Limiting factors of performance at moderate altitude : consequences for training.

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Granada
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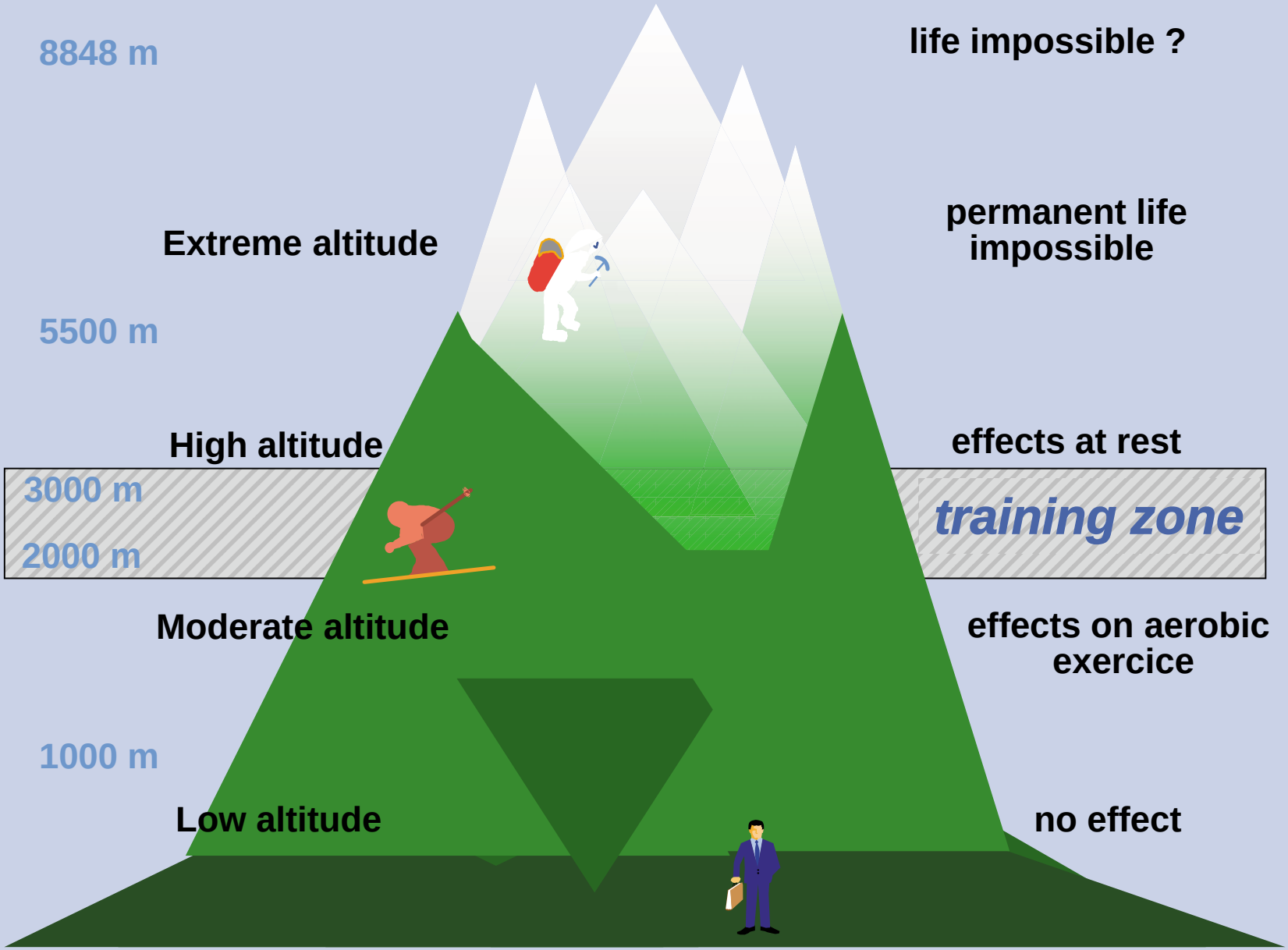
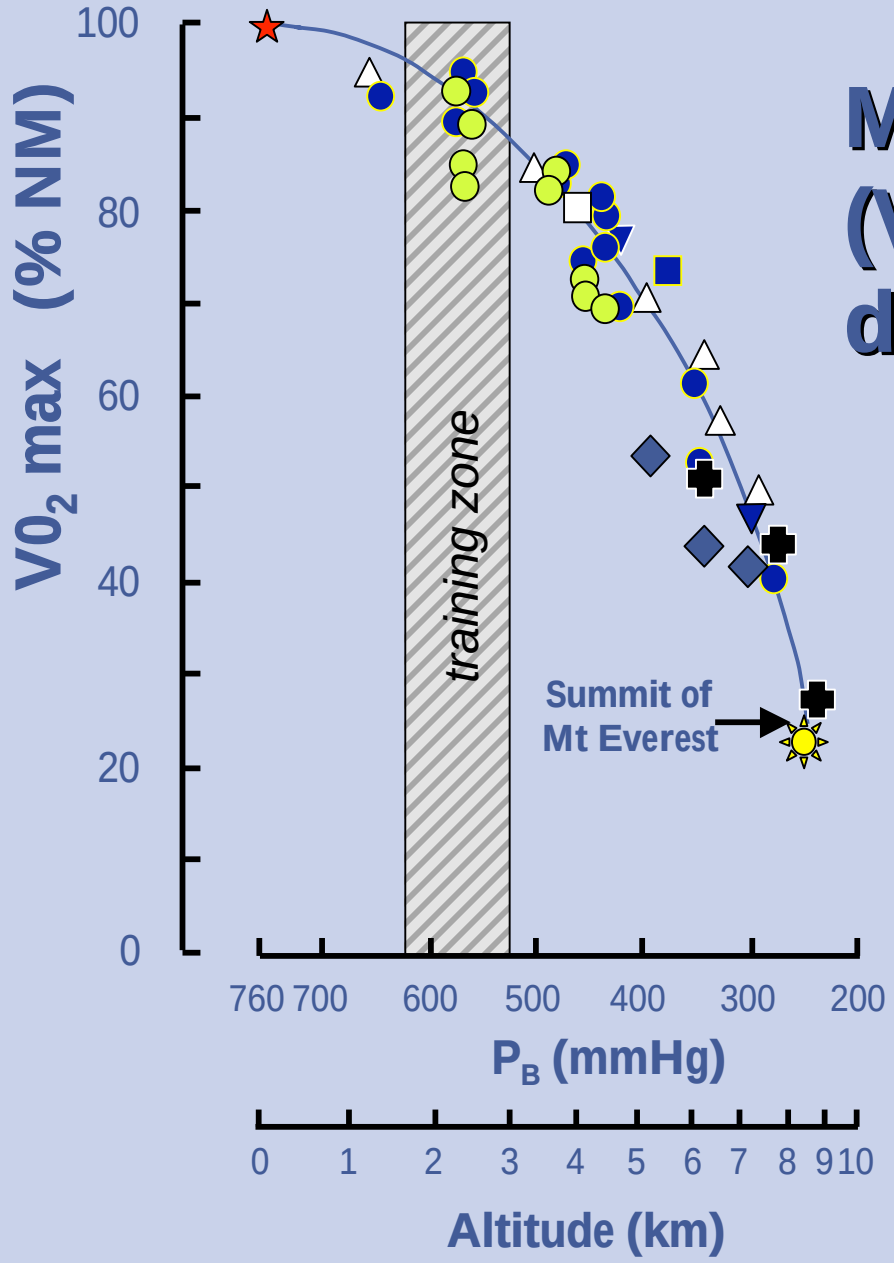
BIOLOGICAL DEFINITION OF ALTITUDE



