Training in hypoxia: for better or for worse?

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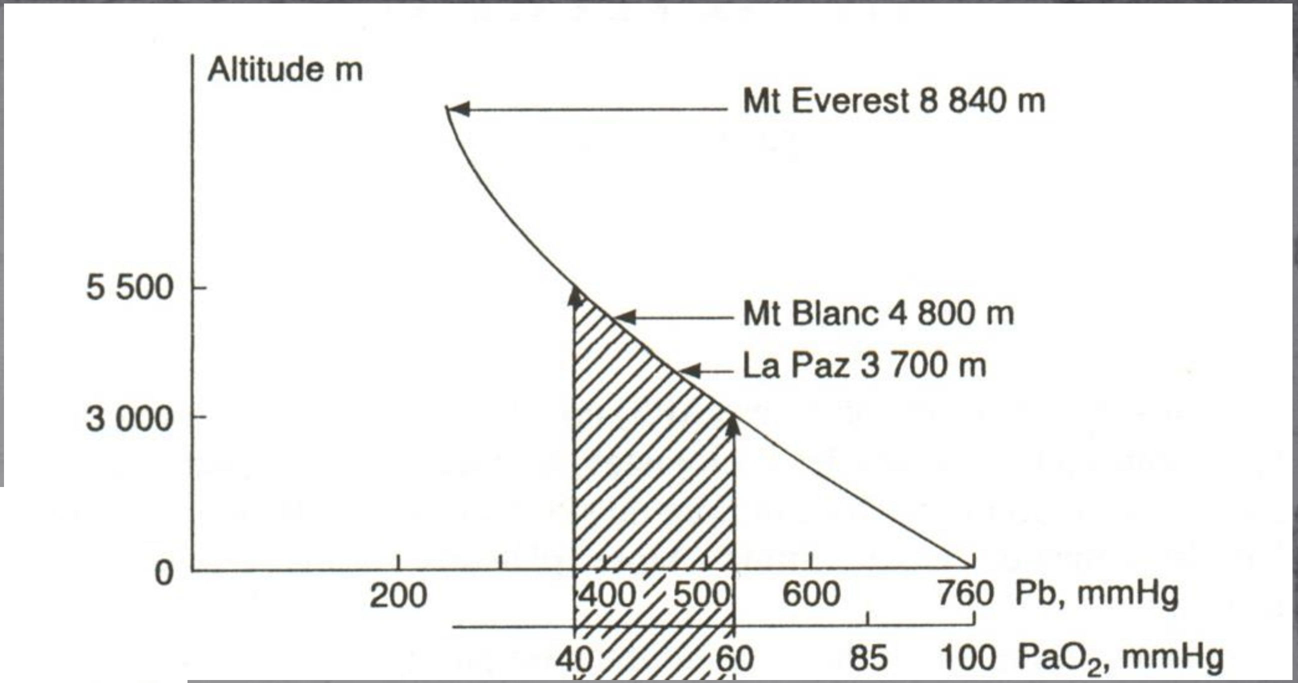
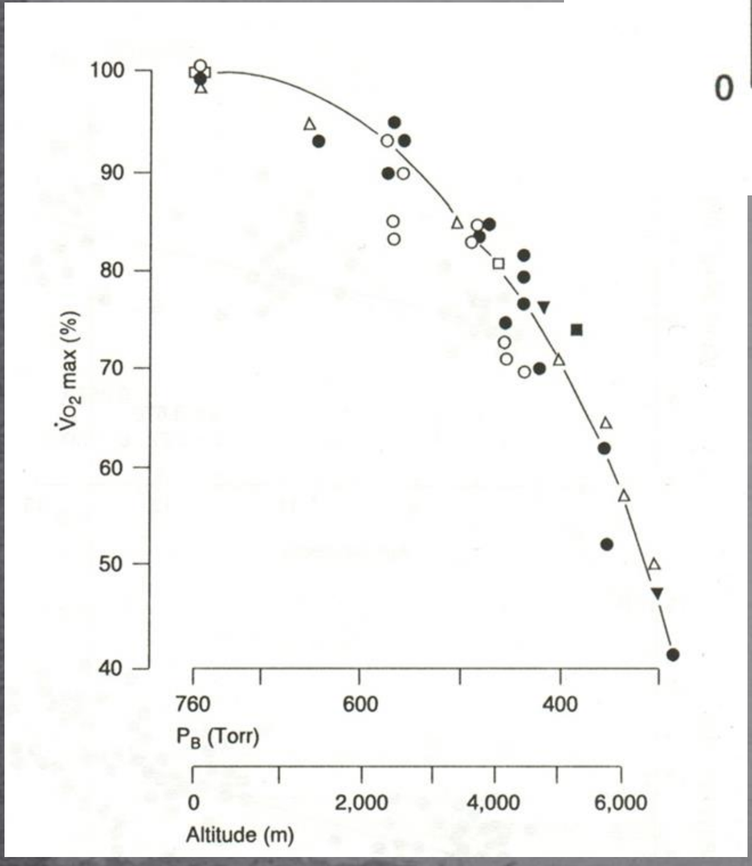
UPFR des Sports Besançon (France)

7th International Congress "Mountain Sport & Health"
Rovereto
9-10 November 2017

Hypoxia?



Altitude m
Mt Everest 8 840 m
5 500
Mt Blanc 4 800 m
La Paz 3 700 m
3 000
0
200
400
500
600
760 Pb, mmHg
40
60
85
100 PaO_2, mmHg

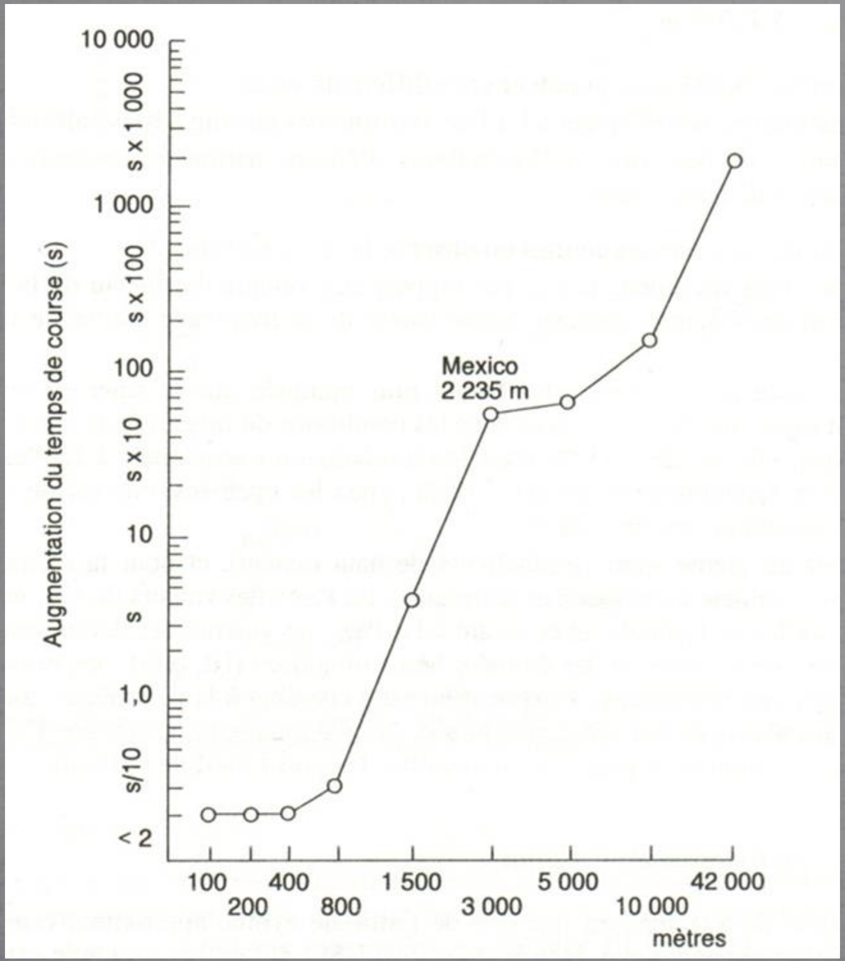


$\dot{V}O_2$ max (%)
100
90
80
70
60
50
40
760
600
400
P_B (Torr)
0
2,000
4,000
6,000
Altitude (m)

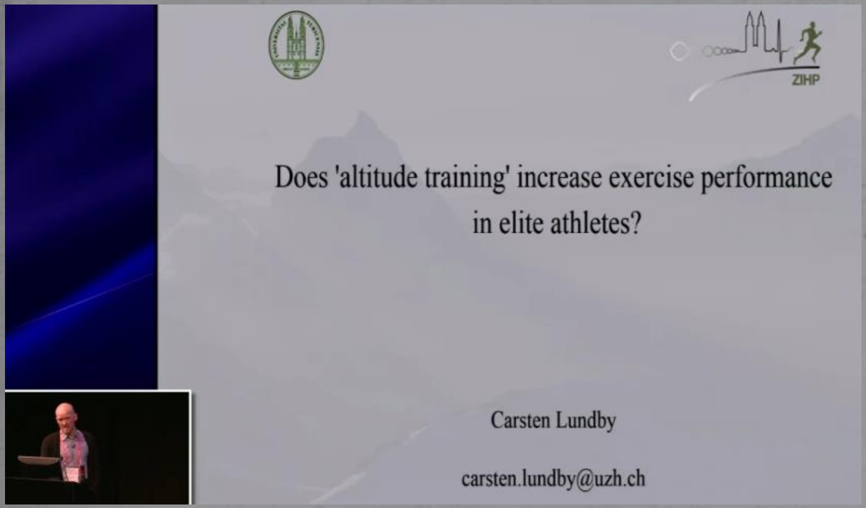
Hypoxia?

