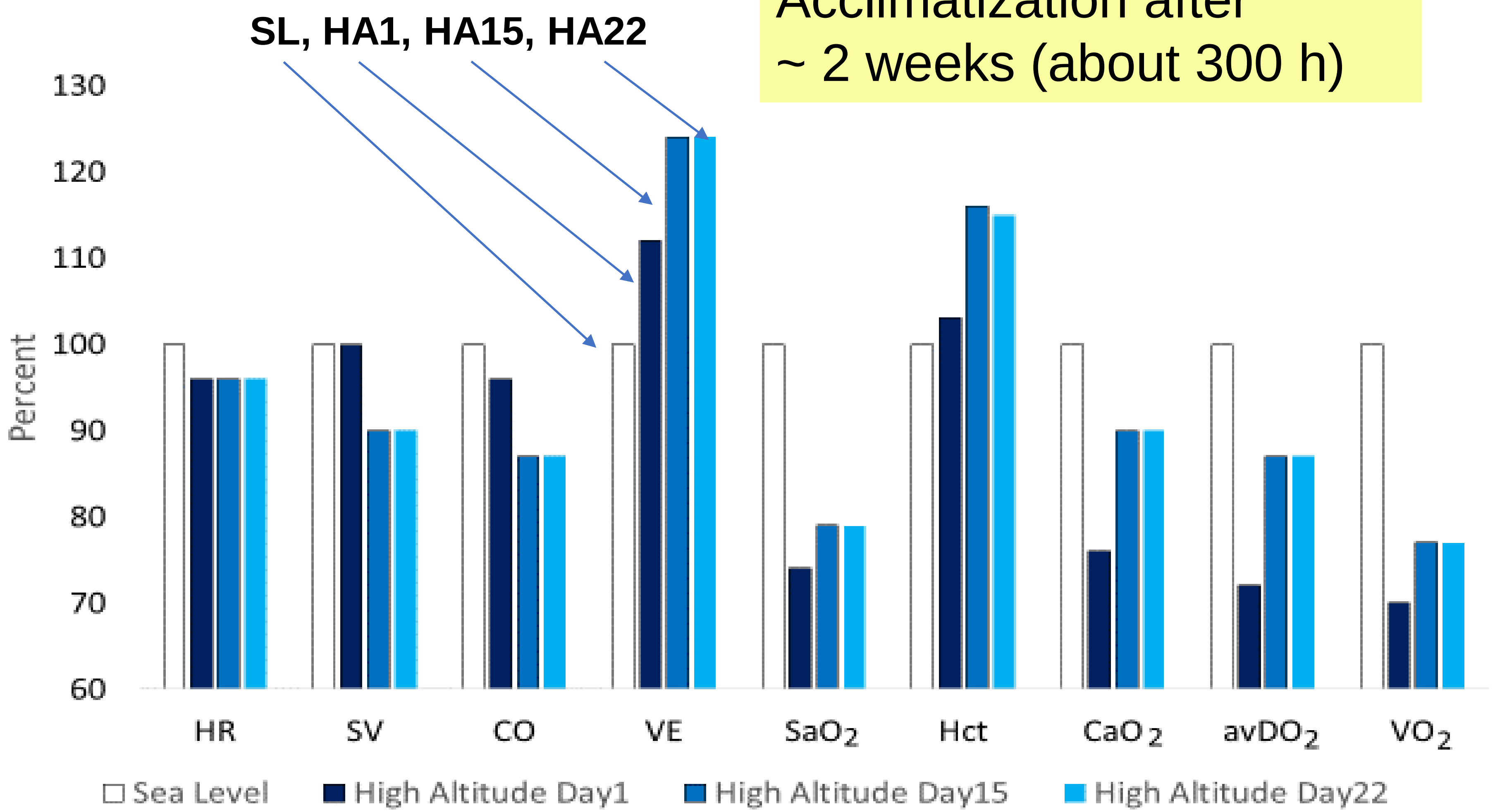
HYPOXIA Models

For High-Altitude Competion:
→Preparation at the Competition Altitude

- **Higher altitudes need longer acclimatization periods!**
- **No large differences between HH and NH**
- **Individually different responses!**

Responses to Maximale Exercise during a 22-day Exposure to High Altitude (4300 m)

Acclimatization after
~ 2 weeks (about 300 h)

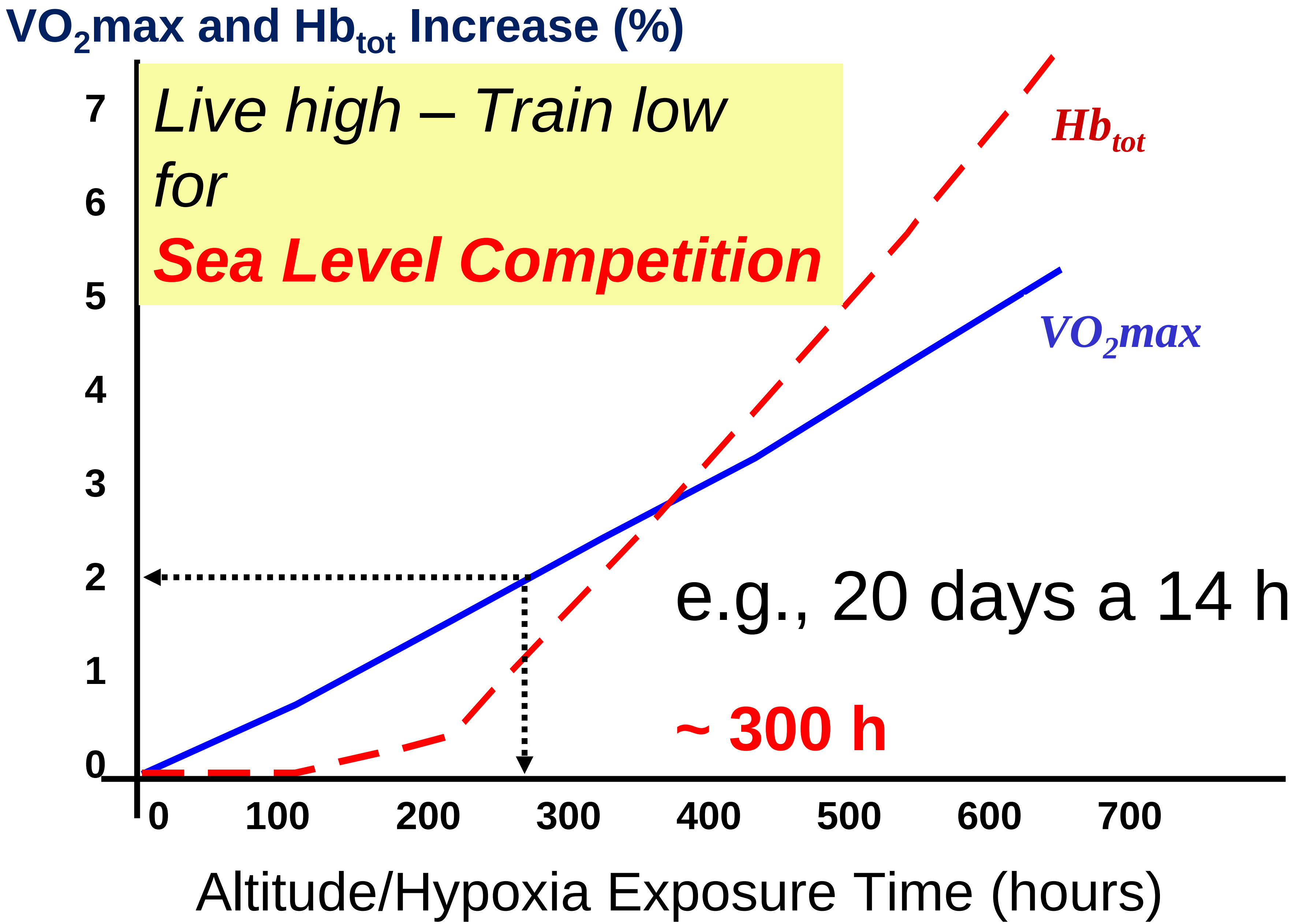


according to Horstman et al. 1980

Tenzing Hillary Everest Marathon

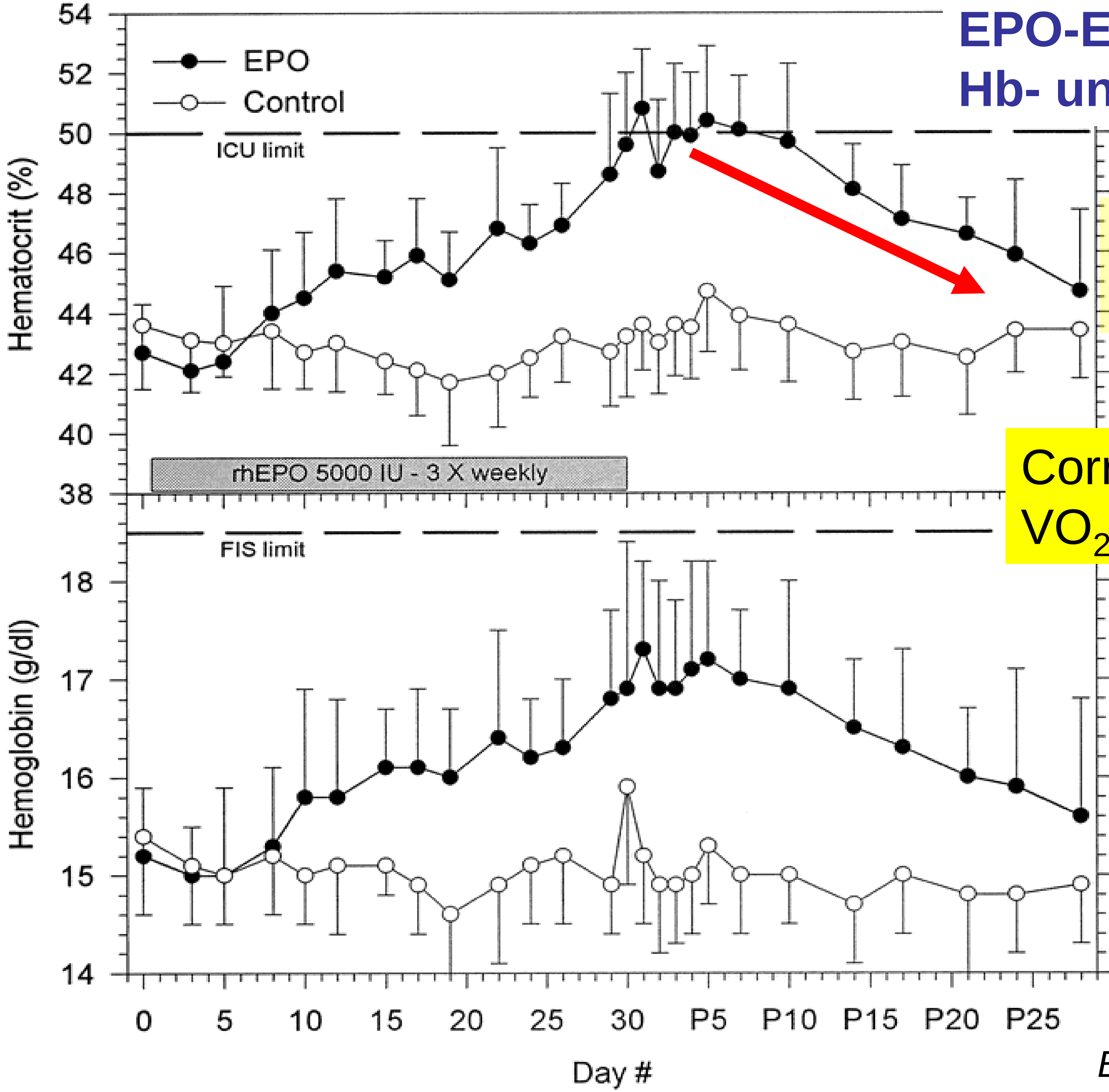
For competitions at (high) altitude you need:
*at least 1-**2** (3) weeks of prior LHTH*
(at the altitude of the competition!)

if not possible:
you can use IHT (2-3 weeks) +
short term arrival (2-10 h) before competition.