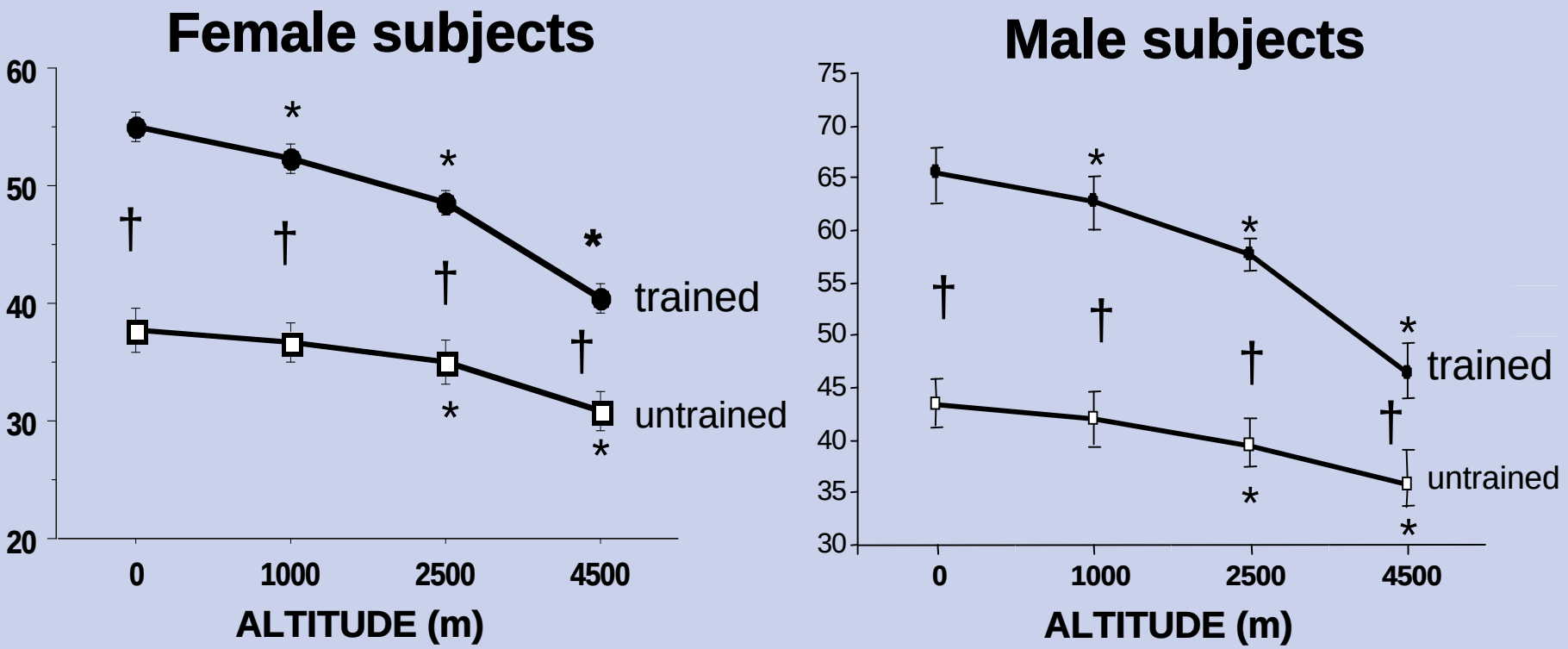


Maximal aerobic power (VO_2max) decreases with altitude

Consequence:
Training load must be lower when training at high altitude

Question ?
What are the limiting factors of performance ?

$\dot{V}O_{2max}$ (ml/min/kg)



* hypoxia vs normoxia † trained vs untrained

Trained subjects show a greater decrease in VO_2max with acute hypoxia

Woorons et al. 2005; Mollard et al., 2006; Mollard et al., 2007

O_2 CO_2

Pulmonary ventilation :
CONVECTION

Central control

O_2 CO_2

Alveolo-capillary transfer of oxygen : **DIFFUSION**

Right heart

Left heart

Transport of oxygen by the blood :
CONVECTION

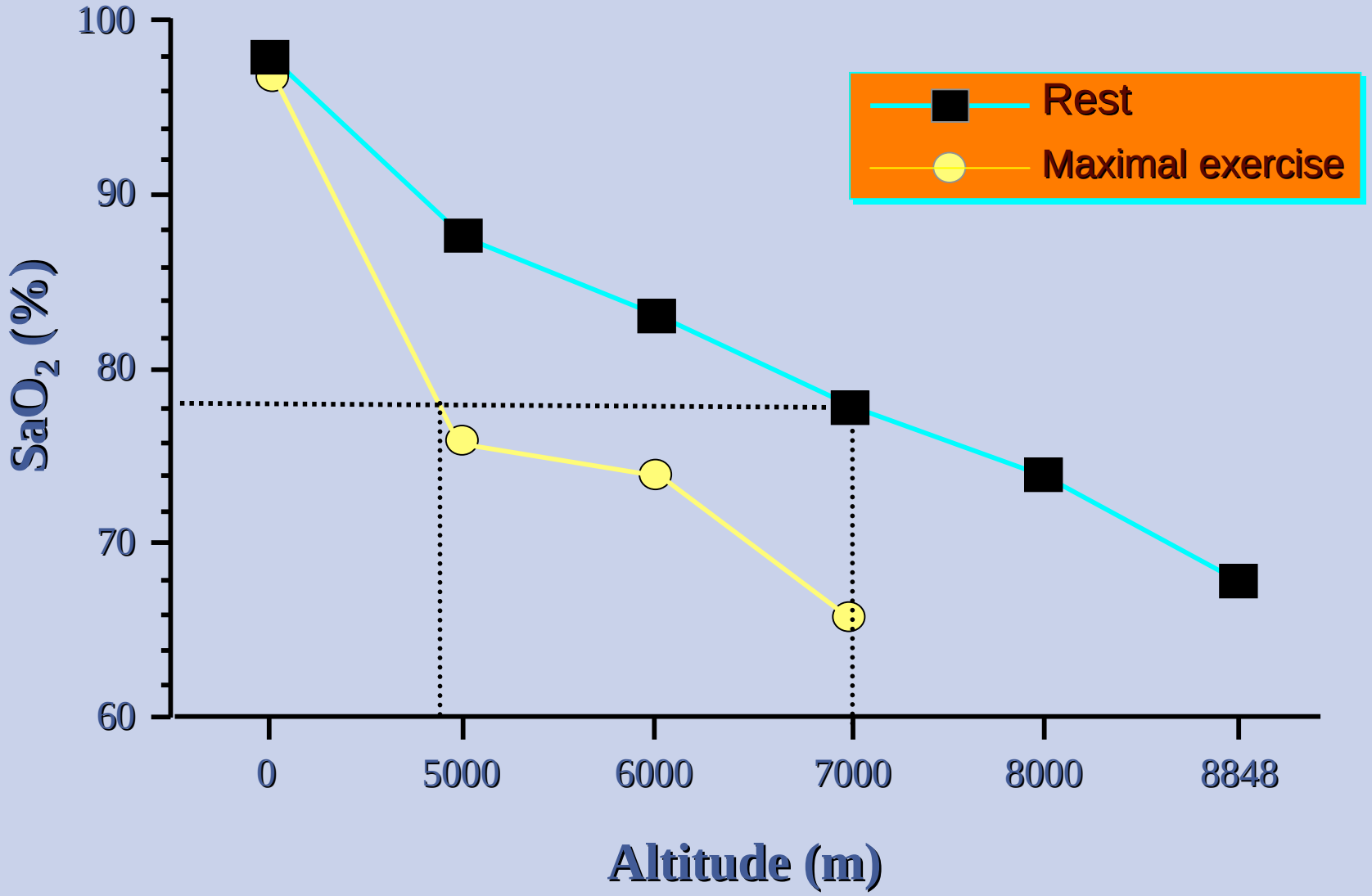
Diffusion of oxygen to the tissues : **DIFFUSION**