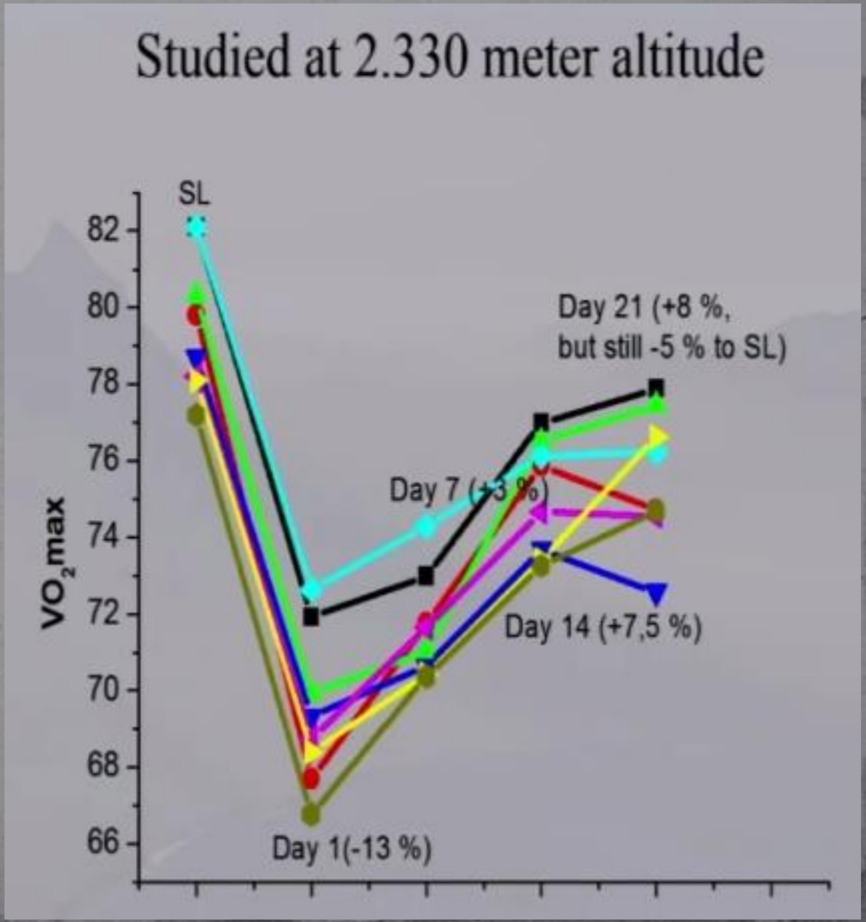
MEXICO68

2250 m



- Train to compet in altitude
- Train to compet at SL
- Train for health purpose ?





High level athletes

Eur J Appl Physiol (1997) 75: 136 – 143

ORIGINAL ARTICLE

C.J. Gore · S.C. Little · A.G. Hahn · G.C. Scroop
K.I. Norton · P.C. Bourdon · S.M. Woolford
J.D. Buckley · T. Stanef · D.P. Campbell · D.B. Watson
D.L. Emonson

Reduced performance of male and female athletes at 580 m altitude

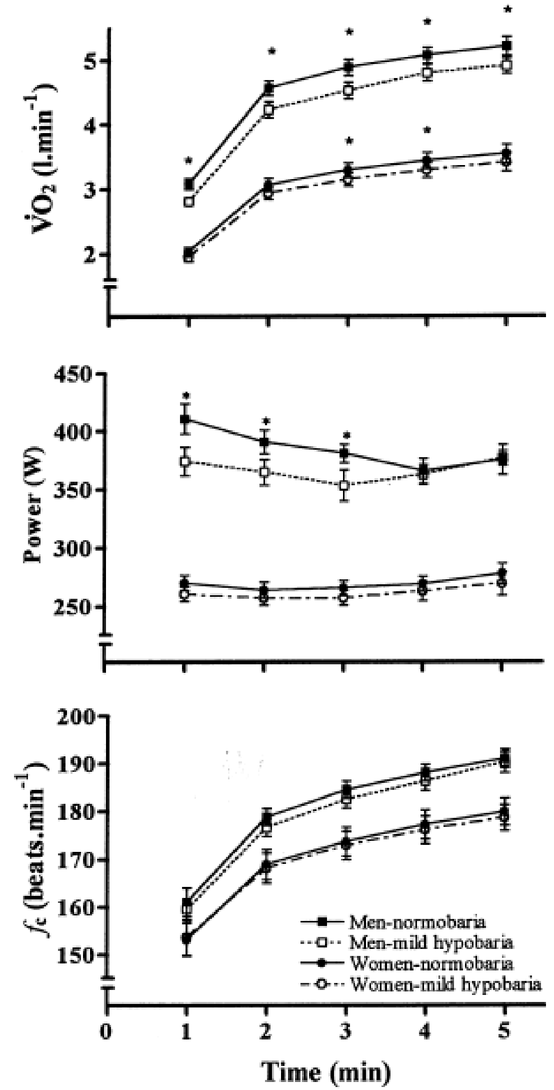


Fig. 1 Oxygen consumption ($\dot{V}O_2$) power output (in watts, W) and cardiac frequency (f_c) of endurance-trained male (n = 10) and female (n = 10) athletes during 5-min all-out performance tests on a cycle ergometer at normobaria (99.33 kPa) and at mild hypobaria (92.66 kPa). This hypobaria is equivalent to 580 m altitude referenced to sea level. Values are means (SEM). *Significantly different from normobaria, within-group comparison. Note that, at all times, the values for women are significantly different from those for the men at the matched chamber pressure

Live low, train high

Hypoxic Training: Effect on Mitochondrial Function and Aerobic Performance in Hypoxia

PAUL ROBACH[1], THOMAS BONNE[2], DANIELA FLÜCK[3,4], SIMON BÜRGI[4], MARCO TOIGO[3,4,5], ROBERT A. JACOBS[3,4], and CARSTEN LUNDBY[3,4]

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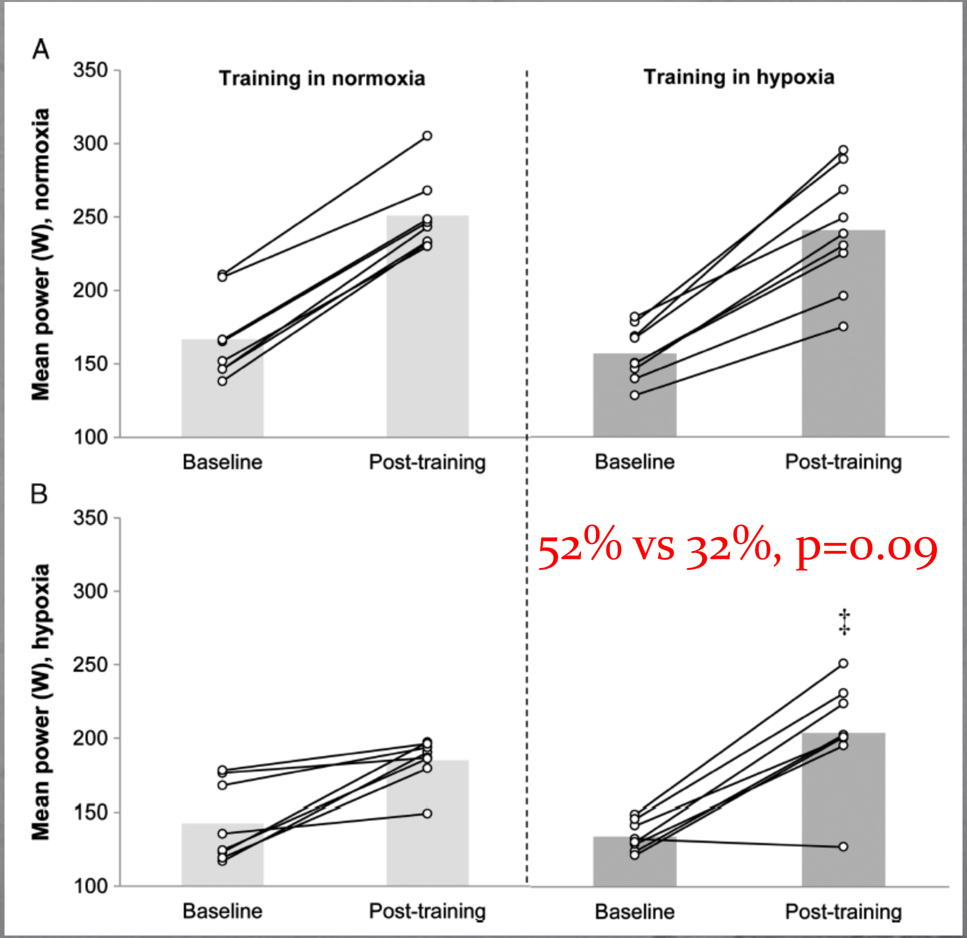
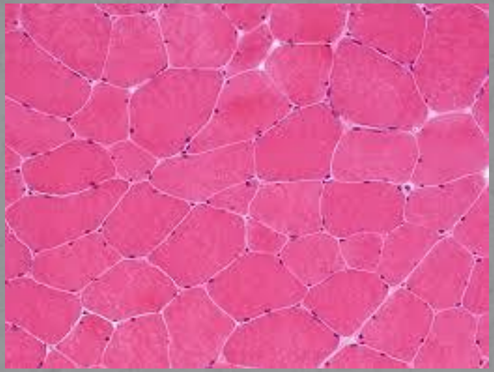
Med. Sci. Sports Exerc., Vol. 46, No. 10, pp. 1936–1945, 2014.