VO2max and Hbtot Increase (%)
Live high – Train low
for
Sea Level Competition
Hbtot
VO2max
7
6
5
4
3
2
1
0
e.g., 20 days a 14 h
~ 300 h
0
100
200
300
400
500
600
700
Altitude/Hypoxia Exposure Time (hours)

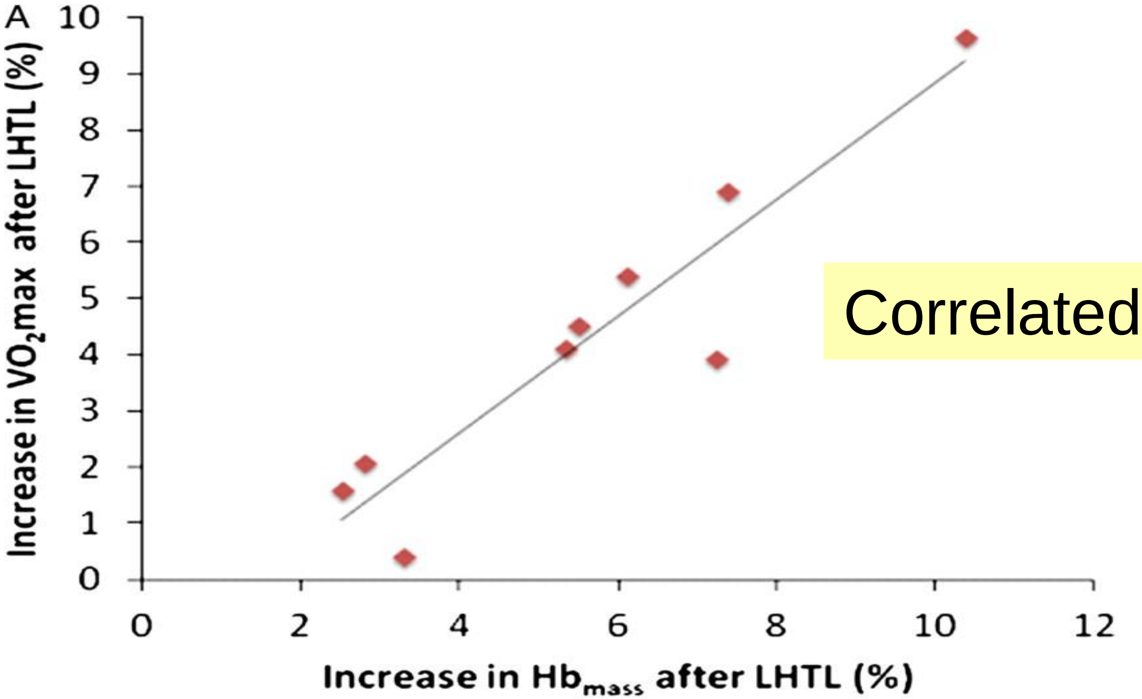
EPO-Effekts on Hb- und Hct-Values



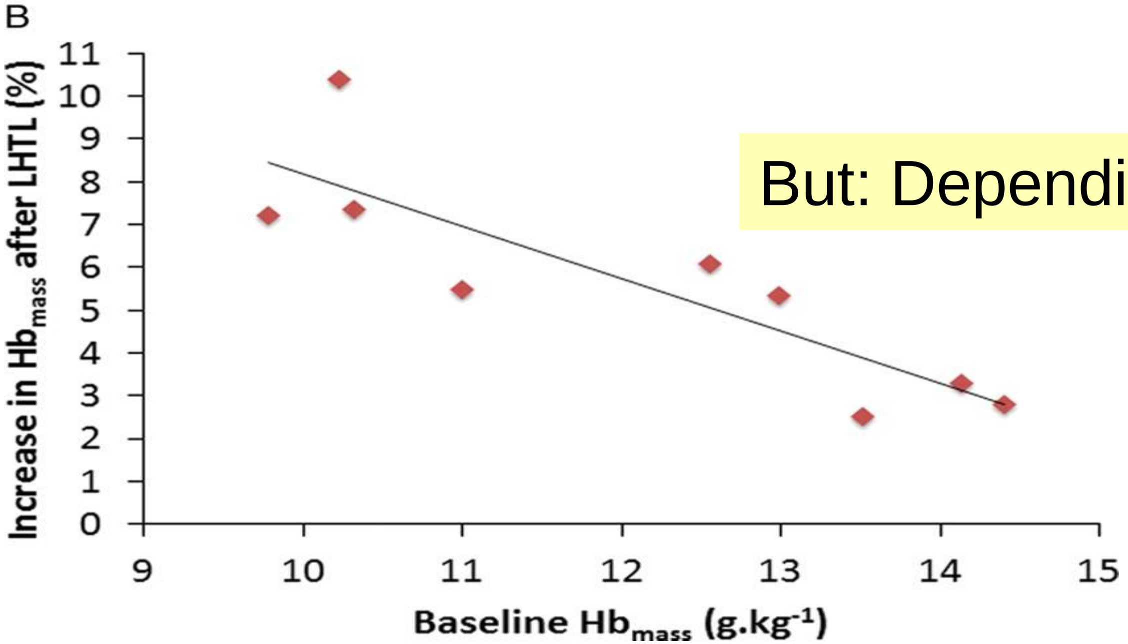
Cave: Decline!

Correlated with VO_2max increase!

Birkeland et al, 2000



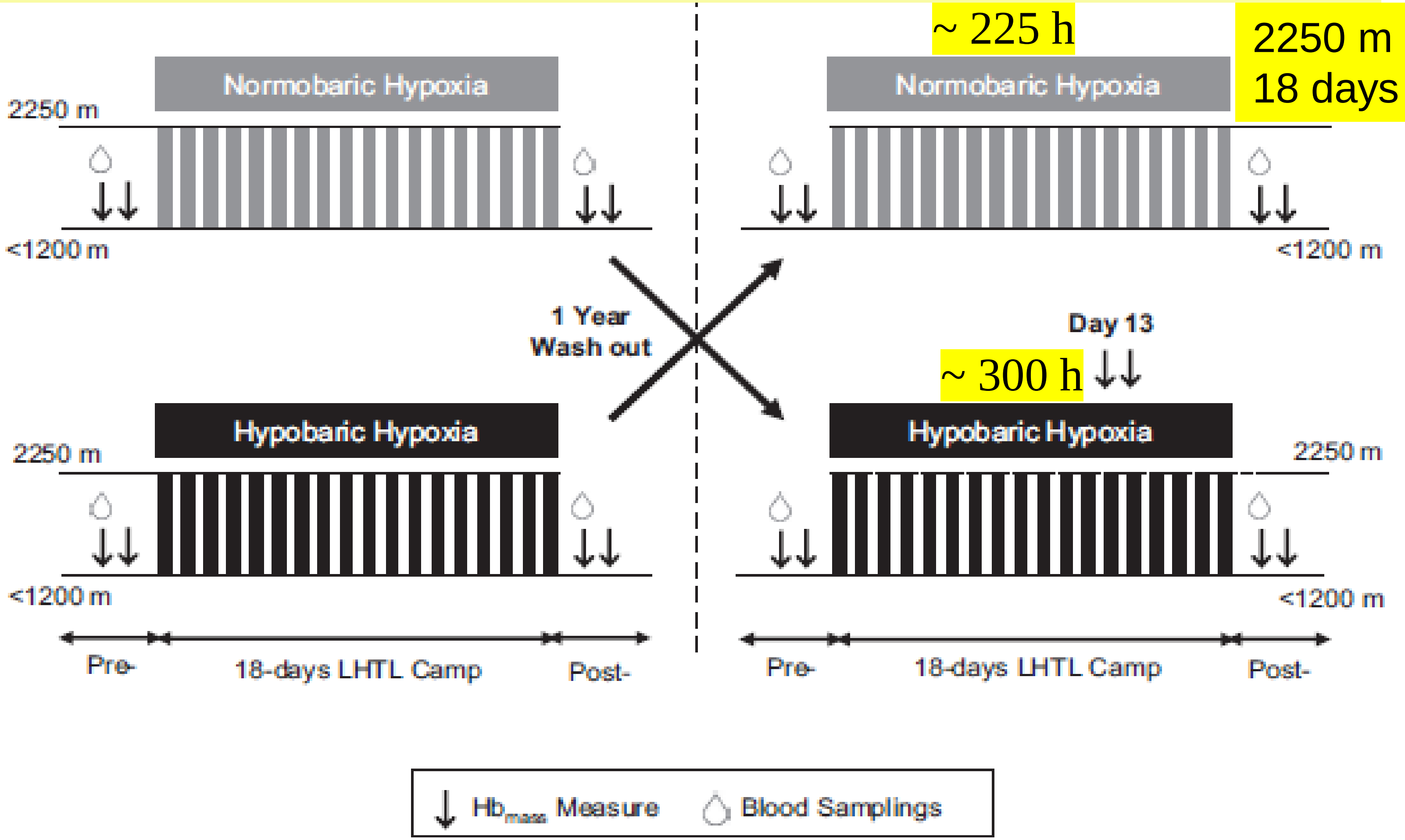
Correlated wit VO_2max increase!