cell O_2 CO_2

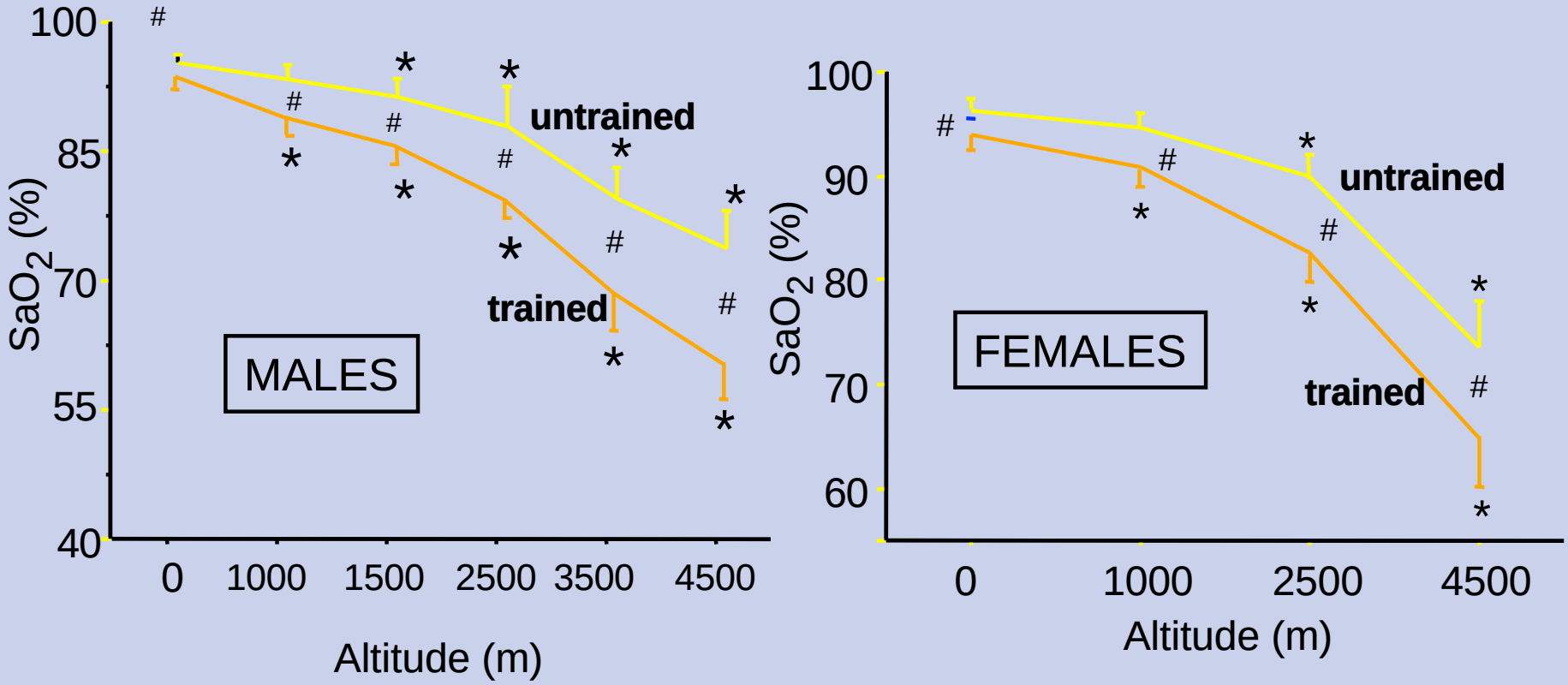
oxygen consumption

Aerobic production of energy

Decrease in arterial O_2 saturation at rest and exercise with increasing altitude



SaO_2 at maximal exercise



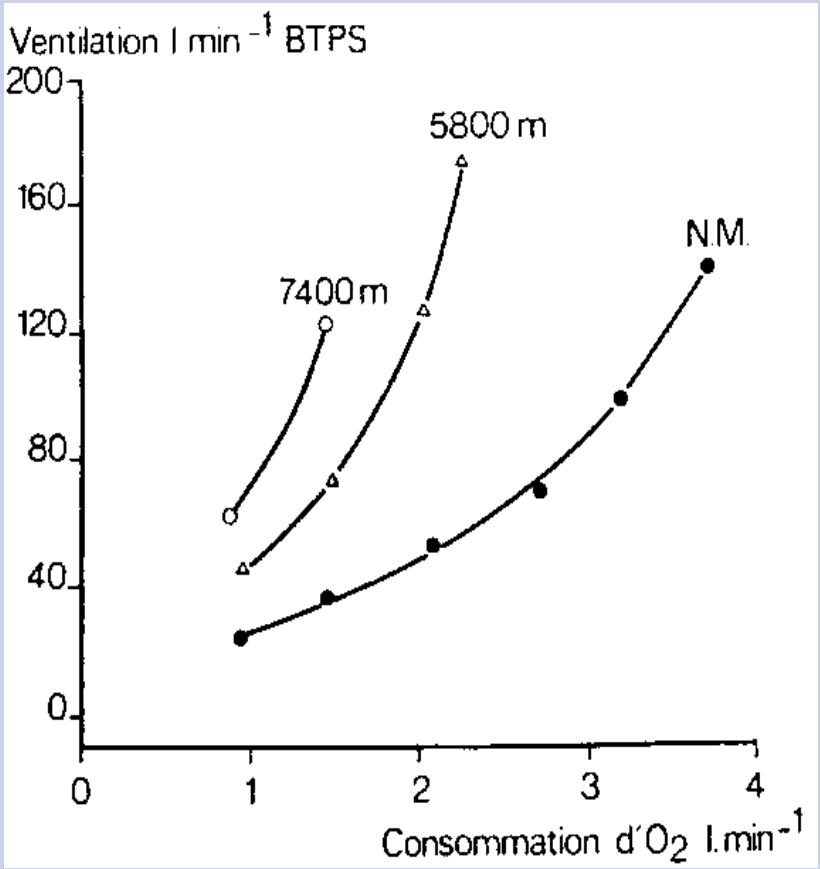
* hypoxia vs normoxia # trained vs untrained

Trained subjects show a greater desaturation at exercise in acute hypoxia

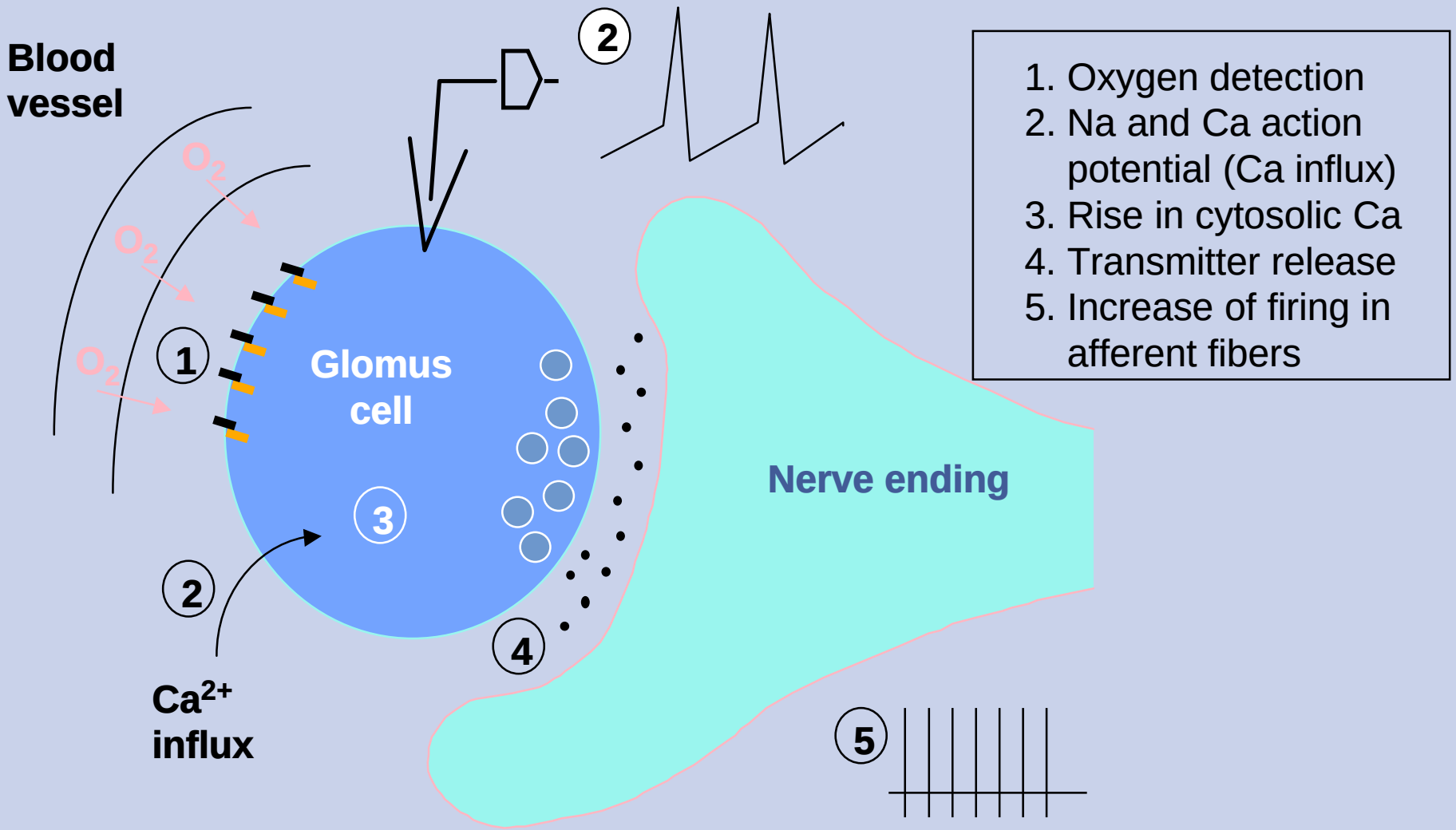
Woorons et al. 2005; Mollard et al., 2006

Chemoreceptors and acclimatization:

Ventilation increases
at rest and
at each level
of exercise



Carotid chemoreceptors : hypoxic sensors

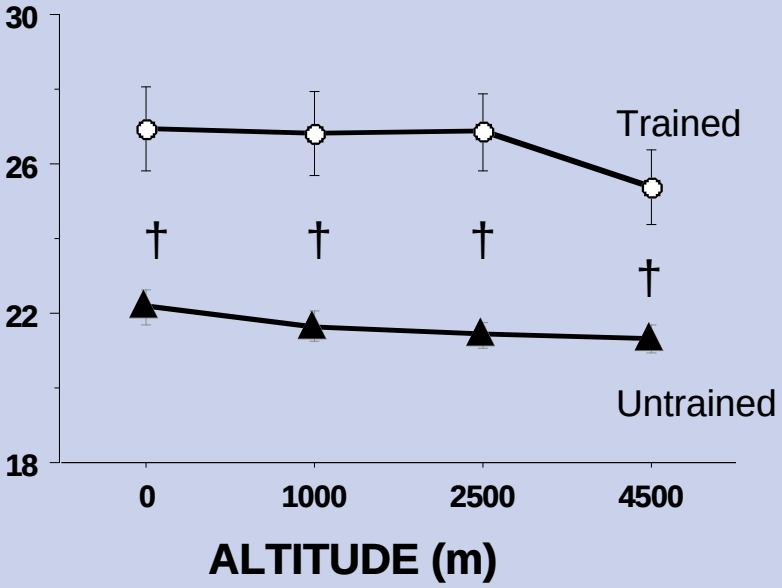


1. Oxygen detection
2. Na and Ca action potential (Ca influx)
3. Rise in cytosolic Ca
4. Transmitter release
5. Increase of firing in afferent fibers

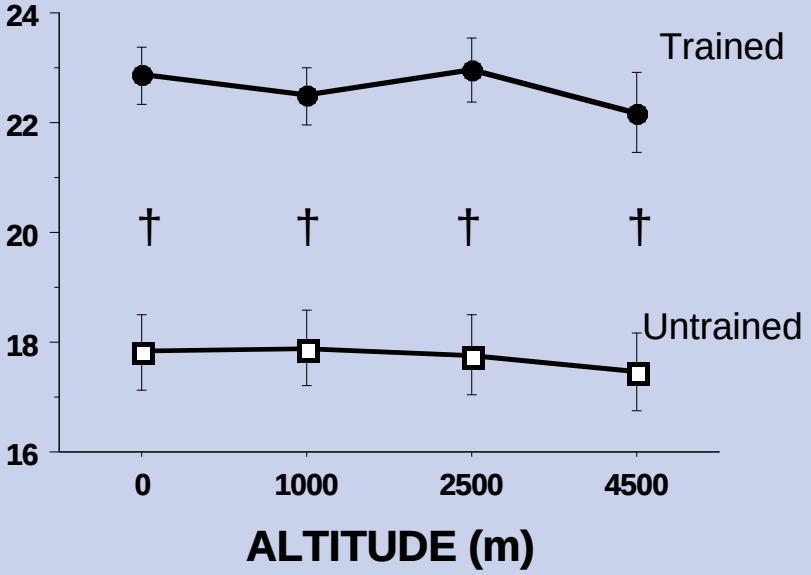
From Lopez-Barneo et al., NIPS, 1993

Max. cardiac output (L/min)