Similar increase in normoxia

Tendency to better increase in hypoxia



Same skeletal mitochondrial volume density



	Before training	After training
Normoxic group	3.6	5.8*
Hypoxic group	4.0	6.2

Training in hypoxia

- **Live low train high**
- Acclimatization to low, moderate and high altitudes increases the performance in those environments.
- If aiming to perform at altitude: acclimatization for 2-3 weeks (more is better ?).
- ~ 3h exercise /day, 2500 m

- **Live high train low**
- Usually, altitude training for performing at sea level
- >14 h/day, 3 weeks, 2500 m
- Effects less clear

Sea-Level Exercise Performance Following Adaptation to Hypoxia

A Meta-Analysis

Darrell L. Bonetti and *Will G. Hopkins*

Institute of Sport and Recreation Research, AUT University, Auckland, New Zealand

Sports Med 2009; 39 (2): 107-127
0112-1642/09/0002-0107/$49.95/0

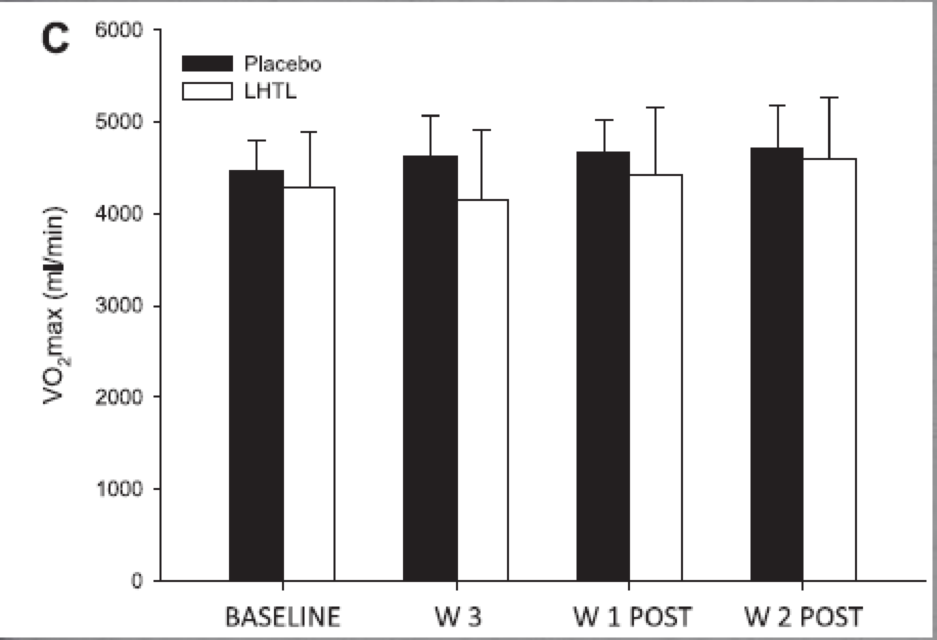
In summary, natural LHTL currently provides the best protocol for enhancing endurance performance in elite and subelite athletes, while some artificial protocols are effective in subelite athletes. Likely mediators include $\dot{V}O_{2max}$ and the placebo, nocebo and training-camp effects. Modification of

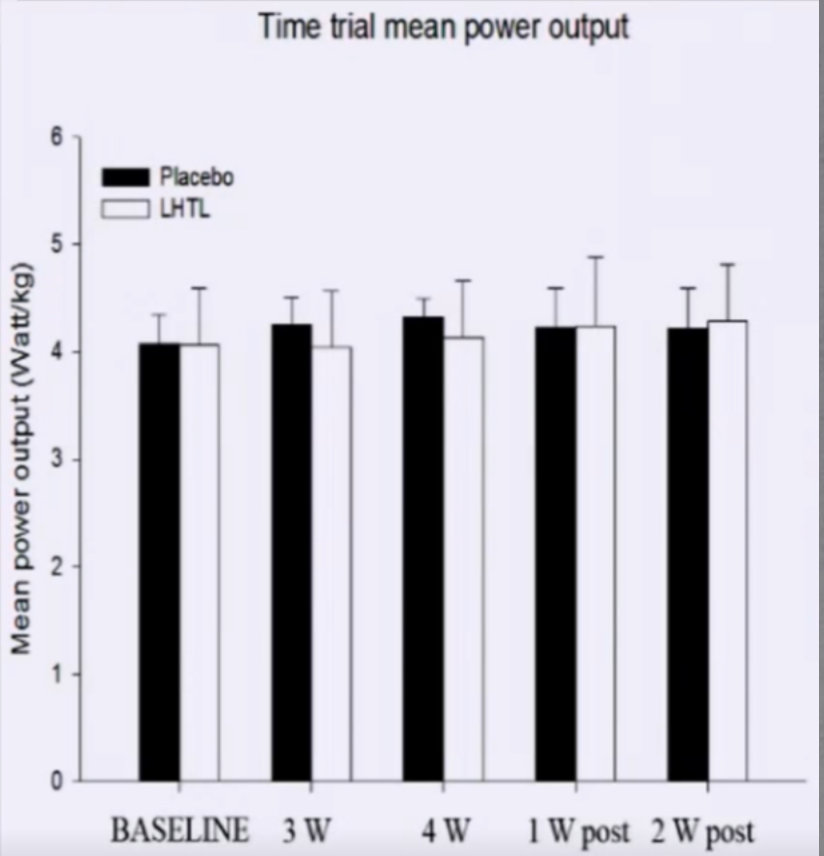
“Live high–train low” using normobaric hypoxia: a double-blinded, placebo-controlled study

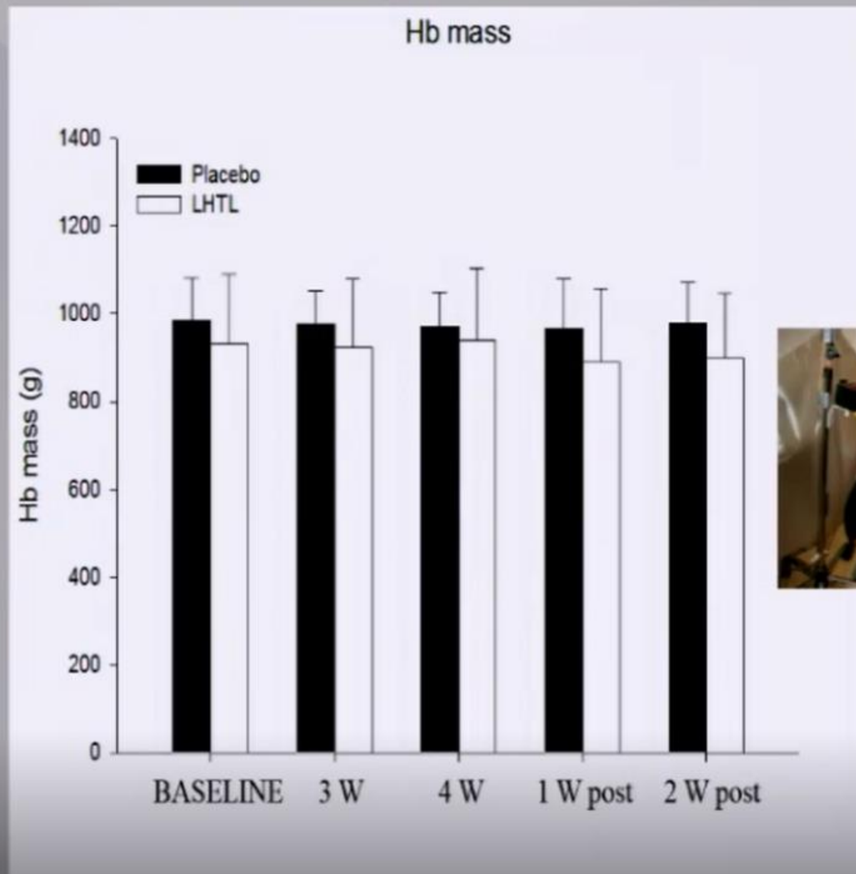
Christoph Siebenmann,[1] Paul Robach,[2] Robert A. Jacobs,[1,3] Peter Rasmussen,[1] Nikolai Nordsborg,[4] Victor Diaz,[1,3] Andreas Christ,[5] Niels Vidiendal Olsen,[6] Marco Maggiorini,[5] and Carsten Lundby[1]
[1]Center for Integrative Human Physiology, Institute of Physiology, University of Zurich, Zurich, Switzerland; [2]Département Médical, Ecole Nationale des Sports de Montagne, Chamonix, France; [3]Institute of Veterinary Physiology, University of Zurich, Zurich, Switzerland; [4]Department of Exercise and Sport Sciences, University of Copenhagen, Copenhagen, Denmark; [5]Intensive Care Unit, Department of Internal Medicine, University Hospital, Zurich, Switzerland; and [6]Department of Neuroanaesthesia, The Neuroscience Centre, Rigshospitalet, Copenhagen, Denmark

Submitted 30 March 2011; accepted in final form 21 October 2011

J Appl Physiol 112: 106–117, 2012.