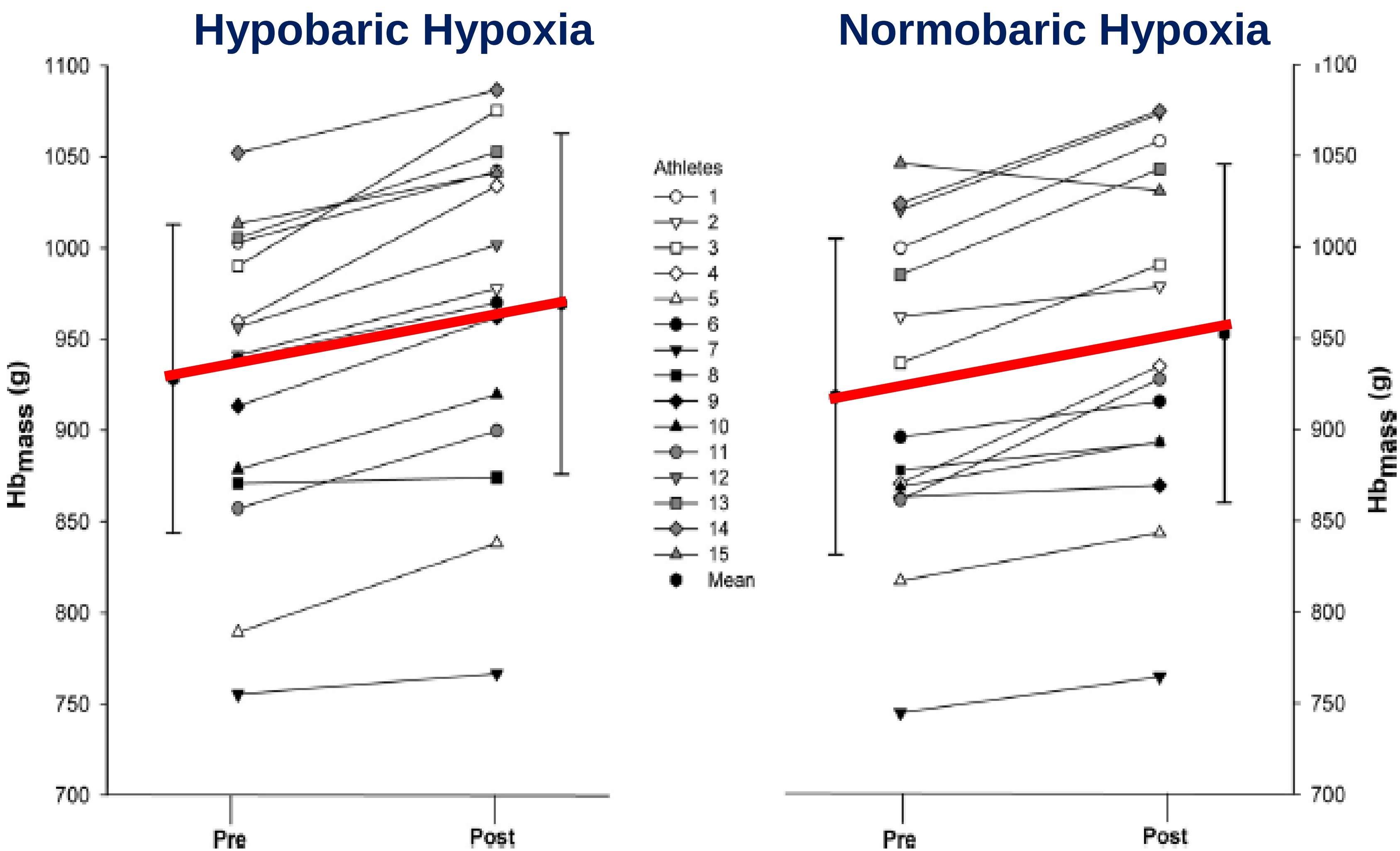
But: Depending on baseline values!

Robach & Lundby 2012

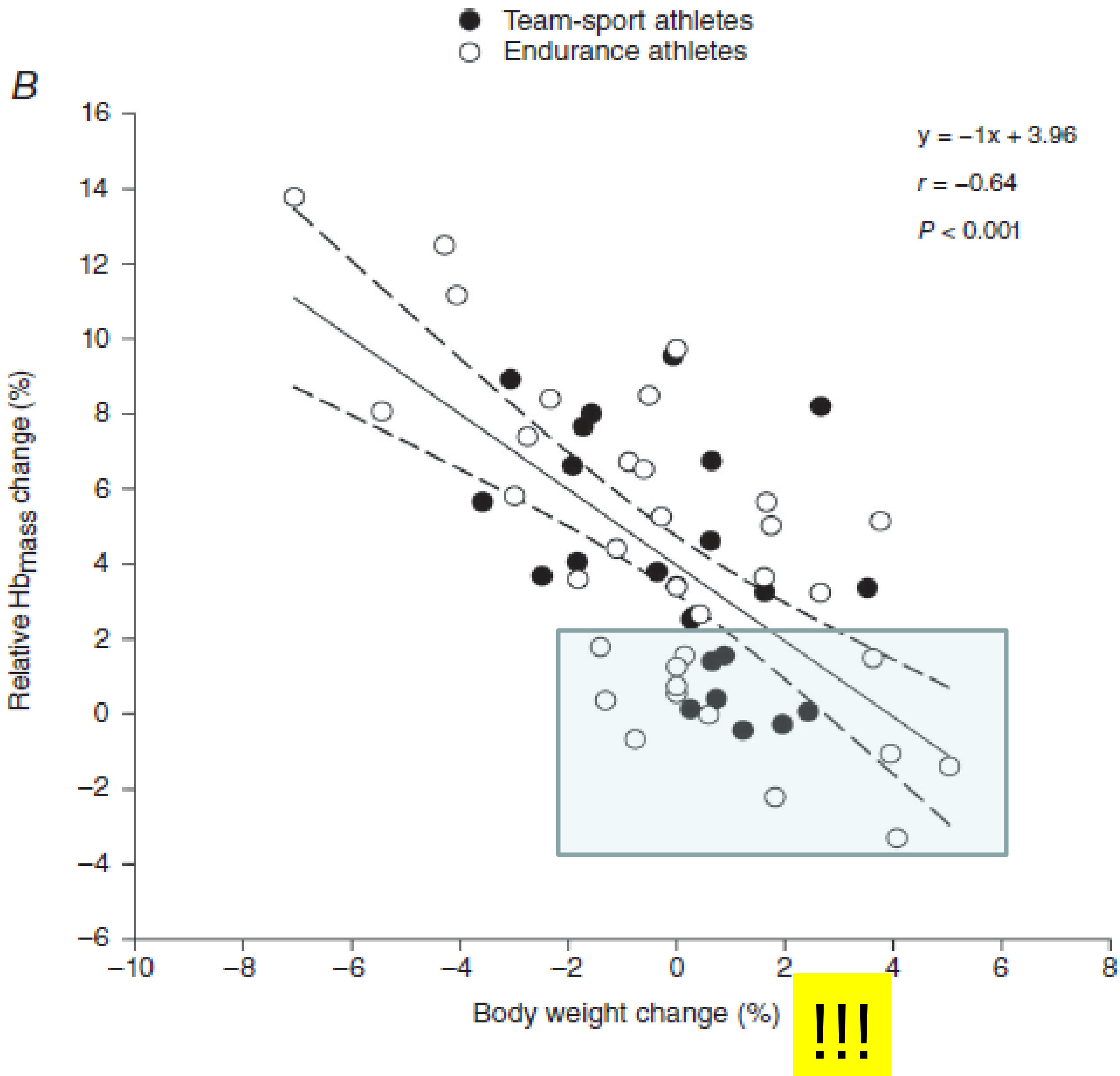
Does Hemoglobin Mass increase with Hypoxia/High Altitude Exposure?



Hauser et al., JAP 2017

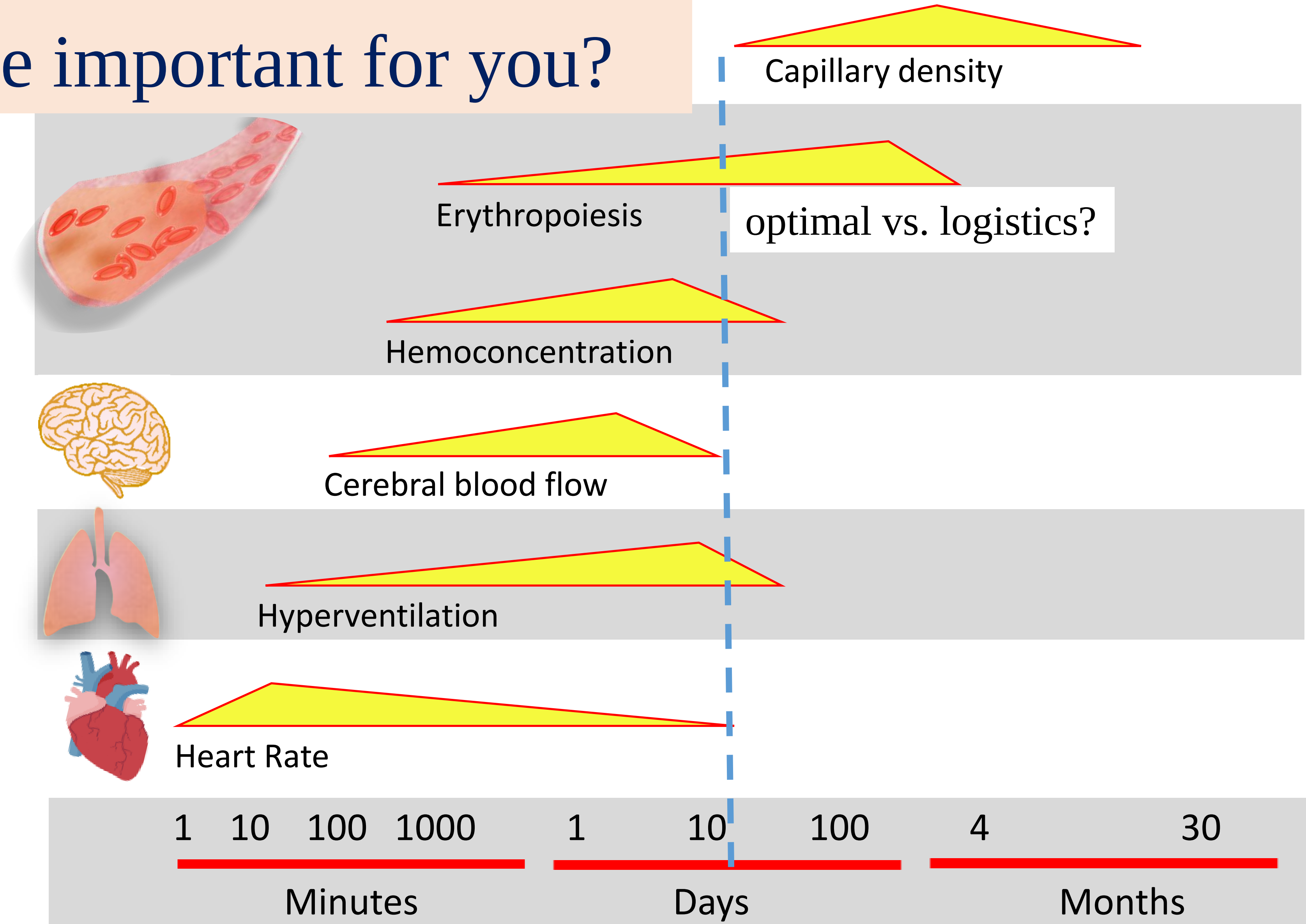


Hauser et al., JAP 2017



Hauser et al., Exp Physiol 2018

Which effects are important for you?



Time-dependent Adaptations to Hypoxia/Altitude Exposure

Vienna City Marathon

For competitions near Sea Level you need:
at least 300 hours of prior LHTL(H)
(altitude: 2,100 – 2,700 m, real or simulated)
intensive training sessions at low altitude

Consider: progressive increase in altitude
pilot trials!
Iron -supplementation

Iron – Supplementation

before and during the high-altitude training (HT); 1 Dosis/d

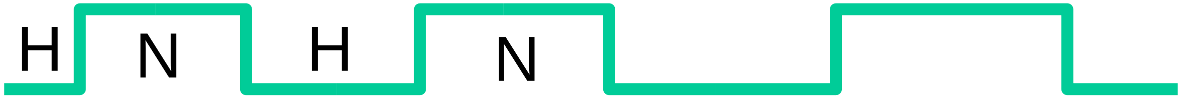
Ferritin		
< 100 ng/mL	→	100 mg 2 wks beforer HT 200 mg 1 wk before HT 200 mg during the HT
100 – 130 ng/mL	→	100 mg 2 wks before and during the HT
>130 ng/mL	→	maybe < 50 mg/d

<u>Intake</u>: 4-6 h after and > 2h before intensive training

<u>Cave</u>: Interactions: Calcium, black tea, coffee, red wine, VitE, ….
may negatively affect iron resporption

Stellingwerff et al., 2019

Effects of Intermittent Exposures?