Male subjects



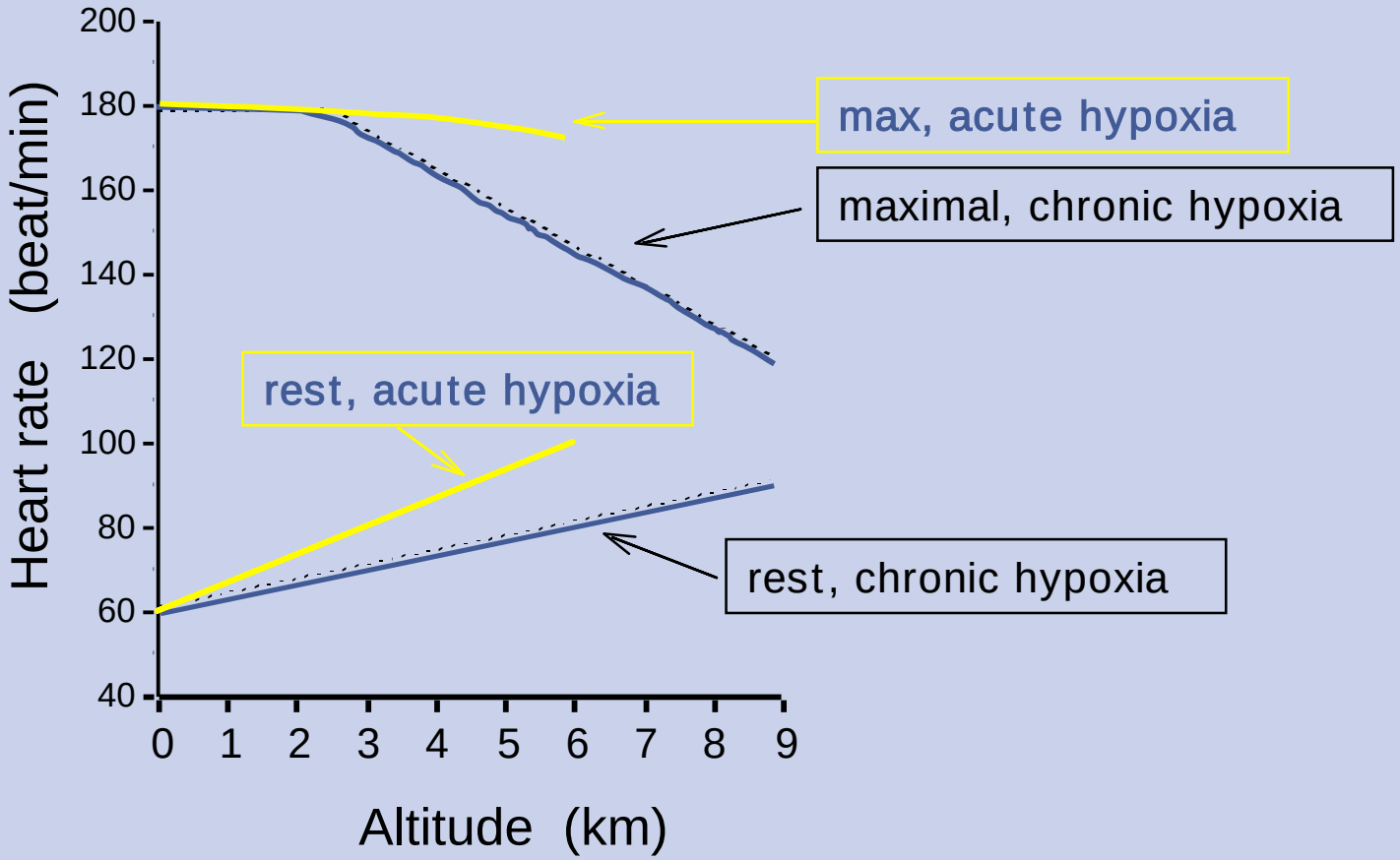
Female subjects



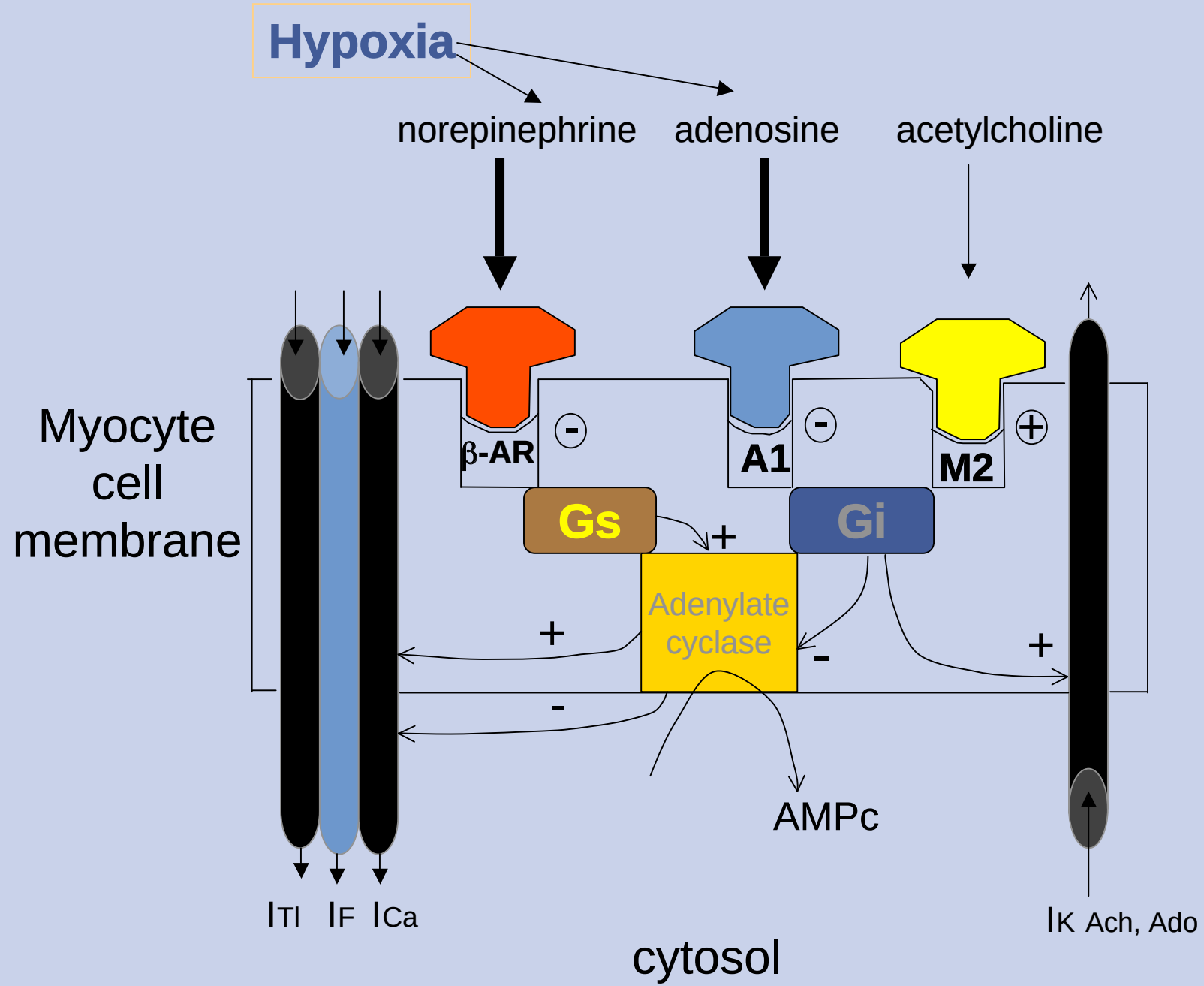
Maximal cardiac output does not change in acute hypoxia

Woorons et al. 2005; Mollard et al., 2006; Mollard et al., 2007

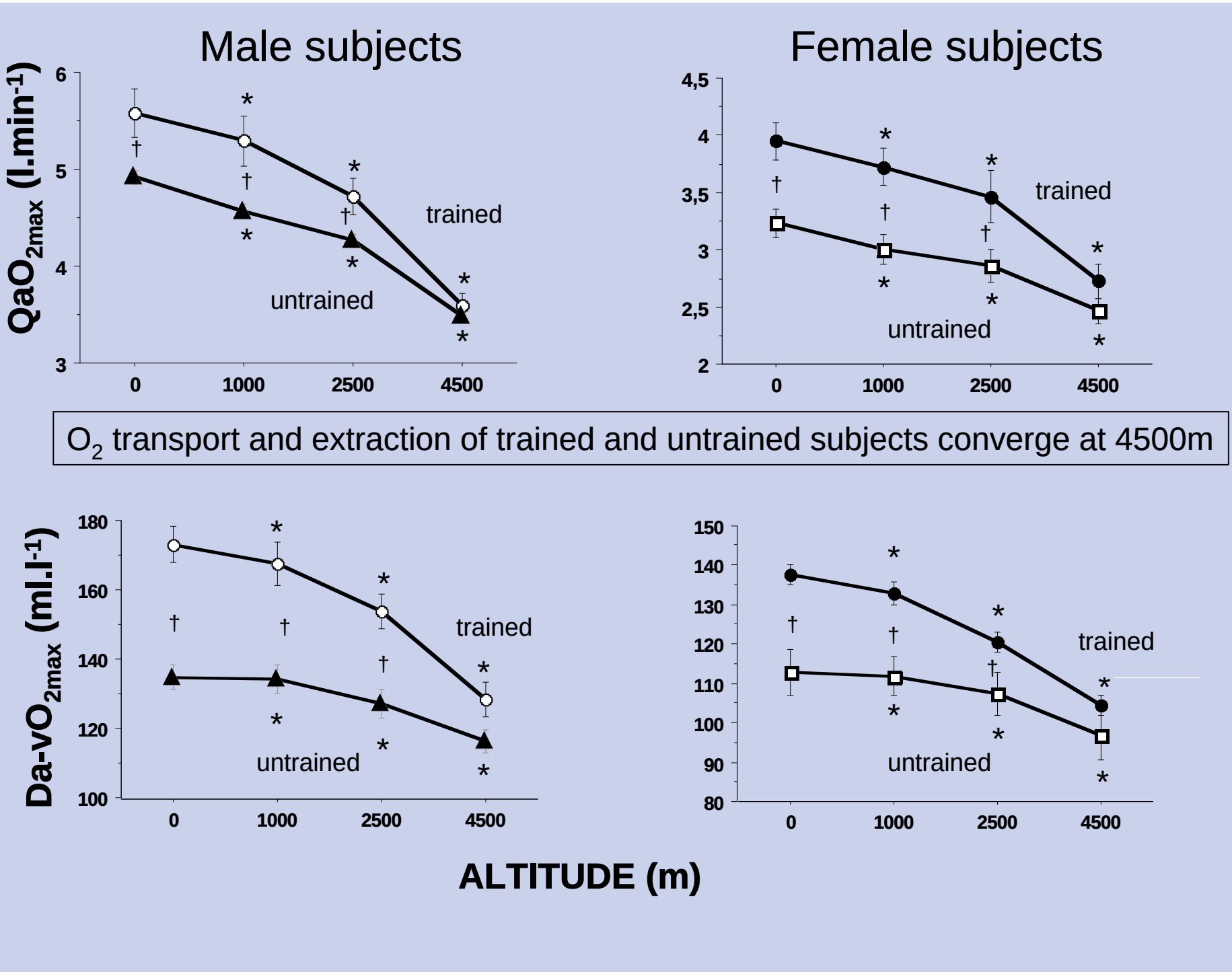
Adaptation of heart rate in acute and chronic hypoxia