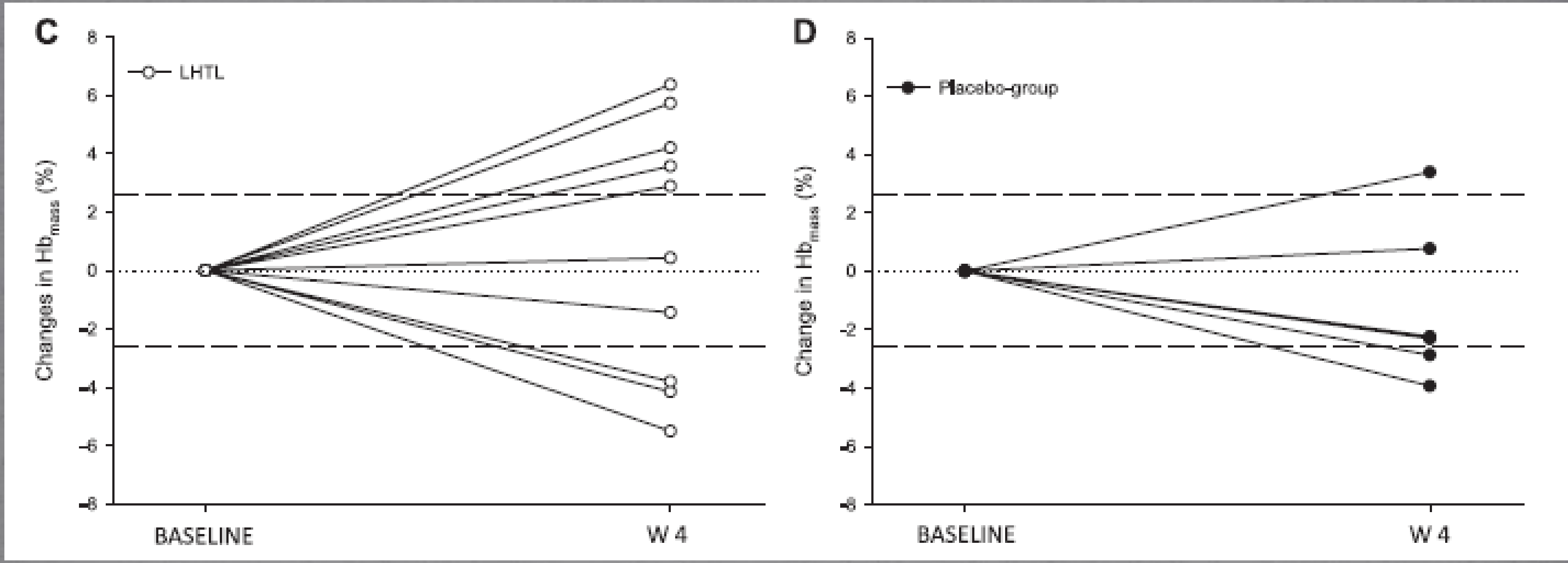






Similar increase in red cells mass

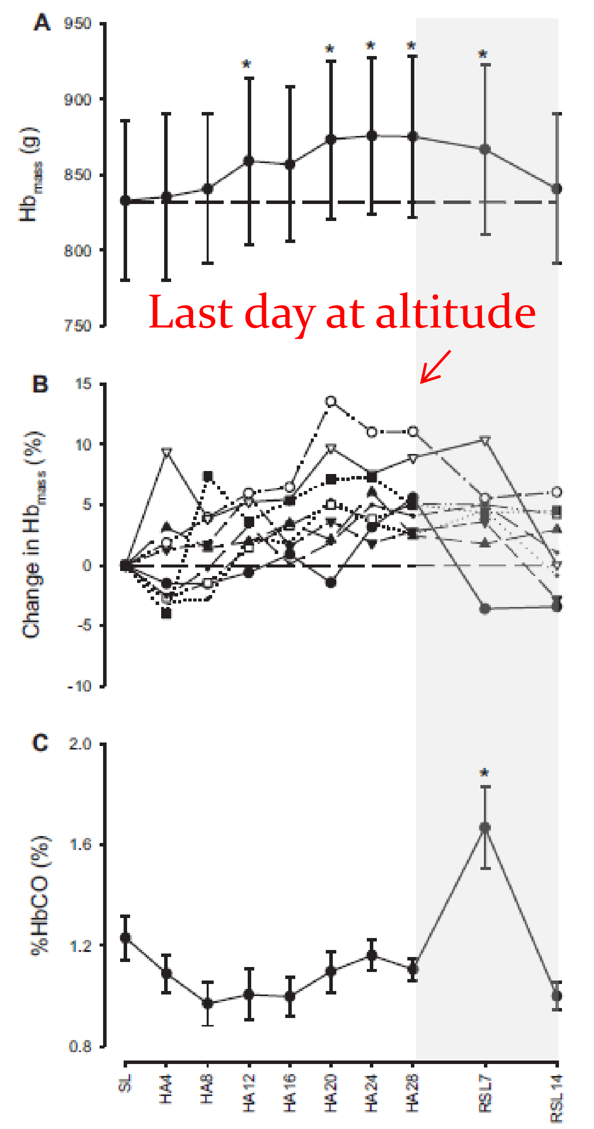
Unpredictable



Increase in red cells mass ?

- How long does it take?
- 3450 m for 4 weeks
- Very high and very long!
-

  1 month at 2500 m
- LHTL: no additionnal benefit than SL training
- Not reproducible



J Appl Physiol 119: 1194–1201, 2015.
First published March 6, 2015; doi:10.1152/japplphysiol.01121.2014.

HIGHLIGHTED TOPIC | *Hypoxia 2015*

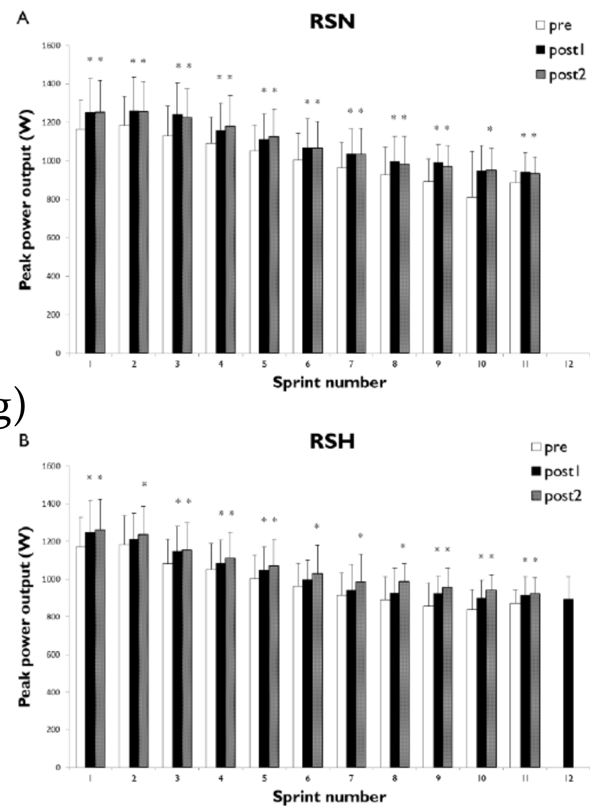
Hemoglobin mass and intravascular volume kinetics during and after exposure to 3,454-m altitude

C. Siebenmann,[1,2] A. Cathomen,[3] M. Hug,[1] S. Keiser,[1] A. K. Lundby,[1] M. P. Hilty,[4] J. P. Goetze,[5] P. Rasmussen,[6] and C. Lundby[1,7]

Sprint interval training / HIT in hypoxia?

No effect, even after fatiguing exercise, both in normoxia and hypoxia

10 sec all-out sprints (cycling) with 20 sec rec



P=0.16

Figure 1. Peak power output (W) in successive sprints during the repeated sprint test performed without prior exercise (RS_{NE}) and normoxic conditions before (pre) and after ($post_1$, $post_2$) repeated sprint training in normoxia (RSN, A) and hypoxia (RSH, B). * $P<0.05$ from pre to post training.

Training for… what?

- Training in hypoxia for performance in high level athletes: questionable.
- Training for high altitude exercise: yes
- Training for health?

HHS Public Access
Author manuscript
Obesity (Silver Spring). Author manuscript; available in PMC 2015 September 01.

Published in final edited form as:
Obesity (Silver Spring). 2014 September ; 22(9): 2080–2090. doi:10.1002/oby.20800.

Inverse Association between Diabetes and Altitude: A Cross Sectional Study in the Adult Population of the United States

Orison O. Woolcott[1], **Oscar A. Castillo**[2], **Cesar Gutierrez**[3], **Robert M. Elashoff**[4], **Darko Stefanovski**[1], and **Richard N. Bergman**[1]

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[2]Instituto Nacional de Biología Andina, Universidad Nacional Mayor de San Marcos, Lima, Peru

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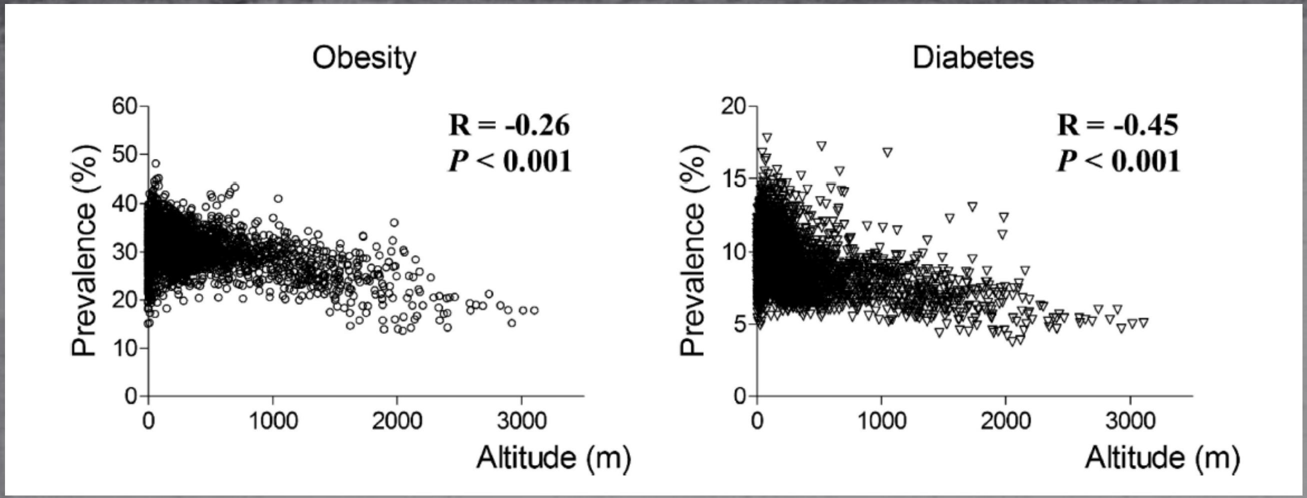
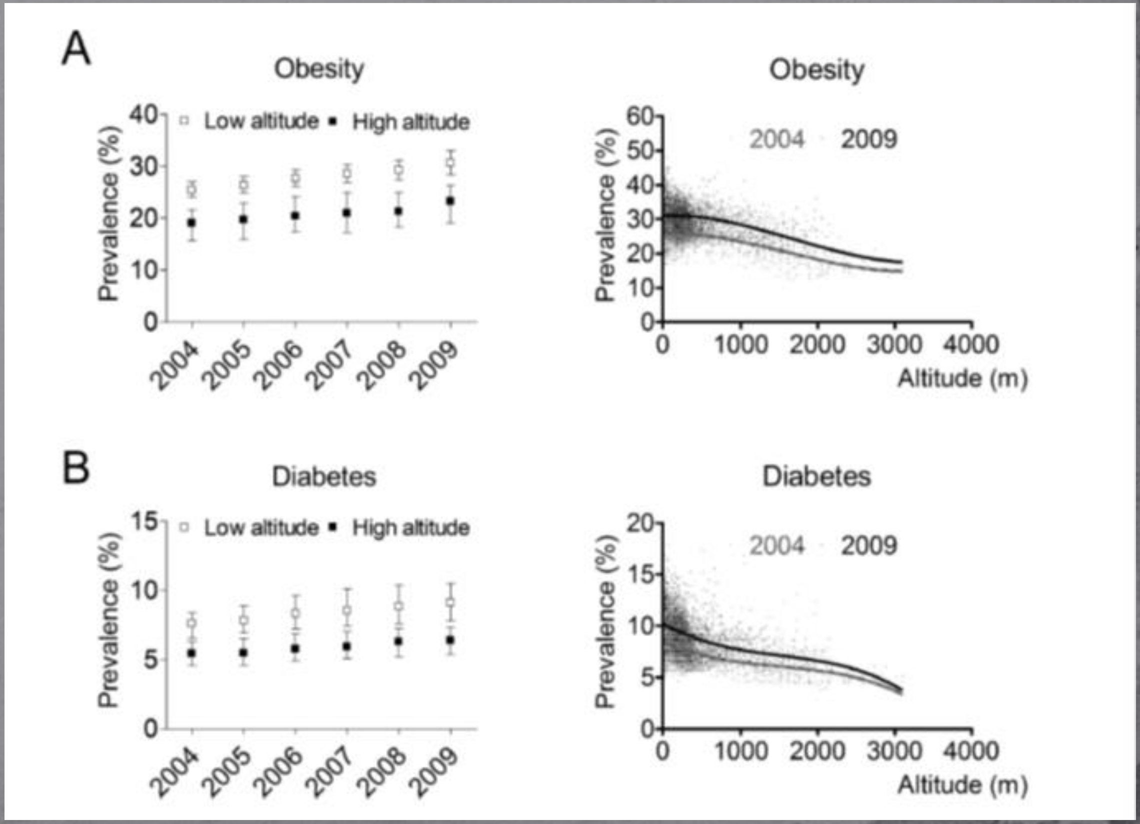
"Among adults of the United States, living at high altitude (1,500–3,500 m elevation) is associated with lower odds of having diabetes than living between 0–499 m, while adjusting for multiple risk factors and potential confounder"