Duration?

HH

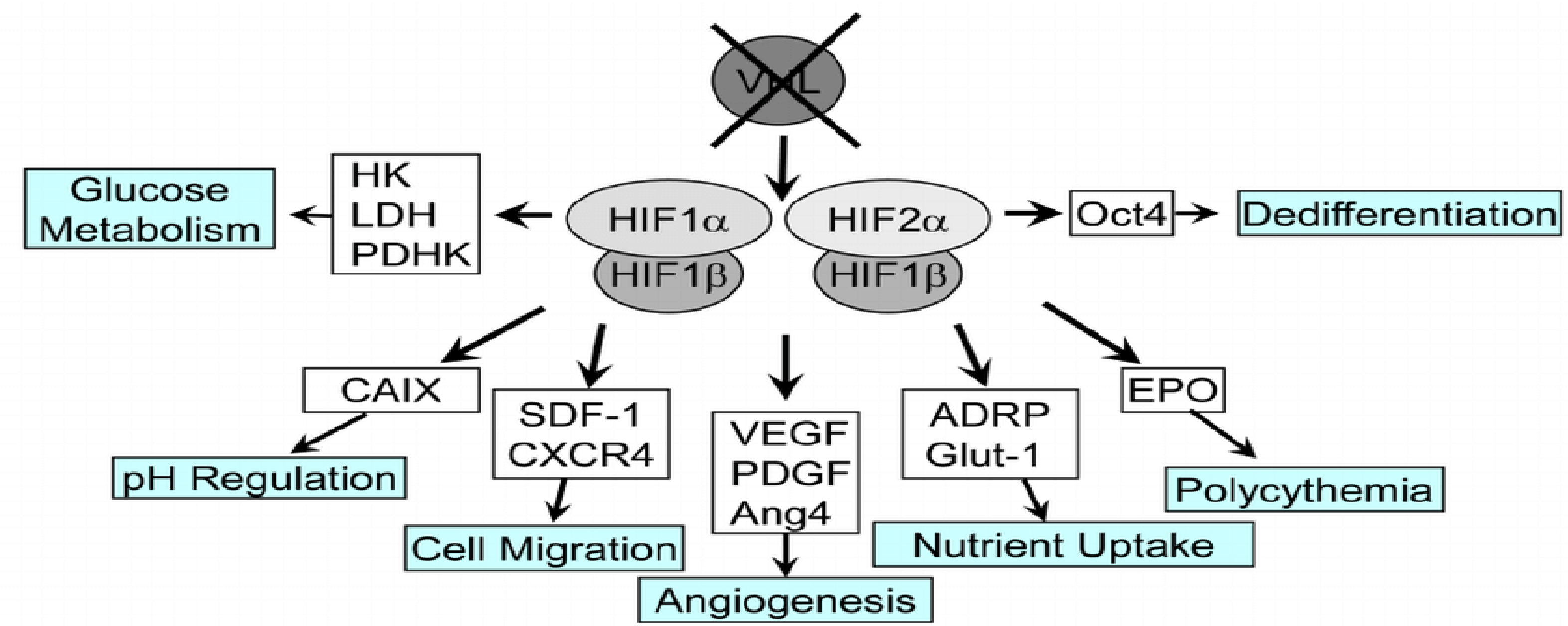
NH

Rest – Exercise?

Hypobaric

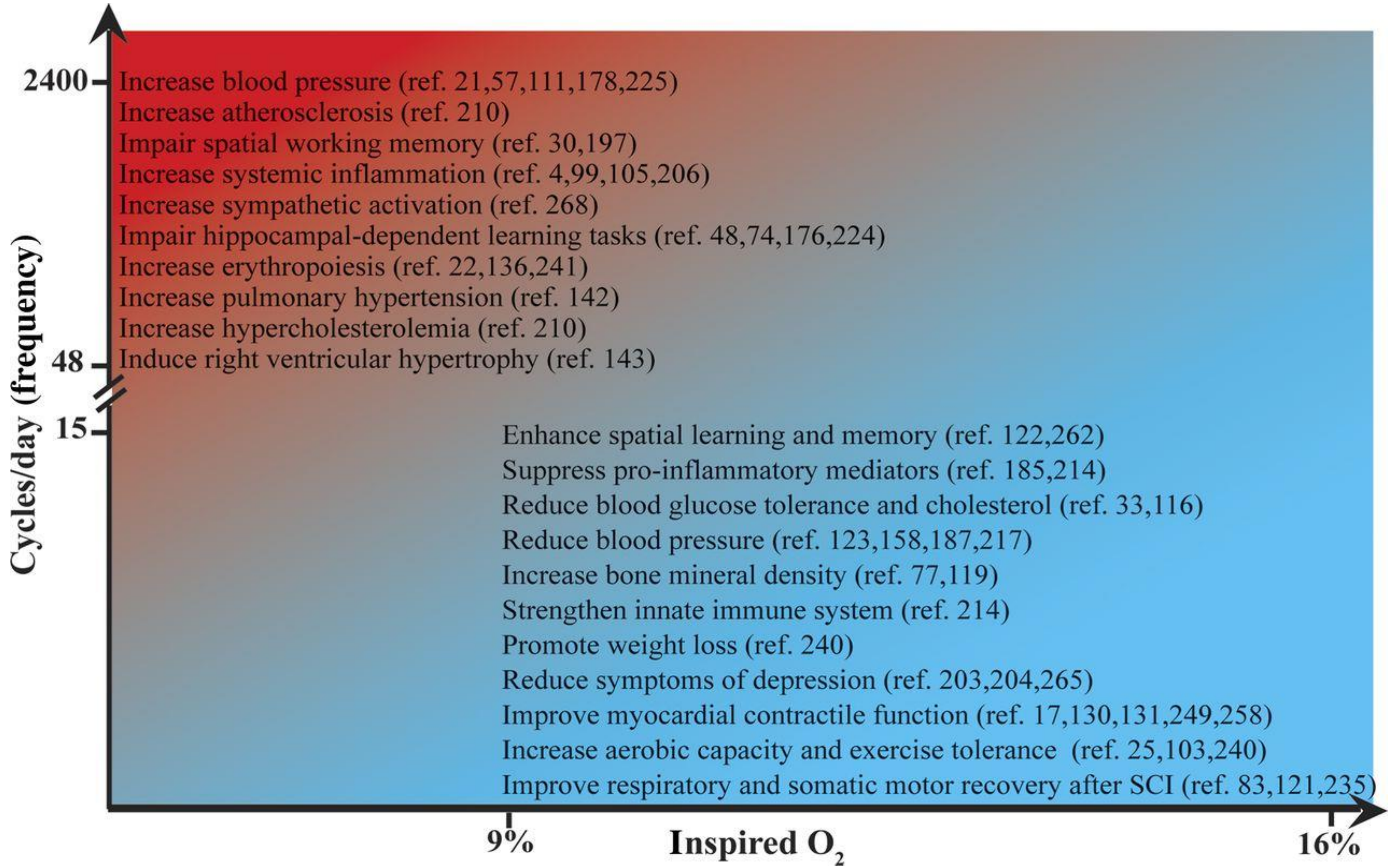
Normobaric HYPOXIA

Hypoxia-related molecular responses: HIF-mediated



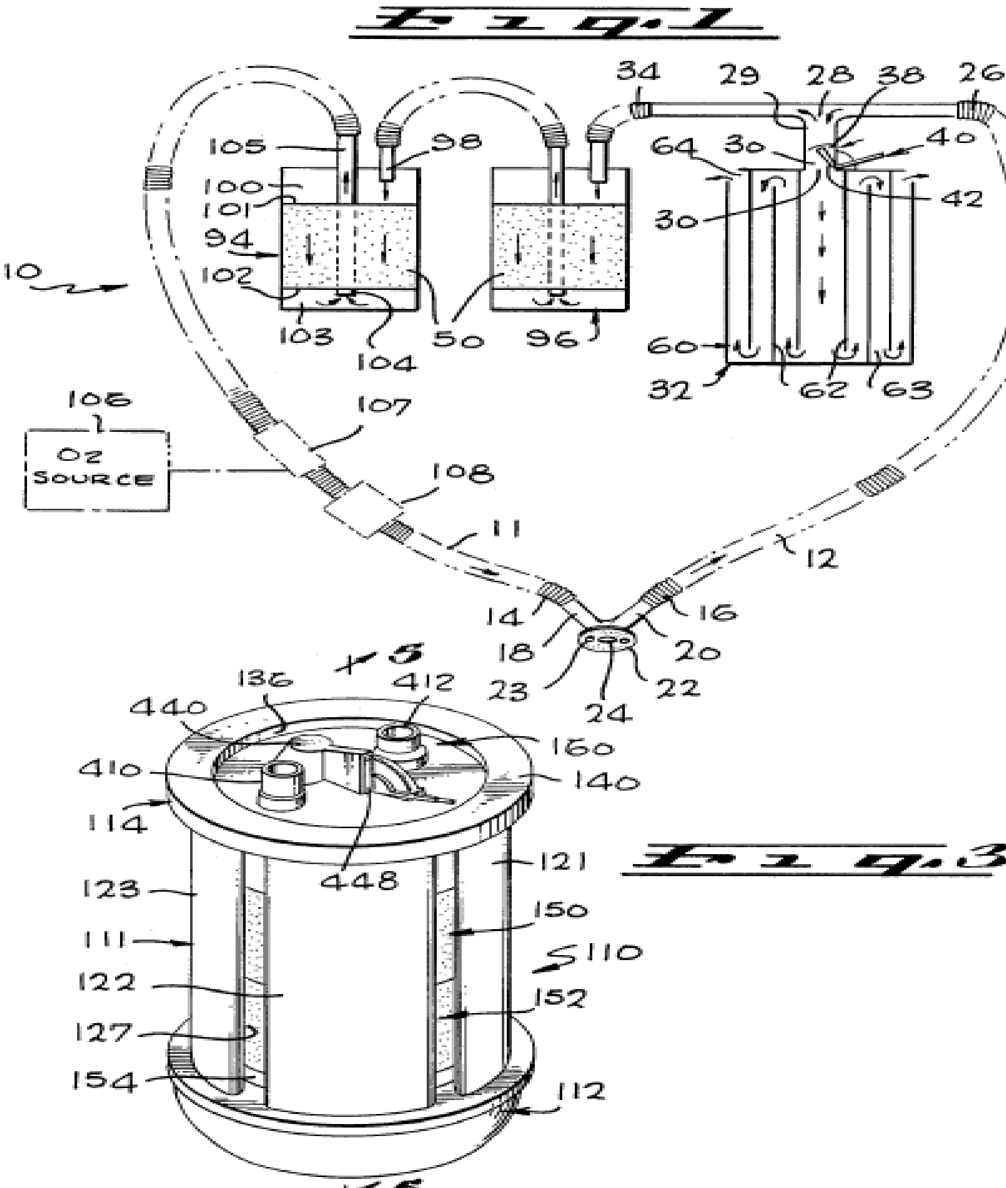
Hypoxia preconditioning effects via ROS signaling:
Prior hypoxia (stress) exposure
protects from later more severe hypoxia (+other stress)!