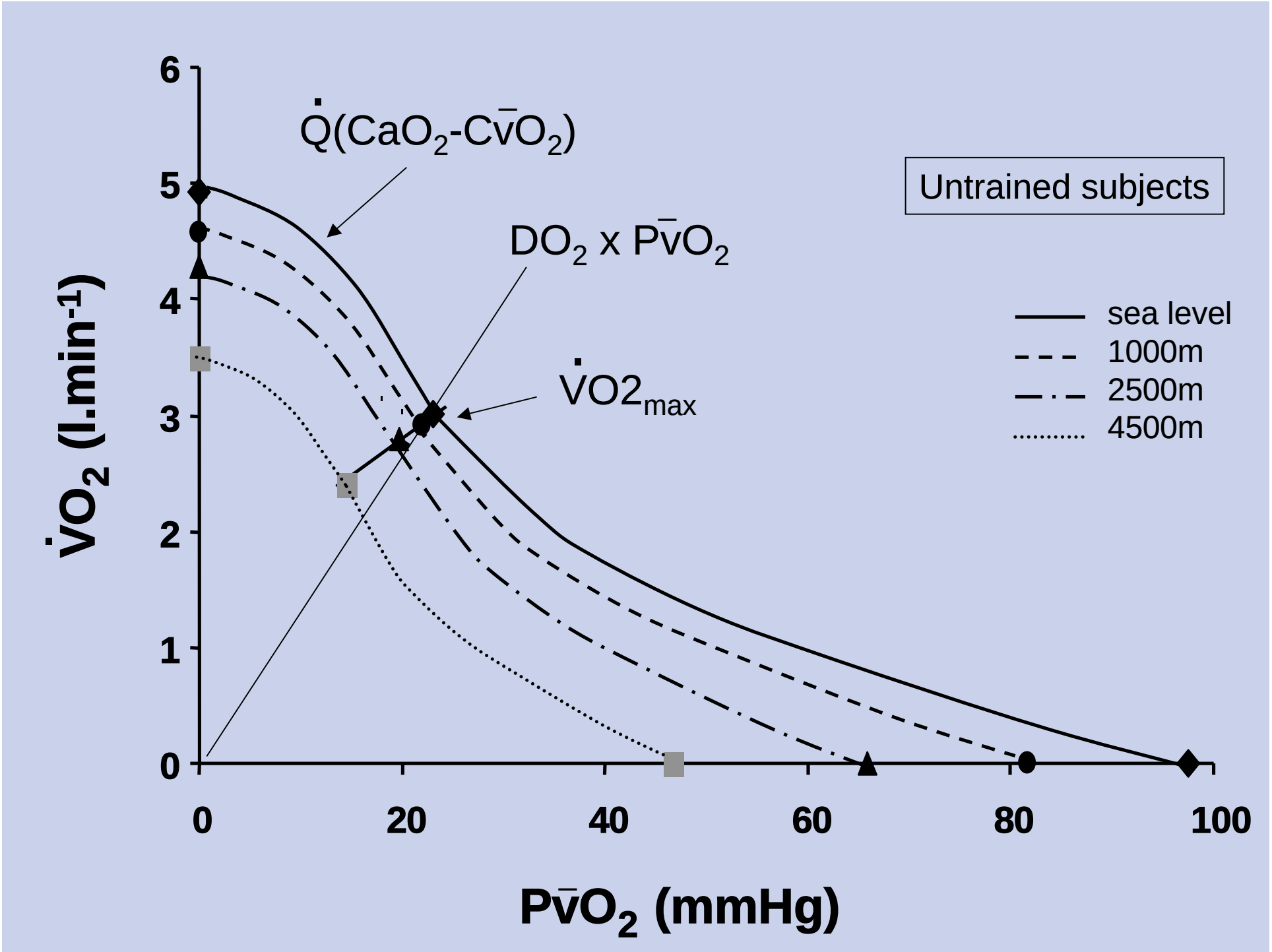


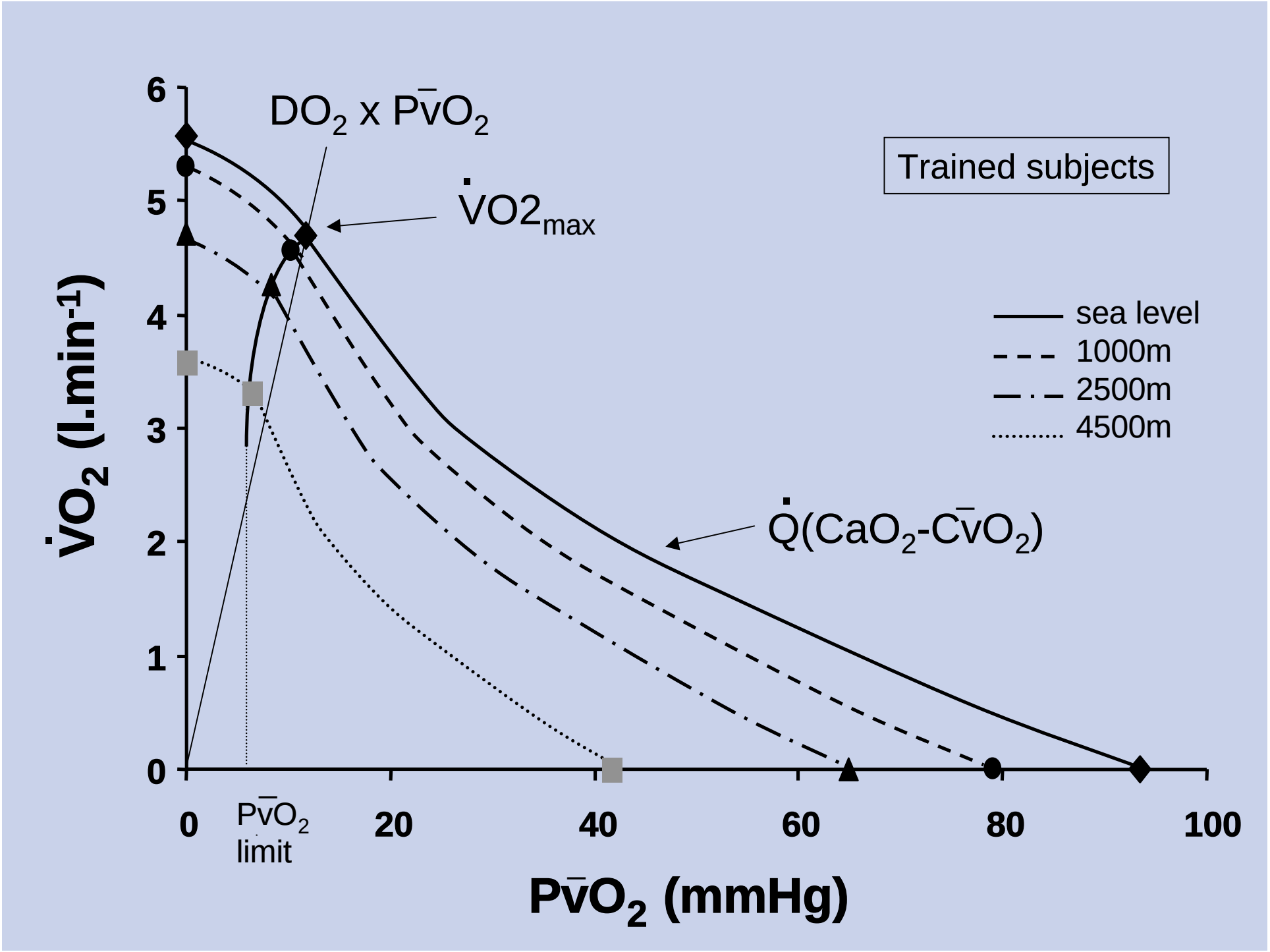
Favret and Richalet, 2007



From: Lerman and Belardinelli, Circulation, 1991 ; Richalet et al. 1990; Favret and Richalet, 2007


Male subjects
Female subjects
QaO2max (l.min-1)
trained
untrained
0
1000
2500
4500
O2 transport and extraction of trained and untrained subjects converge at 4500m
Da-vO2max (ml.l-1)
ALTITUDE (m)


Untrained subjects
sea level
1000m
2500m
4500m
$\dot{Q}(CaO_2-C\bar{v}O_2)$
DO_2 x $P\bar{v}O_2$
$\dot{V}O2_{max}$
$\dot{V}O_2$ (l.min^{-1})
$P\bar{v}O_2$ (mmHg)
0
1
2
3
4
5
6
0
20
40
60
80
100


Trained subjects
DO_2 x $P\bar{v}O_2$
$\dot{V}O2_{max}$
$\dot{Q}(CaO_2-C\bar{v}O_2)$
sea level
1000m
2500m
4500m
$\dot{V}O_2$ (l.min^{-1})
$P\bar{v}O_2$ (mmHg)
$P\bar{v}O_2$ limit
0
1
2
3
4
5
6
0
20
40
60
80
100

Subjects

5 endurance trained athletes (59.6 ± 2.8 ml/min/kg) and 6 physically active men (46.2 ± 2.8 ml/min/kg).

Protocol

Each subject performed five VO_2 peak tests on a cyclo-ergometer at 4 different simulated altitudes: 0m, 1000m, 2500m and 4000m

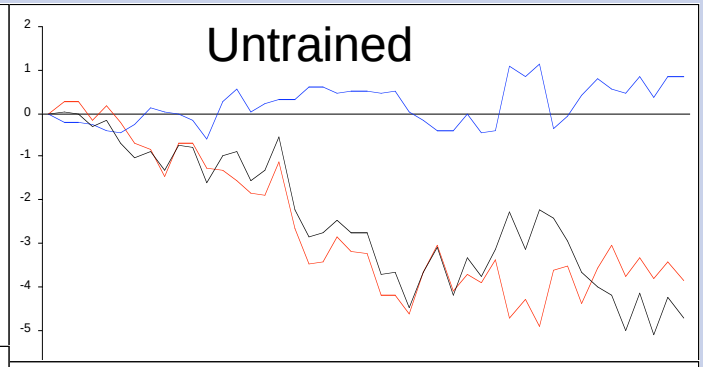
Measurements

Usual ventilatory and cardio-vascular parameters
Cardiac output using thransthoracic bio-impedance
Muscle tissue HbO_2 and HHb using Near InfraRed Spectroscopy (NIRS; InSpectra Tissue Spectrometer Model 325, Hutchinson Technology, MN, USA).