Obesity
R = -0.26
P < 0.001
Prevalence (%)
Altitude (m)
Diabetes
R = -0.45
P < 0.001
Prevalence (%)
Altitude (m)



A
Obesity
Low altitude
High altitude
Prevalence (%)
Obesity
2004
2009
Prevalence (%)
Altitude (m)
B
Diabetes
Low altitude
High altitude
Prevalence (%)
Diabetes
2004
2009
Prevalence (%)
Altitude (m)

HHS Public Access

Author manuscript

Obesity (Silver Spring). Author manuscript; available in PMC 2017 April 01.

Published in final edited form as:

Obesity (Silver Spring). 2016 April ; 24(4): 929–937. doi:10.1002/oby.21401.

Inverse association between altitude and obesity: A prevalence study among Andean and low-altitude adult individuals of Peru

Orison O. Woolcott, MD[1], **Cesar Gutierrez, MD, MPH**[2,3], **Oscar A. Castillo, MD**[4], **Robert M. Elashoff, PhD**[5], **Darko Stefanovski, PhD**[1], and **Richard N. Bergman, PhD**[1]

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“In a nationally representative sample of the adult population of Peru, individuals who live at higher altitudes have a lower adjusted prevalence ratio of obesity and abdominal obesity (based on direct anthropometric measurements) as compared with individuals who live closer to sea level”

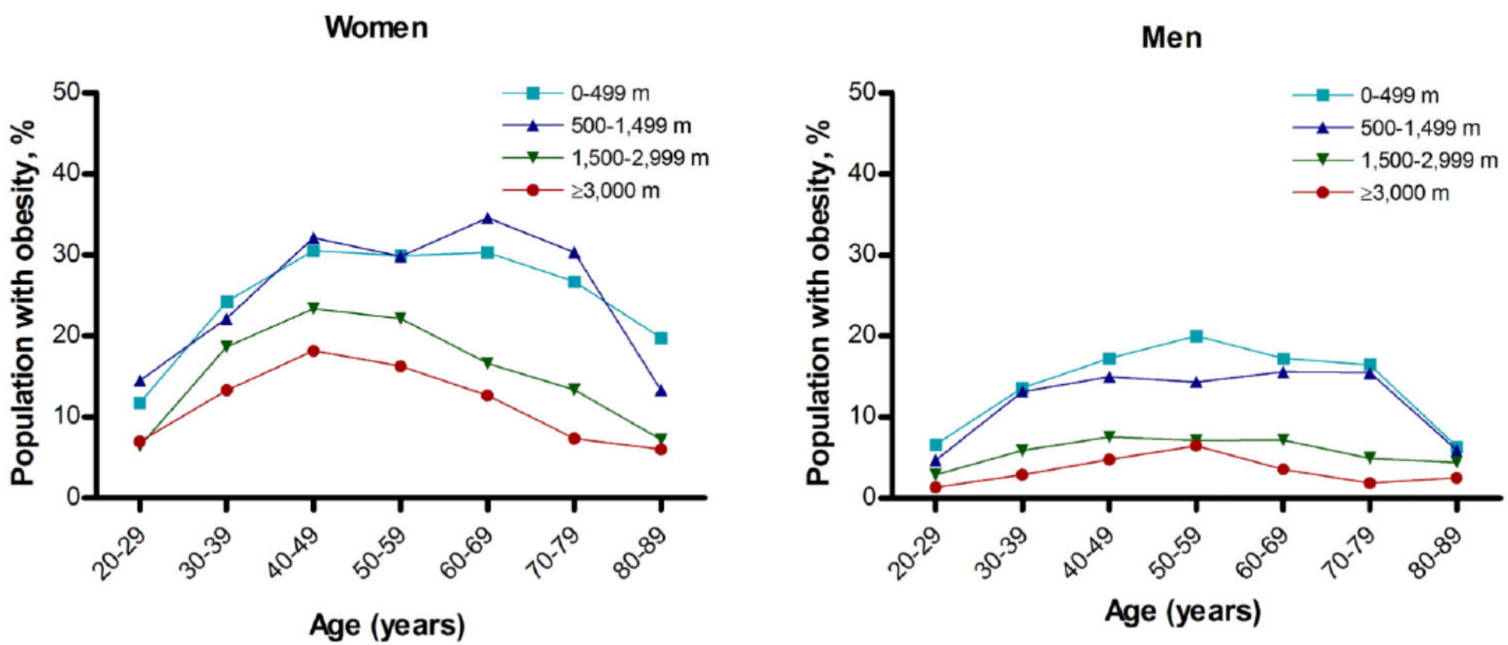


Figure 2. Age-specific percentage of Peruvian adult individuals with obesity by altitude bands, 2009–2010

Profiles are shown for women (A) and for men (B).

PLOS | ONE

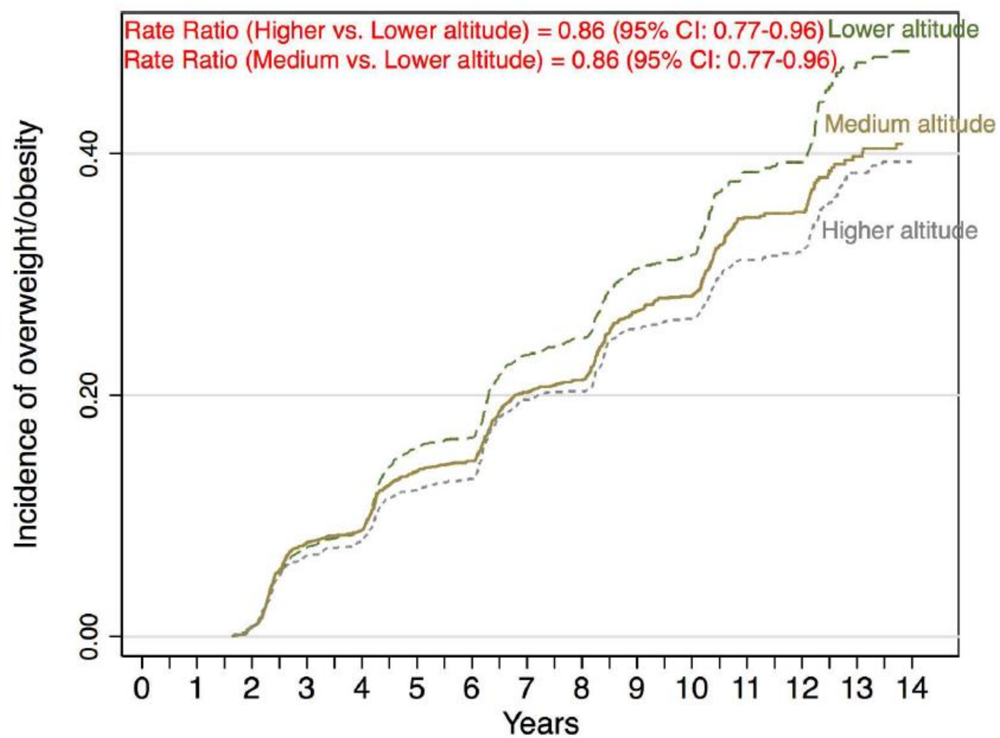
PLOS ONE | DOI:10.1371/journal.pone.0164483 November 3, 2016

RESEARCH ARTICLE

Living at Higher Altitude and Incidence of Overweight/Obesity: Prospective Analysis of the SUN Cohort

Jesús Díaz-Gutiérrez[1], Miguel Ángel Martínez-González[1,2,3,4], Juan José Pons Izquierdo[5], Pedro González-Muniesa[2,3,6], J. Alfredo Martínez[2,3,6], Maira Bes-Rastrollo[1,2,3]*

1 University of Navarra, Department of Preventive Medicine and Public Health, School of Medicine, Pamplona, Spain, 2 IDISNA Navarra's Health Research Institute, Pamplona, Spain, 3 CIBER Fisiopatología de la Obesid
School of Pul
Art History, a
Navarra, Dep