Schematic summarizing factors most influential in determining the balance of beneficial vs. pathogenic intermittent hypoxia (IH) effects.



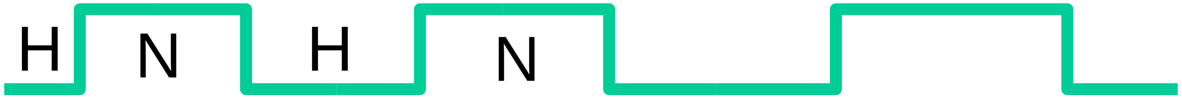
Angela Navarrete-Opazo, and Gordon S. Mitchell Am J Physiol Regul Integr Comp Physiol 2014;307:R1181-R1197

Altitude Conditioning Apparatus, 1987



NH

Intermittent Exposures



Acclimatization near home?
Ricart et al., 2000

9 participants were exposed
to simulated altitude of 5000 m (HH)
2 hours/day for 14 days (**28 hours**)

HH

During submaximal exercise
SaO_2 rose from 65 to 71%
VE rose from 55.5 to 67.6 L/min

Intermittent hypoxia (at rest) may improve exercise tolerance, exercise performance, and running economy

Patients, healthy individuals, athletes?
Protocol?

e.g., 3/3 or 5/5 cycles – hypoxia (16-10%)/normoxia
60 min/d, 5 d/wk, 3 weeks

Acutely intermittent hypoxia produced substantial enhancement in endurance performance in male competitive cyclists and triathletes,
but the relative benefit of 3- vs 5-min exposure intervals remains unclear.

Bonetti et al., 2009

Training in normobaric hypoxia and its effects on acute mountain sickness after rapid ascent to 4559 m

Schommer et al., 2010

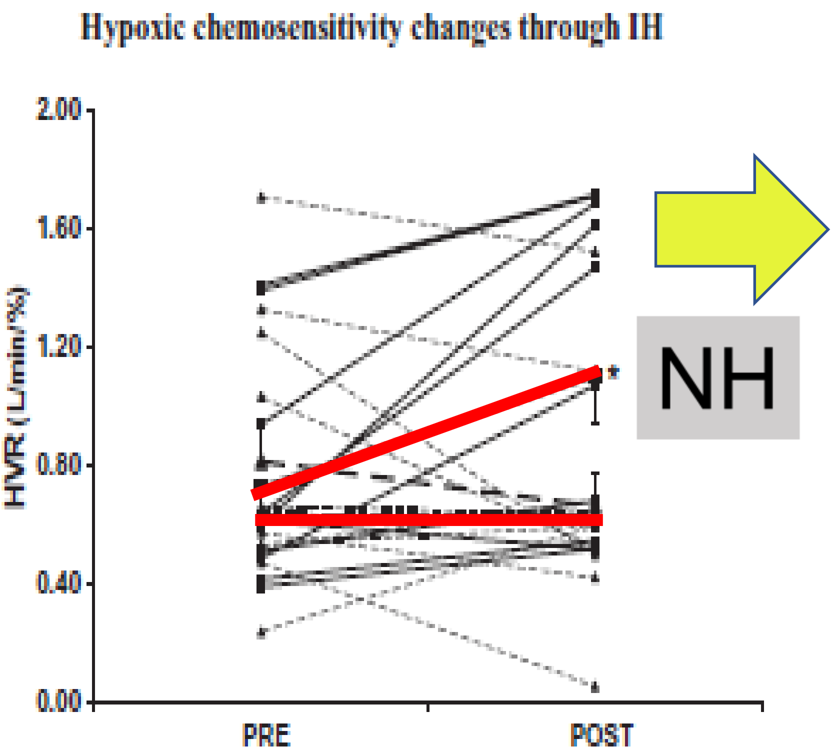
40 participants exercised 70 min, 3 x /week for 3 weeks at 60% VO_2max in N or NH (2500, 3000, and **3500** m during 3 weeks) + 4 passive exposures of 90 min N or NH in week 4
Total exposure time: **16.5 hours**
5 days later ascent to **4559 m**

NH

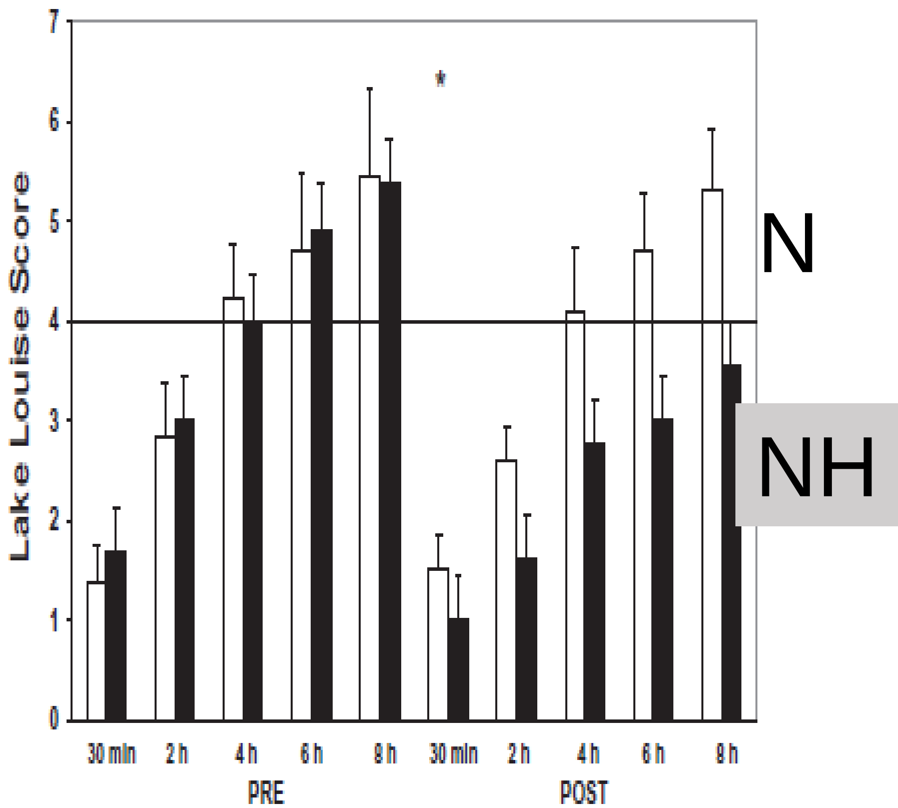
AMS at 3611 m: 6% (NH) vs. 47% (N), p = 0.01)
No significant difference at 4559 m