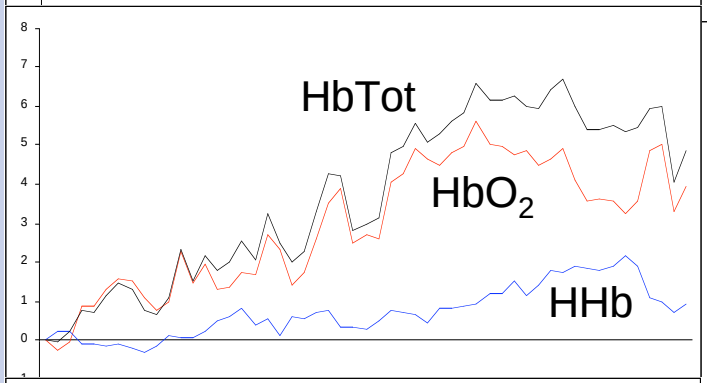
NIRS

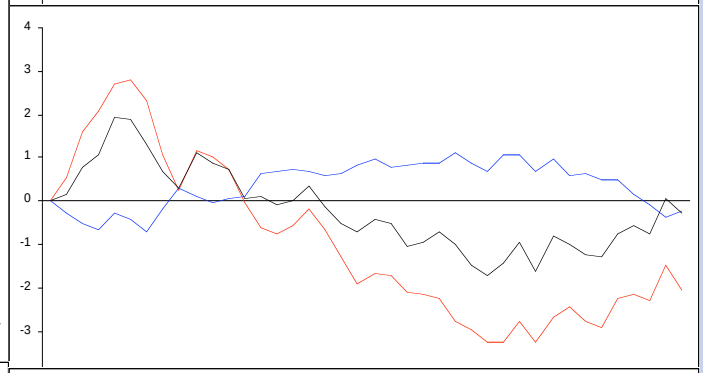
Vastus lateralis

0 m

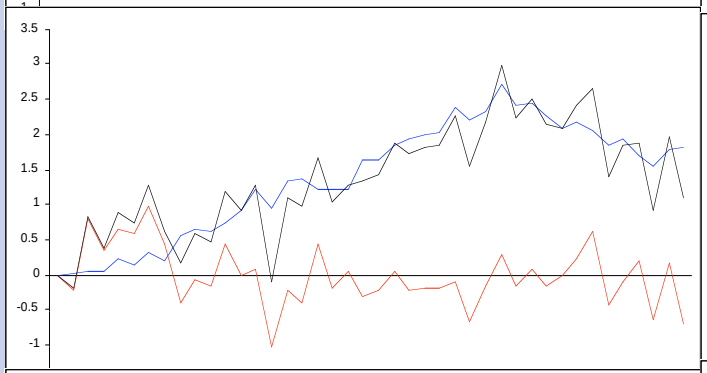


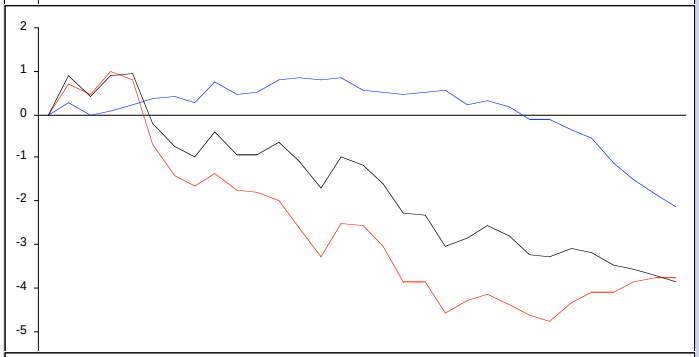
1000m



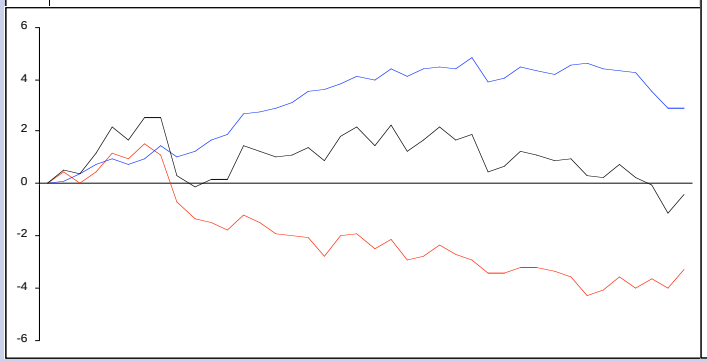


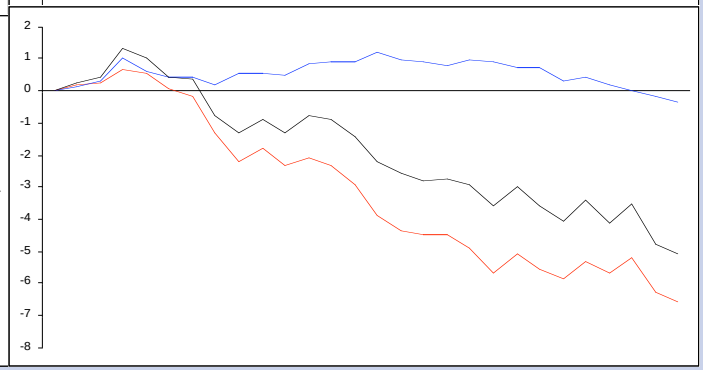
2500m





4500m





Training in hypoxia in the endurance-trained athlete

Effects on performance
Individual response factors
Potential risks for health

International Olympic Committee
Ministère des Sports, France
Groupe français de recherche sur l 'entraînement en hypoxie

COMITE INTERNATIONAL OLYMPIQUE

14 Scientific teams participated in the study

ARPE, Laboratoire « Réponses cellulaires et fonctionnelles à l'hypoxie », EA 2363,
UFR de Médecine, Université Paris 13, Bobigny

Centre National de Ski Nordique , Prémanon

Ecole Nationale de Ski et d'Alpinisme, Chamonix

Service de Physiologie Appliquée, Explorations Fonctionnelles Respiratoires, Hôpital de Strasbourg, Strasbourg

Laboratoire de Biologie des Activités Physiques et Sportives, Faculté de Médecine,
Clermont-Ferrand

EA 3759 – Laboratoire « Approche Bio-Psycho-Sociale du Dopage », Faculté des Sciences du Sport, Montpellier

Service Central de Physiologie Clinique, CHU de Montpellier

Groupe Rhône-Alpes d'analyse du système nerveux autonome,
St Etienne, Lyon, Grenoble

Institut d'Anatomie, Université de Berne, Suisse**.**

UFR STAPS, Université de Reims, Reims

Laboratoire National de Dépistage du Dopage, Chatenay-Malabry

Laboratoire de Biochimie, Hôpital Henri Mondor, Créteil

Laboratoire de Neurophysiologie Aérospatiale, IMASSA, Bretigny s/ Orge

Université Blaise Pascal, Clermont-Ferrand

Laboratoire de Biochimie, H.I.A. Bégin, Paris

Main objectives

Evaluate the physiological changes induced by various modalities of training in hypoxia and their impact on performance.

- *Hypothesis: these methods improve performance at sea-level*

Evaluate the individual response to training

- *Hypothesis: there are biological, physiological or psychological markers of the variability of individual response to training in hypoxia*

Evaluate the potential risks for health

- *Hypothesis: these methods are safe at short, medium and long term, provided a medical control of training procedures*

« Live/sleep high - train low »

Effects of intermittent exposure to hypoxia coupled to training at low altitude on performance in elite endurance athletes

(nordic ski, swimming, track and field, using hypoxic rooms)

Nordic ski

Hypoxia
Control
Tests
Blood sampling

- **VO_2max (treadmill)**
- **time limit at VO_2 max**
- **TFM, TDF**
- **hypoxic test**
- **Blood sampling, PV**

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- **time limit at VO_2 max**
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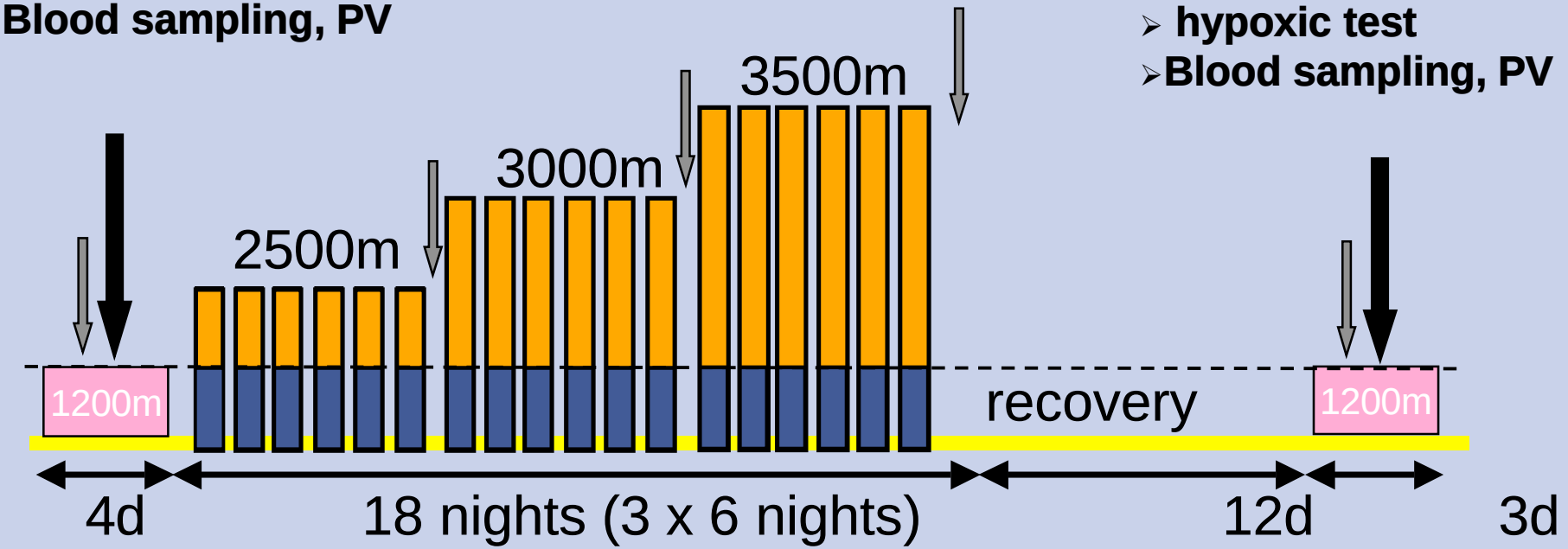
- **Blood sampling, PV**