Number at risk

0-122 meters (lower altitude)	3124	3124	3079	2669	2588	2173	2100	1551	1495	1183	1135	639	608	230	208
123-456 meters (medium altitude)	3254	3254	3198	2772	2688	2267	2197	1700	1649	1325	1266	894	841	304	277
457-2 329 meters (higher altitude)	2987	2987	2936	2606	2526	2157	2094	1587	1542	1298	1265	953	899	335	314

Intermittent hypoxia training

Intermittent hypoxia training as non-pharmacologic therapy for cardiovascular diseases: Practical analysis on methods and equipment

Tatiana V Serebrovskaya[1] **and Lei Xi**[2,3]

[1]Department of Hypoxia, Bogomoletz Institute of Physiology, National Academy of Sciences of Ukraine, Kiev 01024, Ukraine; [2]Pauley Heart Center, Division of Cardiology, Department of Internal Medicine, Virginia Commonwealth University, Richmond, VA 23298-0204, USA; [3]Department of Sports Medicine, Chengdu Sport University, Chengdu 610041, China
Corresponding author: Lei Xi. Email: lei.xi@vcuhealth.org

Experimental Biology and Medicine 2016; 241: 1708–1723. DOI: 10.1177/1535370216657614

Intermittent hypoxia training

- 1) improvement of metabolic processes in the myocardium
- 2) enhancement of the myocardial tolerance to ischemia–reperfusion injury (i.e. anti-ischemic effect),
- 3) reduction of free radical damage at cellular level,
- 4) improvement of endothelial function and microcirculation,
- 5) positive inotropic effect on cardiac function,
- 6) normalization of blood pressure,
- 7) reduction in activity of the sympathetic nervous system,
- 8) limiting blood viscosity and platelet aggregation.

Journal of Cardiac Failure Vol. 18 No. 5 2012

Improved Exercise Performance and Skeletal Muscle Strength After Simulated Altitude Exposure: A Novel Approach for Patients With Chronic Heart Failure

OMAR SAEED, MD,[1] VIVEK BHATIA, MD, MS,[1] PHILIP FORMICA, MD,[1] AURIS BROWNE, MD,[1] THOMAS K. ALDRICH, MD,[2] JOOYOUNG J. SHIN, MD,[1] AND SIMON MAYBAUM, MD[1]

New York, New York

10 sessions of 3-4h over 22 days; starting 1500 m up to 2700 m

Table 3. Baseline and 48 Hours and 4 Weeks After Altitude Exposure Protocol

	Baseline	48 h After	4 wk After	48 h vs Baseline (*P*)	4 wk vs Baseline (*P*)
Exercise					
Peak VO_2 (mL kg^{-1} min^{-1})	13.5 ± 1.8	14.2 ± 1.9	14.5 ± 2.9	.036	.123
RER	1.10 ± 0.07	1.12 ± 0.12	1.15 ± 0.08	.401	.048
Exercise time (s)	615.5 ± 98.3	677.9 ± 85.6	682.3 ± 111.1	.028	.023
6MW (m)	387.4 ± 48.2	415.3 ± 52.2	441.1 ± 57.1	.013	.003
Muscle testing					
MVC (lb)	56.7 ± 10.3	62.2 ± 12.4	62.5 ± 13.1	.039	.016
Quality of life					
MLHFQ	33.8 ± 22.1	24.1 ± 20.6	22.6 ± 19.8	<.001	.027
Echocardiography					
LVEDD (mm)	71.1 ± 11.8	72.8 ± 13.7	67.9 ± 13.6	.078	.071
LVEF (%)	31.7 ± 7.6	34.4 ± 8.3	36.1 ± 9.5	.121	.054

VO_2, oxygen consumption; RER, respiratory exchange ratio; 6MW, 6-minute walk; MVC, maximal voluntary contraction; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; MLHFQ, Minnesota Living with Heart Failure Questionnaire.

HIGH ALTITUDE MEDICINE & BIOLOGY
Volume 00, Number 00, 2017

DOI: 10.1089/ham.2017.0050

Review

The Use of Simulated Altitude Techniques for Beneficial Cardiovascular Health Outcomes in Nonathletic, Sedentary, and Clinical Populations: A Literature Review

Catherine A. Lizamore and Michael J. Hamlin

Therapeutic Use of Exercising in Hypoxia: Promises and Limitations

Gregoire P. Millet[1], Tadej Debevec[2], Franck Brocherie[1], Davide Malatesta[1] and Olivier Girard[1]*

[1] Institute of Sport Sciences of the University of Lausanne (ISSUL), Lausanne, Switzerland, [2] Department of Automation, Biocybernetics and Robotics, Jožef Stefan Institute, Ljubljana, Slovenia

Walking in Hypoxia: An Efficient Treatment to Lessen Mechanical Constraints and Improve Health in Obese Individuals?

Olivier Girard[1,2], Davide Malatesta[2] and Grégoire P Millet[2]*

[1] Athlete Health and Performance Research Center, Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar,
[2] Faculty of Biology and Medicine, Institute of Sport Sciences, University of Lausanne, Lausanne, Switzerland

Keywords: obesity, altitude training, hypoxic exercise, walking, mechanical loading

Sleep Breath (2014) 18:591–597
DOI 10.1007/s11325-013-0922-4

ORIGINAL ARTICLE

Normobaric hypoxia training causes more weight loss than normoxia training after a 4-week residential camp for obese young adults

Zhaowei Kong · Yanpeng Zang · Yang Hu

“Weight loss was found in HT (–6.9 kg or –7.0 %, p <0.01) and NT groups (–4.3 kg or –4.2 %, p <0.01) significantly, and the former lost more weight than the latter (p< 0.01). Hypoxia training improved systolic BP (–7.6 %) and mean BP (–7.1 %) significantly (p< 0.05) despite having no effect on baPWV”

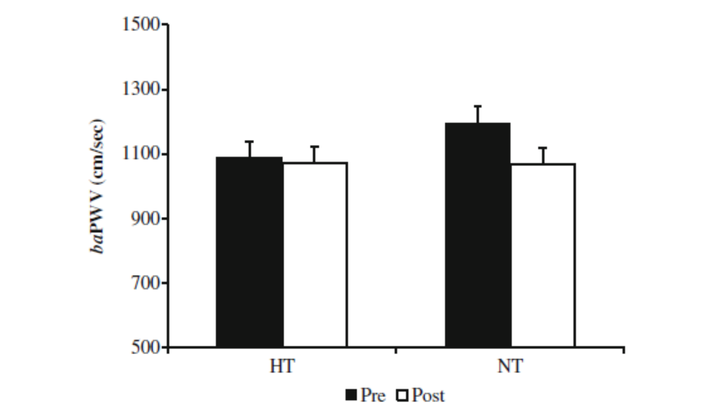


Fig. 1 Changes in brachial-ankle pulse wave velocity (*baPWV*) at pre- and post-training. *HT* normobaric hypoxia training, *NT* normoxia training

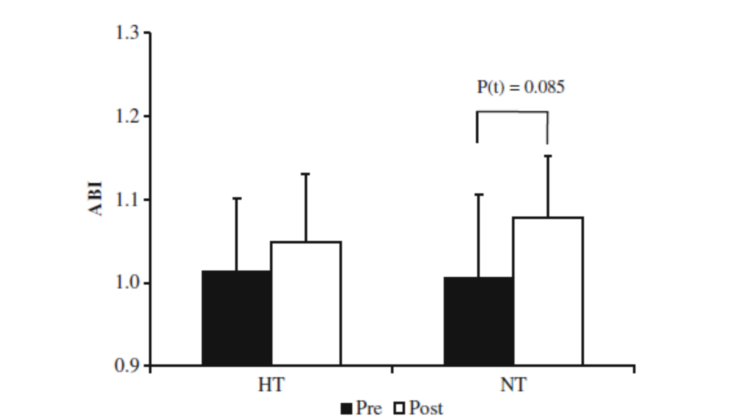


Fig. 2 Changes in ankle brachial index (*ABI*) at pre- and post-training. *p* <0.10 vs. pre-training. *HT* normobaric hypoxia training, *NT* normoxia training

Articles in PresS. Am J Physiol Regul Integr Comp Physiol (July 5, 2017). doi:10.1152/ajpregu.00160.2017

Title

Normobaric hypoxic conditioning to maximise weight-loss and ameliorate cardio-metabolic health in obese populations: A systematic review

Authors

L Hobbins [1], S Hunter [1], N Gaoua [1], O Girard [2,3]

- “Overall, reductions in weight, BMI and individual tissue mass are found following active HC (moderate-intensity cardio-based exercise, 3 sessions per week, 4–8 week duration). This also occurs without hypoxia but to a lesser extent”
- However, no sure a stat difference exists

Hypoxia for weight loss

Table 4: A summary of the passive and active hypoxic conditioning protocols for improving cardio-metabolic health and promoting weight loss of overweight or obese humans, based on the evidence presented in this review.

	Type of exposure	
Variable	**Passive**	**Active**
Level of hypoxia (FiO_2%)	10.0–12.0	13.0–14.0
Number of cycles	5–15	N/a
Intensity	N/a	55–65% $VO2_{max}$ / 60–70% HR_{max}
Duration (hours)	1–1.5	1–1.5
Frequency	Daily	2–3 times per week
Periodisation (weeks)	2–4	4–6

FiO_2 = fraction of inspired oxygen; HR = heart rate; N/a = not applicable; VO_{2max} = maximal oxygen uptake.

The Circulatory and Metabolic Responses to Hypoxia in Humans – With Special Reference to Adipose Tissue Physiology and Obesity

Ilkka H. A. Heinonen[1,2,3], Robert Boushel[4] and Kari K. Kalliokoski[1]*

[1] Turku PET Centre, University of Turku, Turku, Finland, [2] Department of Clinical Physiology and Nuclear Medicine, University of Turku, Turku, Finland, [3] Division of Experimental Cardiology, Thoraxcenter, Erasmus MC, University Medical Center Rotterdam, Rotterdam, Netherlands, [4] School of Kinesiology, University of British Columbia, Vancouver, BC, Canada

Front. Endocrinol. 7:116.
doi: 10.3389/fendo.2016.00116

"Emerging evidence also indicates that exercise training during hypoxic exposure may provide additive benefits with respect to many traditional cardiovascular risk factors as compared to exercise performed in normoxia, but unfavorable effects of hypoxia have also been documented"

Deleterious?