HVR changes post IH

7 x 1h **(7 h)** 4500 m, post = 2d



HVR

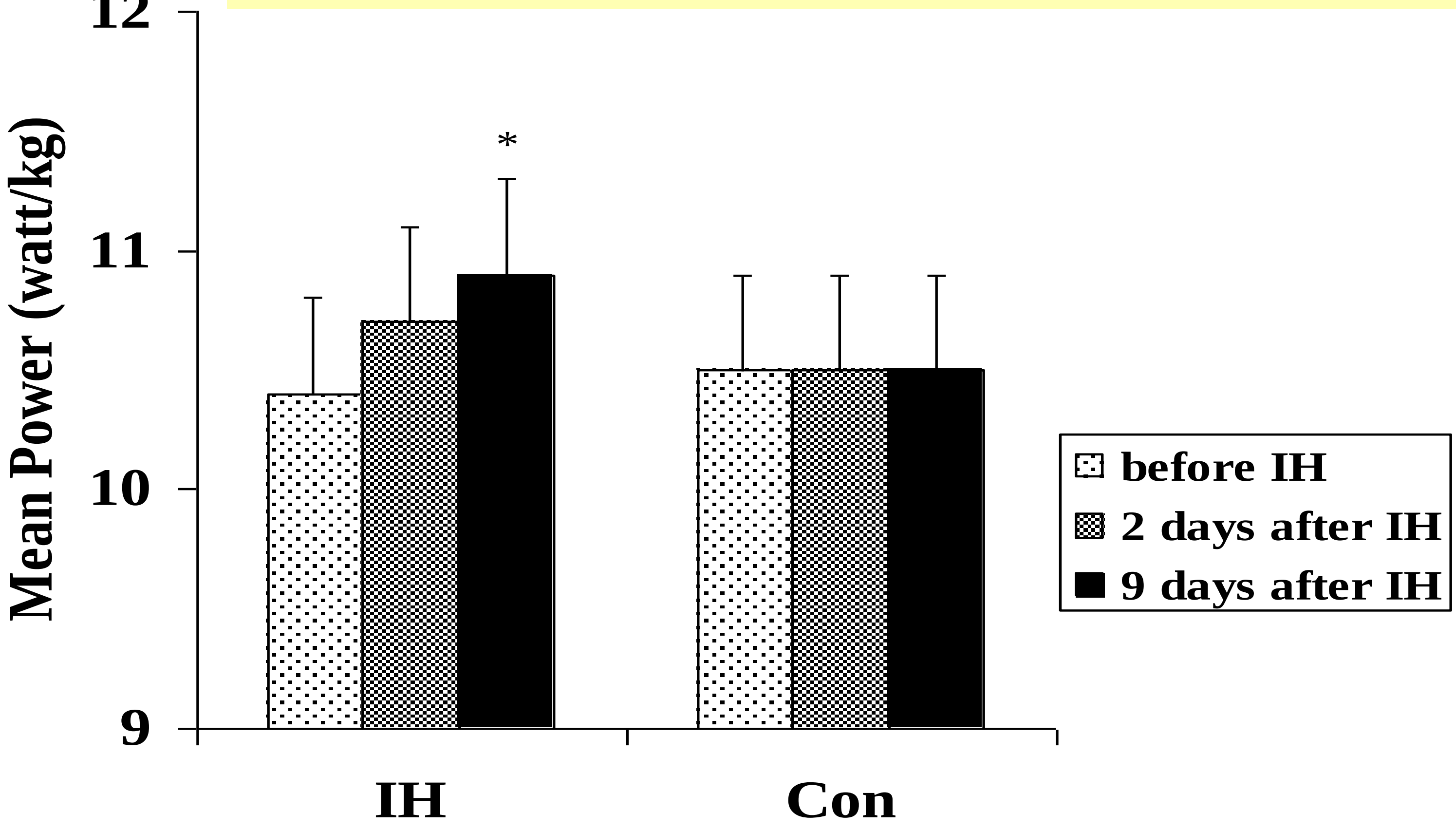


AMS

Wille et al., SJMSS 2012

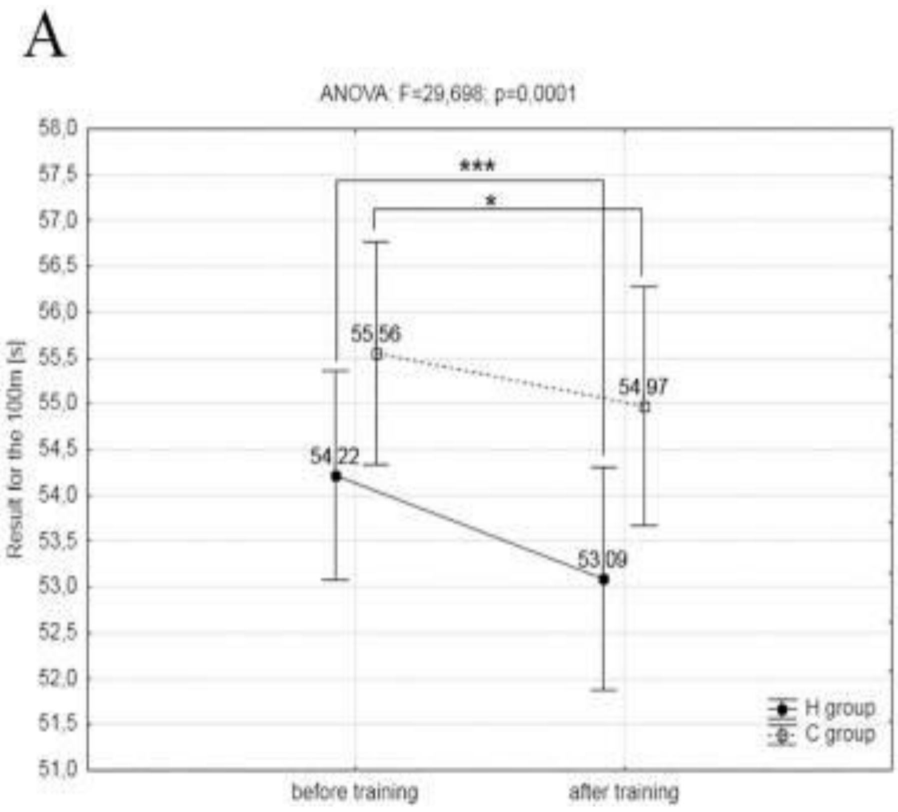
Anaerobic Power after IHT

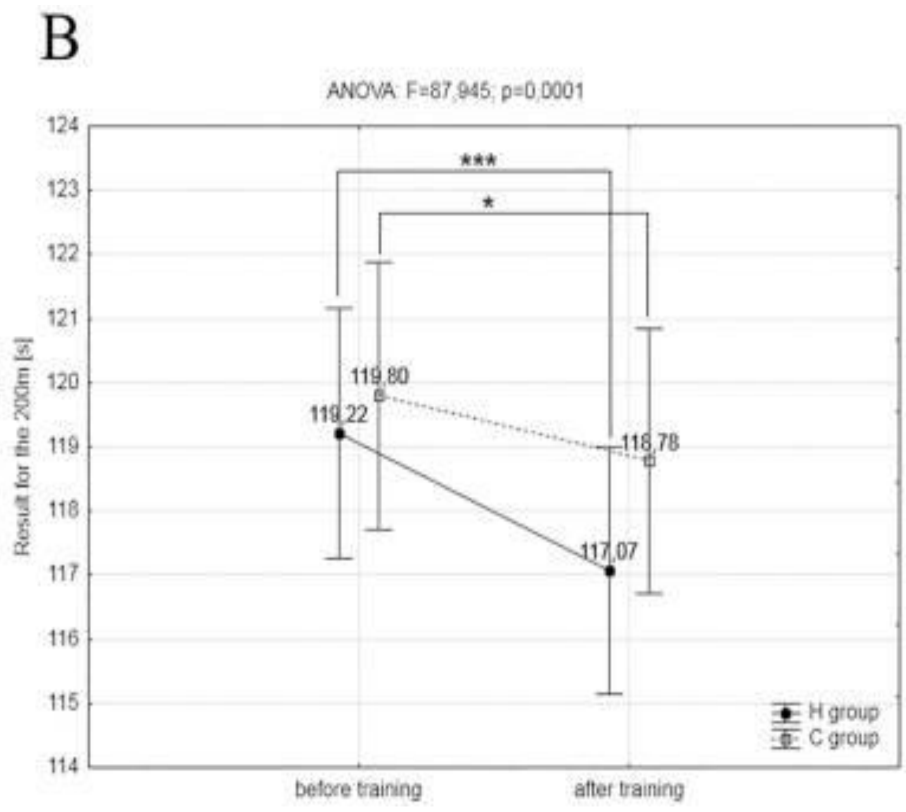
10 days a 2 h (AT) in 2,500 m or Sea Level (simulated; hypobaric chamber)



Meeuwsen et al. 2001

IHT (FiO_2 15.5 %, 2,500 m; 2 times per week over 4 weeks; competition mesocycle) in swimmers

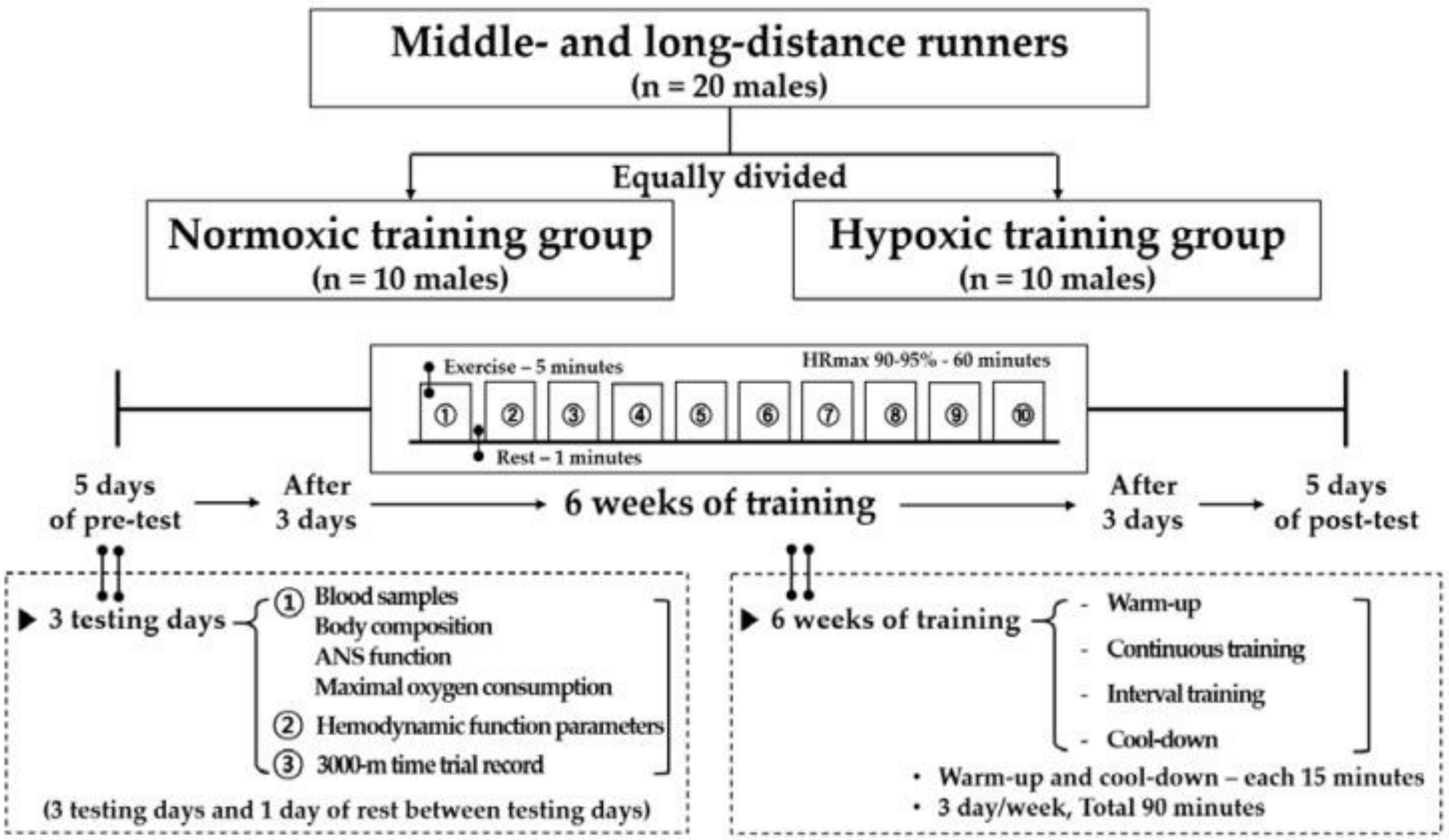




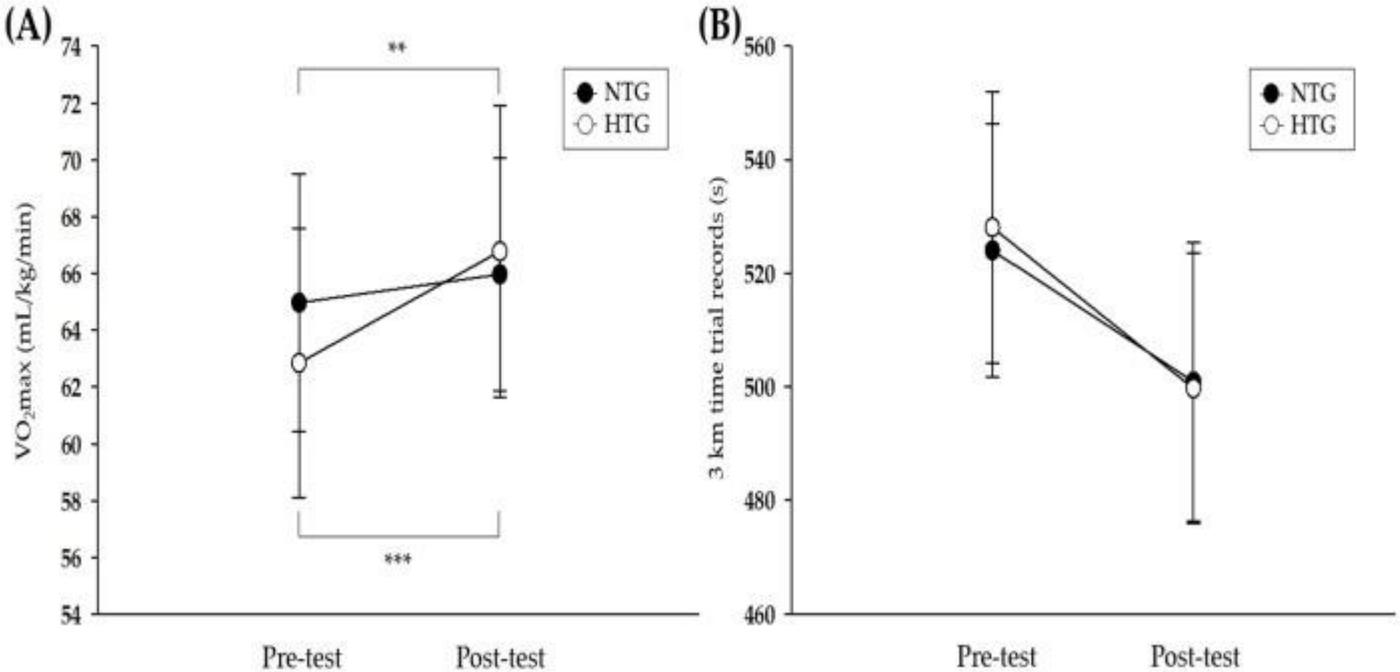
Improved swimming performance was associated with improved anaerobic capacity!

Czuba et al., 2017

Interval training in hypoxia vs. normoxia in male middle and long distance runners: 526 mmHg; simulated altitude of 3000 m



Jung et al., 2020



Improved VO_2max, hemodynamic and ANS function, but improvement of 3 km TT were the same!
Immune function was not adversely affected by IHT.
So, what are the benefits of IHT?

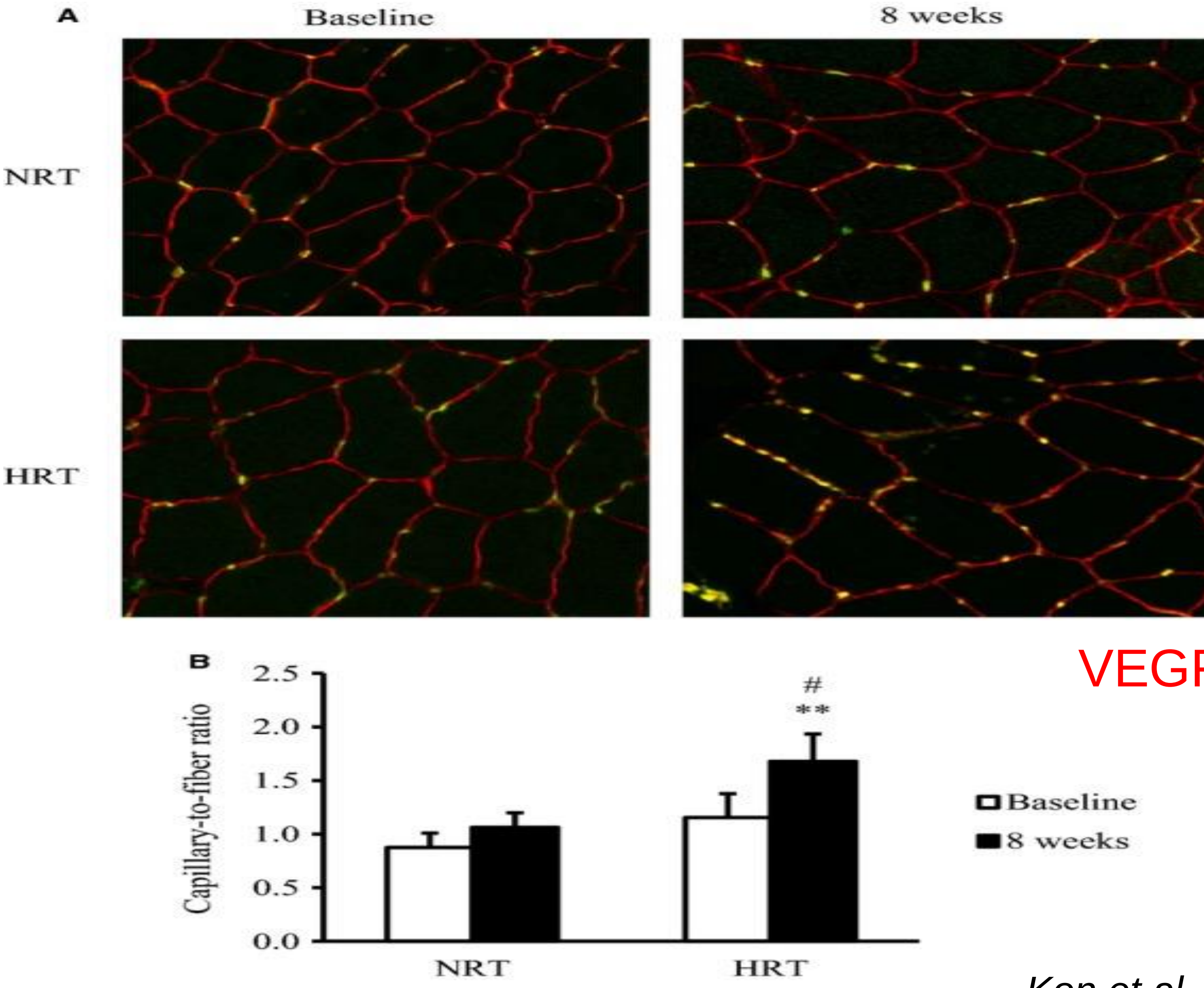
Jung et al., 2020

LLTH: 3,850m, 33 (untrained) men, low and high intensity; 30 min/d, 5 d/wk, 6 weeks

Morphological measurements in M. vastus lateralis. Comparisons after 6 weeks of training					
Group		N-high	N-low	H-high	H-low
Increase of knee extensor volume (%)		1.36 ± 0.74	3.24 ± 1.65	4.96 ± 1.01*	1.09 ± 1.03
Volume density of total mitochondria (%)	before training	6.01 ± 0.48	5.53 ± 0.39	5.25 ± 0.38	5.22 ± 0.45
	after training	7.45 ± 0.39*§	6.16 ± 0.59	**8.11 ± 0.53*§&**	**6.55 ± 0.45*&**
Volume density of subsarcolemmal mitochondria (%)	before training	1.42 ± 0.25	1.01 ± 0.16	1.00 ± 0.17	0.80 ± 0.22
	after training	1.61 ± 0.24	0.88 ± 0.18	**2.05 ± 0.37*&**	**1.54 ± 0.35&**
Capillary length density (mm^{-2})	before training	762 ± 35	729 ± 31	735 ± 44	644 ± 42
	after training	760 ± 37	655 ± 52	**821 ± 35*&**	**658 ± 23&**
Mean values ± SE. N stands for normoxic conditions. H for hypoxia. Volume density of mitochondria is volume/fiber volume in %. Total mitochondria are the sum of central and subsarcolemmal mitochondria. Symbols as in Table [3]					