- Some of the adaptive responses may represent risk factors in patients with cardiovascular pathology:

- stimulation of the already activated SNS
- unfavorable increase in heart rate,
- myocardial oxygen demand and ventricular afterload
- increased pulmonary artery pressure

International Journal of Cardiology 109 (2006) 82 – 87

Transient impairment of flow-mediated vasodilation in patients with metabolic syndrome at moderate altitude (1700 m)☆

Matthias Frick [a], Alexander Rinner [a], Johannes Mair [a], Hannes F. Alber [a], Markus Mittermayr [b], Otmar Pachinger [a], Egon Humpeler [c], Wolfgang Schobersberger [c], Franz Weidinger [a,*]

[a] Division of Cardiology, Innsbruck Medical University, Anichstrasse 35, A-6020 Innsbruck, Austria, Europe
[b] Division of Clinic for Anesthesia and Intensive Care Medicine, Innsbruck Medical University, Austria
[c] Institute for Leisure, Travel and Alpine Medicine, University for Health Sciences, Medical Informatics and Technology, Austria

Table 1
Changes in clinical characteristics

	FMD 1	FMD 2	FMD 3	FMD 4	FMD 5	*p*-value
Number	18	18	18	18	18	
BMI (kg/m²)	30.6 ± 1.9	n.a.	29.6 ± 1.7	29.7 ± 1.7	30.4 ± 1.9	<0.001
RR systolic (mm Hg)	137 ± 11	144 ± 17	133 ± 15	126 ± 14	129 ± 14	<0.001
RR diastolic (mm Hg)	87 ± 10	91 ± 9	84 ± 9	77 ± 9	80 ± 9	<0.001
Heart rate (bpm)	76 ± 11	70 ± 10	67 ± 12	77 ± 12	68 ± 11	<0.001
Total cholesterol	213 ± 32	n.a.	199 ± 27	209 ± 24	212 ± 33	0.029
LDL-C	136 ± 19	n.a.	116 ± 25	127 ± 13	127 ± 20	NS
HDL-C	48 ± 13	n.a.	44 ± 11	46 ± 15	42 ± 17	NS
Triglycerides	188 ± 101	n.a.	209 ± 107	206 ± 148	273 ± 206	0.026

esterol, LDL-C=low-density lipoprotein cholesterol, n.a.=not available, RR=blood pressure.

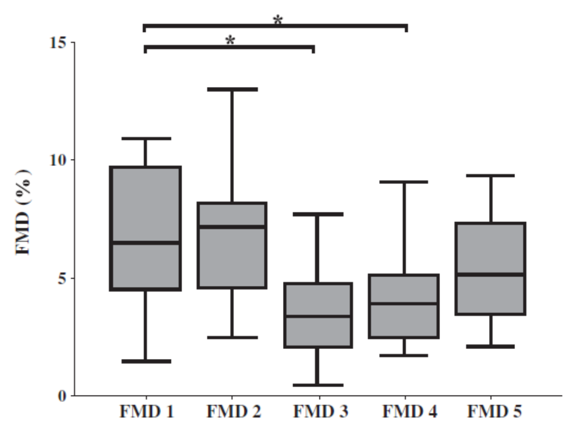


Fig. 1. Box plots showing changes in endothelial function. After 3-week stay at moderate altitude (FMD 3) peripheral endothelial function was significantly reduced. *$p < 0.05$; FMD=flow-mediated vasodilation.

Clinical Biochemistry 48 (2015) 1059–1063

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Vascular reactivity and biomarkers of endothelial function in healthy subjects exposed to acute hypobaric hypoxia

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Table 2
Basal and intra-chamber cardiovascular health-related parameters from the studied population (n = 10).

Hypobaric hypoxia	Basal	Intra-chamber[a]	Paired differences[b]	p[c]
DBP (mmHg)	76 ± 7	78 ± 8	2 (−4 to 7)	0.278
SBP (mmHg)	122 ± 11	130 ± 9	8 (1–16)	<0.05
Heart Rate (bpm)	64 ± 10	78 ± 9	13 (5–21)	<0.005
O_2 Sat (%)	98 ± 1	80 ± 3	−18 [−20 to (−16)]	<0.001

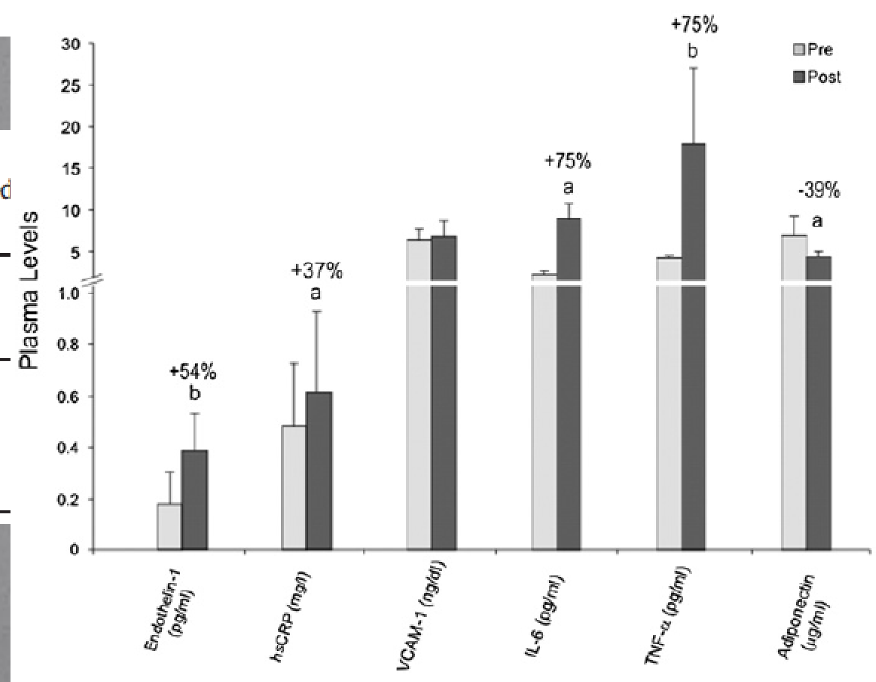

Fig. 1. Biomarkers of endothelial function and adiponectin levels in healthy volunteers exposed to hypobaric hypoxia (n = 10). [a]$p < 0.05$; [b]$p < 0.005$. hsCRP, high sensitivity C reactive protein; VCAM-1, vascular cell adhesion molecule 1; IL-6, interleukin 6; TNF-α, tumor necrosis factor- α.

What type of hypoxia?

A Four-Way Comparison of Cardiac Function with Normobaric Normoxia, Normobaric Hypoxia, Hypobaric Hypoxia and Genuine High Altitude

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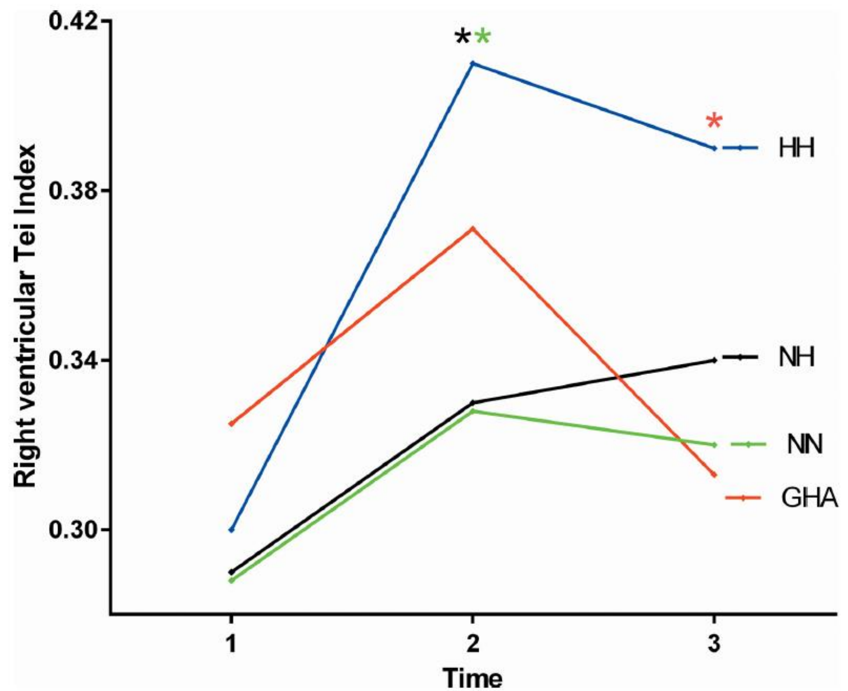

Fig 3. Changes in the right ventricular Tei Index (marginal means) with differing experimental conditions and duration of hypoxia (time 1 = baseline rest, time 2 = 15 minutes post exercise and time 3 = 120 minutes post exercise) * demonstrates between group differences on post test.

Sports Med
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REVIEW ARTICLE

Effects of Altitude/Hypoxia on Single- and Multiple-Sprint Performance: A Comprehensive Review

Olivier Girard[1,3] · Franck Brocherie[2,3] · Grégoire P. Millet[3]

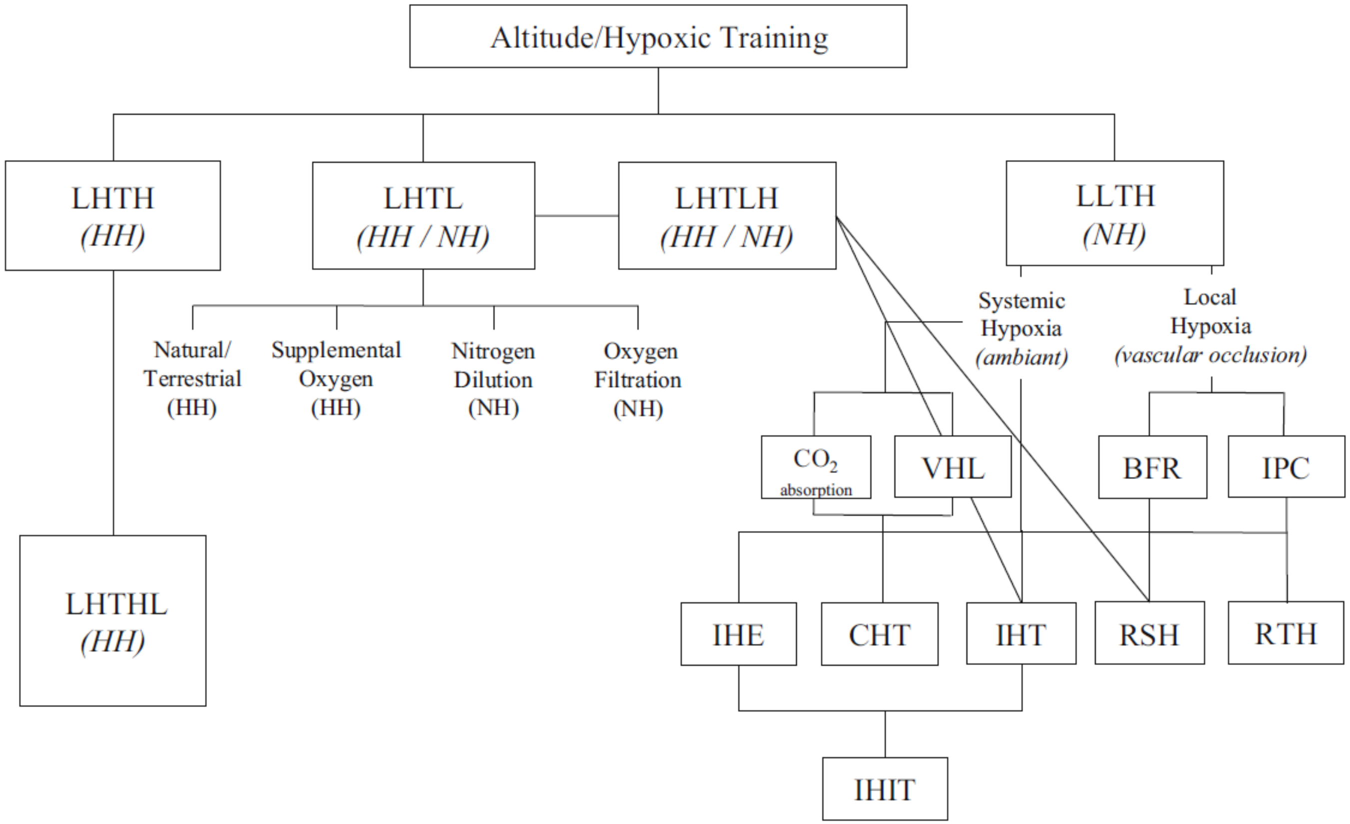

Fig. 1 Updated panorama of the different hypoxic/altitude training methods used for a range of athletes. Adapted from [147]. *BFR* blood flow restriction, *CHT* continuous hypoxic training, *CO_2 absorption* rebreathing with a mask, *HH* hypobaric hypoxia, *IHE* intermittent hypoxic exposure, *IHIT* IHE during interval-training, *IHT* interval hypoxic training, *IPC* ischemic pre-conditioning, *LHTH* live high-train high, *LHTL* live high-train low, *LLTH* live low-train high, *LHTHL* live high-train high and low, *LHTLH* live high-train low and high, *NH* normobaric hypoxia, *RSH* repeated sprint training in hypoxia, *RTH* resistance training in hypoxia, *VHL* voluntary hypoventilation at low lung volume

Thank you!

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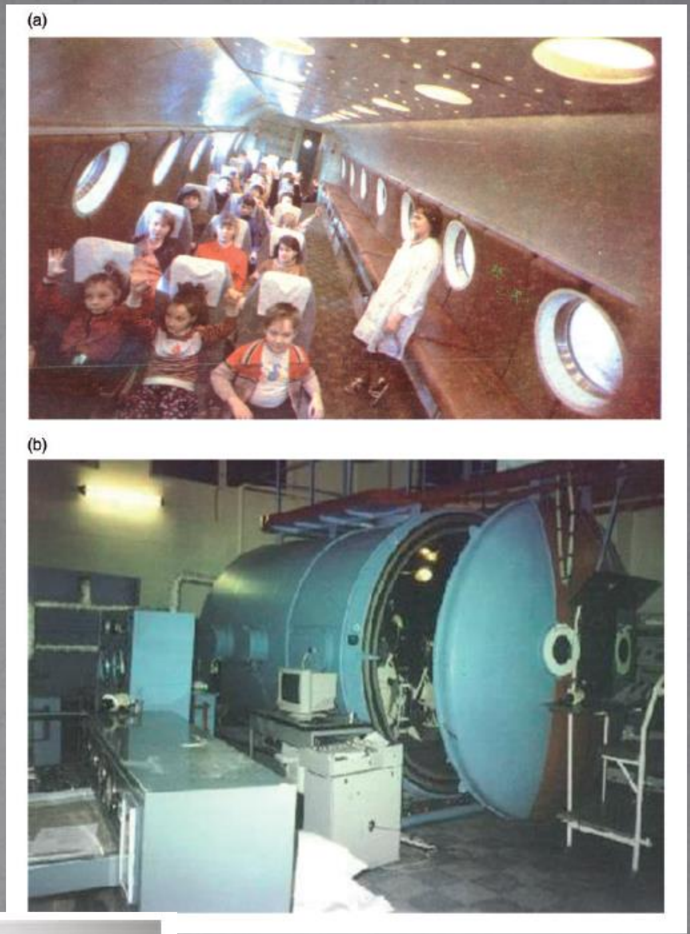
(a)
(b)

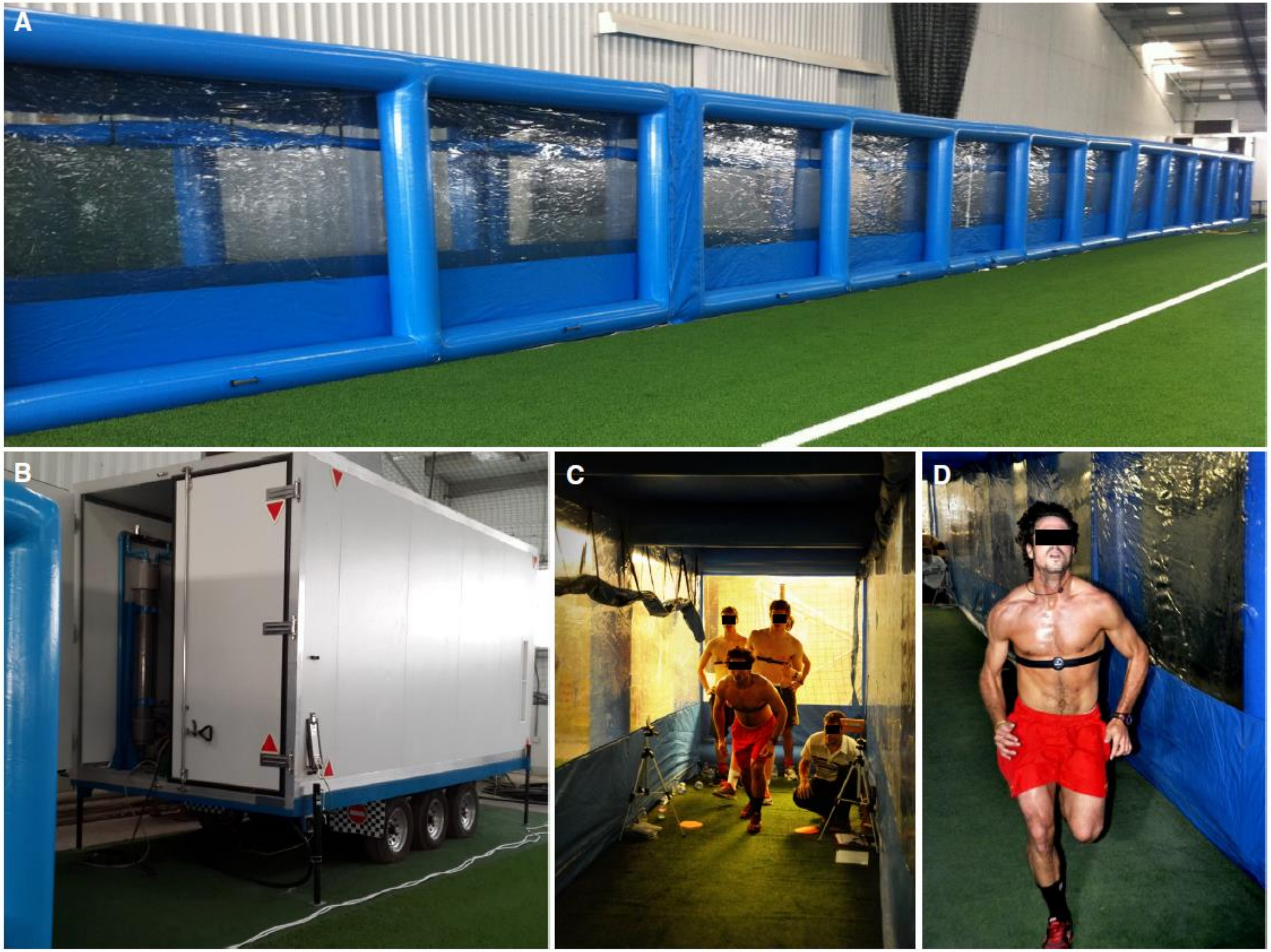

Fig. 4 Mobile inflatable simulated hypoxic equipment [122]. External 45-m running lane (1.8 m width and 2.5 m height) tunnel design (**a**), hypoxic system trailer (including a 55-kW screw compressor) (**b**) and athletes sprinting inside the marquee (**c**, **d**)