Geiser et al., IJSM 2001

Effects of RT in Hypoxia

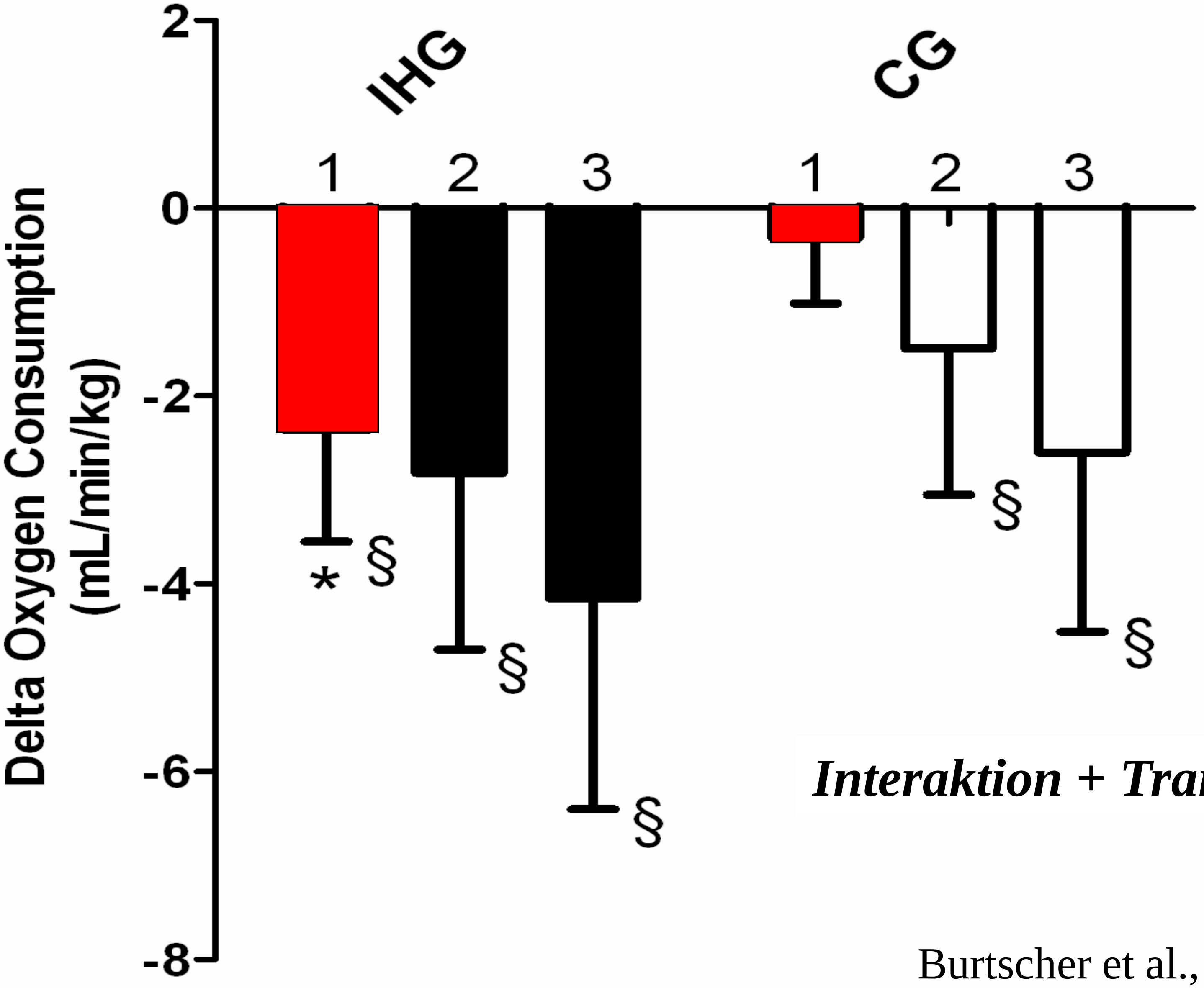


16 males
14.4% FiO_2
8 weeks RT

VEGF and Caps ↑

Kon et al., PhysiolRep 2014

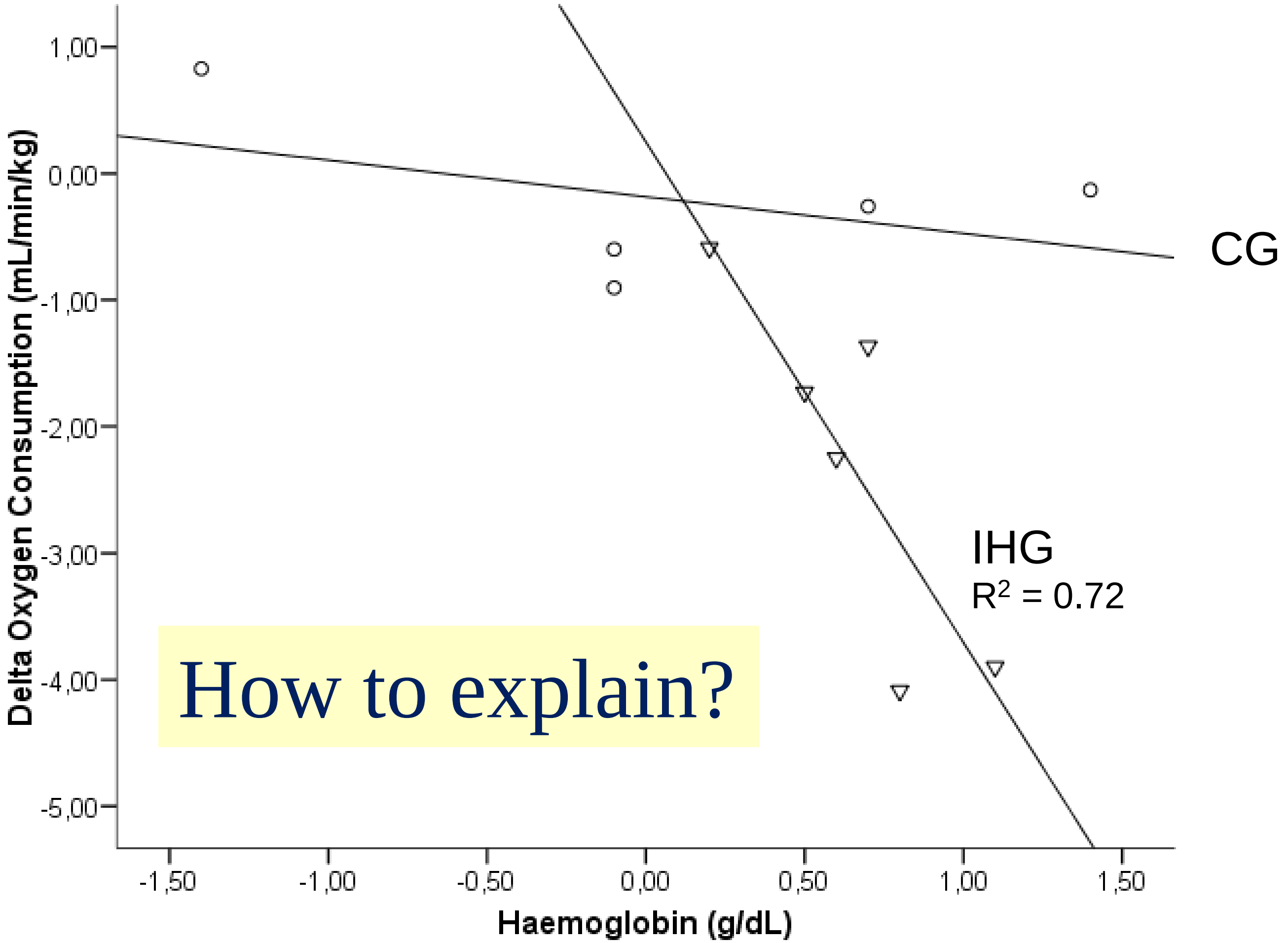
Running economy after 2 x 5 wks of IHrest



Interaktion + Training!

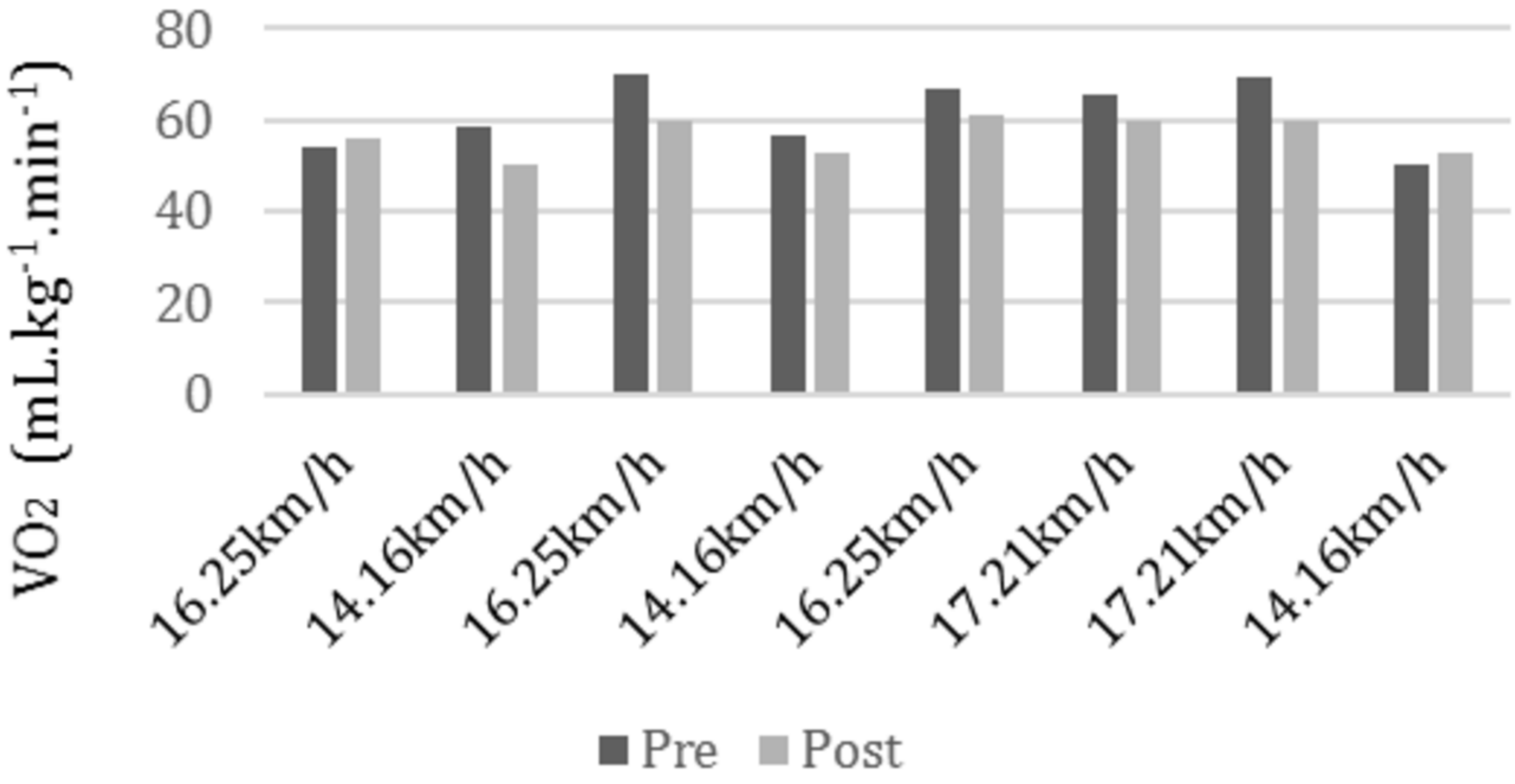
Burtscher et al., IJSM, 2010

Running economy after 2 x 5 wks of IHrest



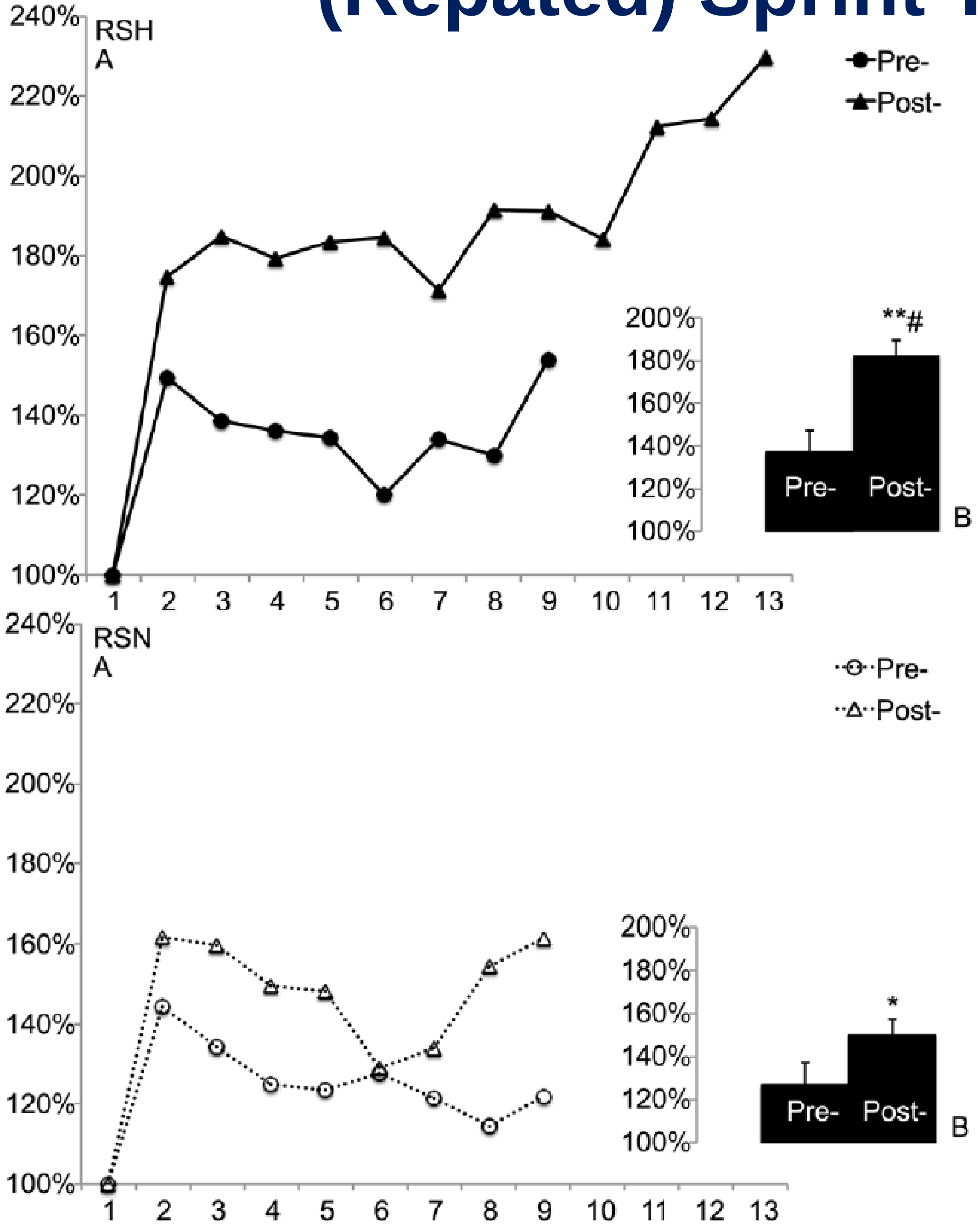
Similar findings after IHrest were observed in Basketball players by Kilding et al., 2016

Running Economy after 10 days Training at ~1800 m



Diebel et al., 2017

(Repated) Sprint Training in Hypoxia



Delta [tHb]

pre and post sprint training
in hypoxia (RSH)
in normoxia (RSN)

Improved blood perfusion

Faiss et al., Plos One 2013

Suggested Upregulation/Increase after Sprint Training in Hypoxia

Mitochondrial density
Capillary-to-fibre ratio
Fibre cross-sectional area

Oxidative stress defence
pH regulation
NO-dependent vasodilation
→ benefits of FT-fibres
→ higher microvascular PO_2
→ reduced PCr breakdown, faster PCr recovery

Faiss et al., BJSM 2013

2000-3000 m may be more effective than higher altitudes!
Goods et al., 2014

Altitude training before competition - models and use of intermittent hypoxia

Why?
What do you expect (based on scientific evidence)?
Appropriate (available) hypoxia methode?
Potential disadvantages?
Pilot testing (individual responses)?
Accompanying measures e.g., diet)?
…………..

Thank you!!