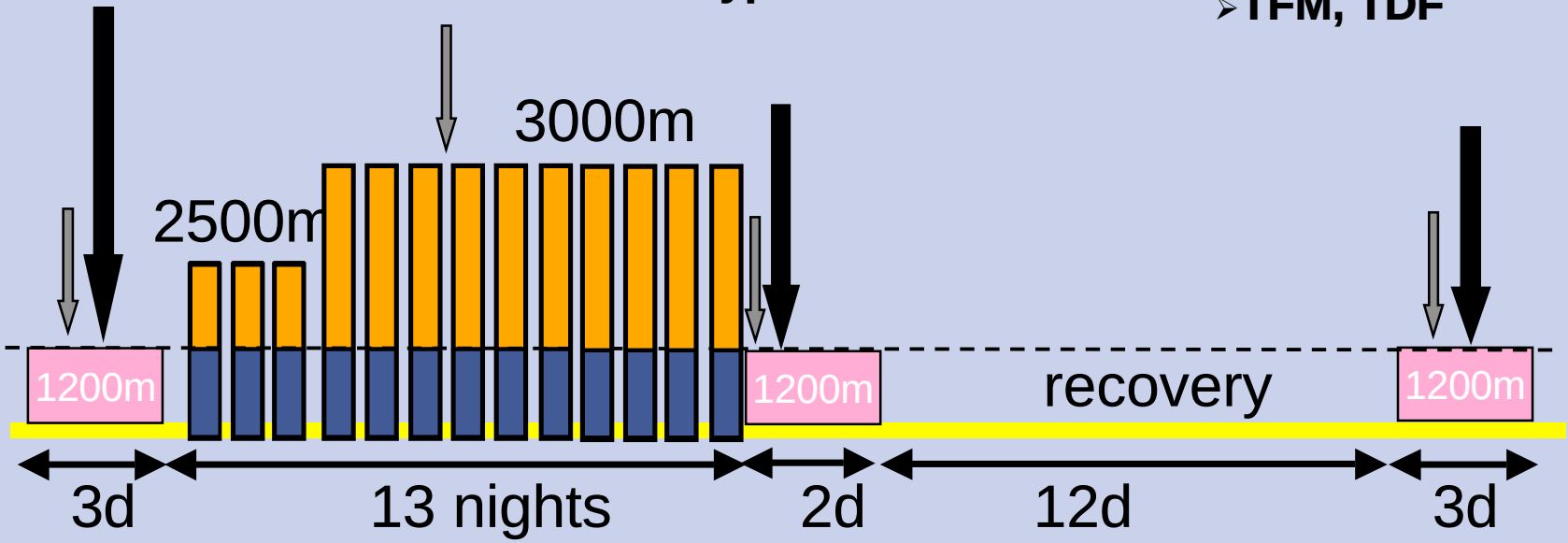
Swimming

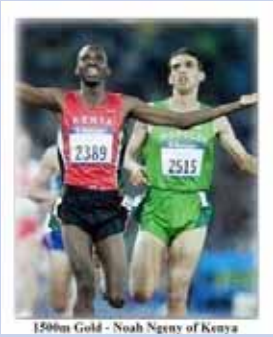
Hypoxia
Control
Tests
Blood sampl., TDF

- VO_2max (ergocycle)
- VO_2max (swim)
- 2000m swin free style
- Blood sampl., PV
- TFM, TDF
- hypoxic test

- VO_2max (swim)
- 2000m swin free style
- Blood sampl., PV
- TFM, TDF
- hypoxic test

- VO_2max (ergocycle)
- VO_2max (swim)
- 2000m swin free style
- Blood sampl., PV
- TFM, TDF



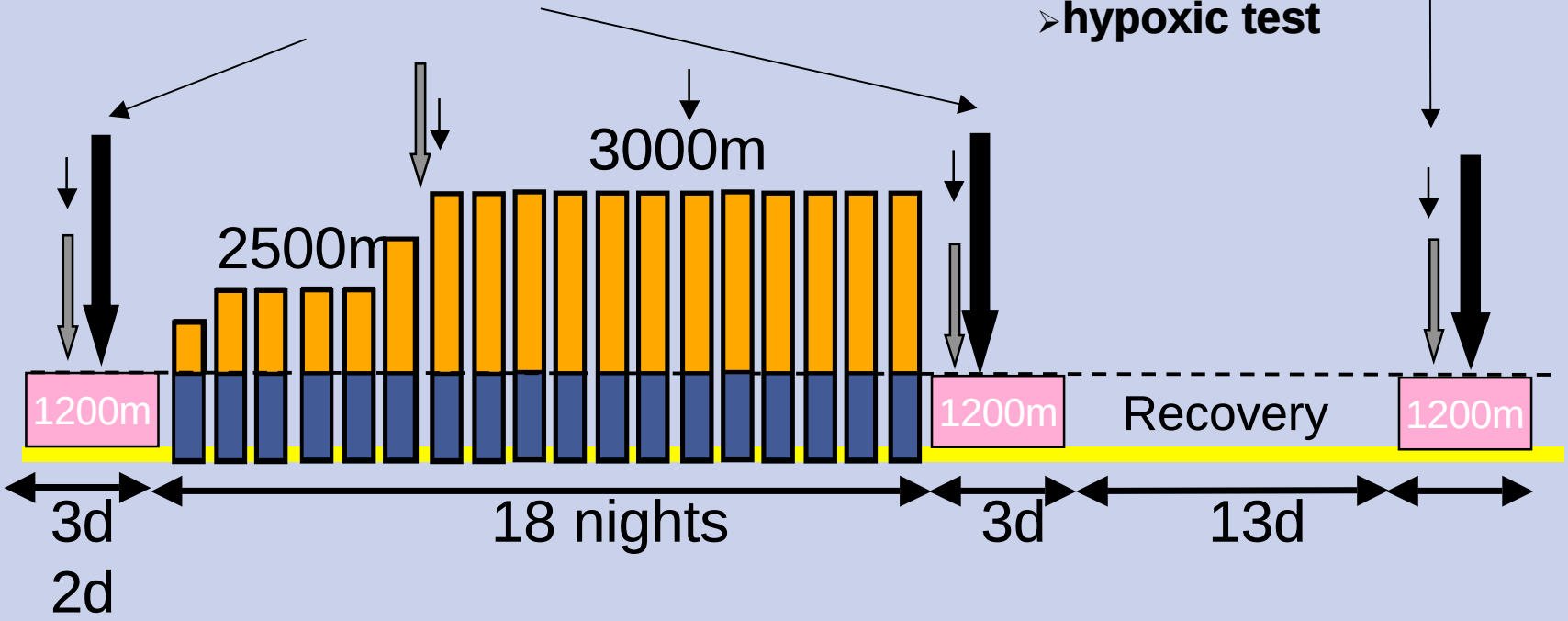


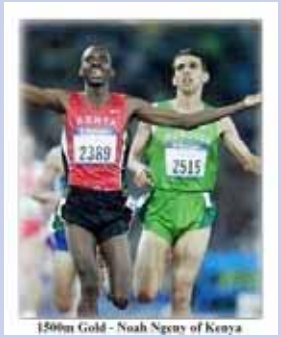
Track and field

Hypoxia
Control
Tests
Blood sampl. TDF

- VO_2max (treadmill)
- field test 10 min at 90% MAS.
- Blood sampl., PV
- TFM, TDF
- hypoxic test

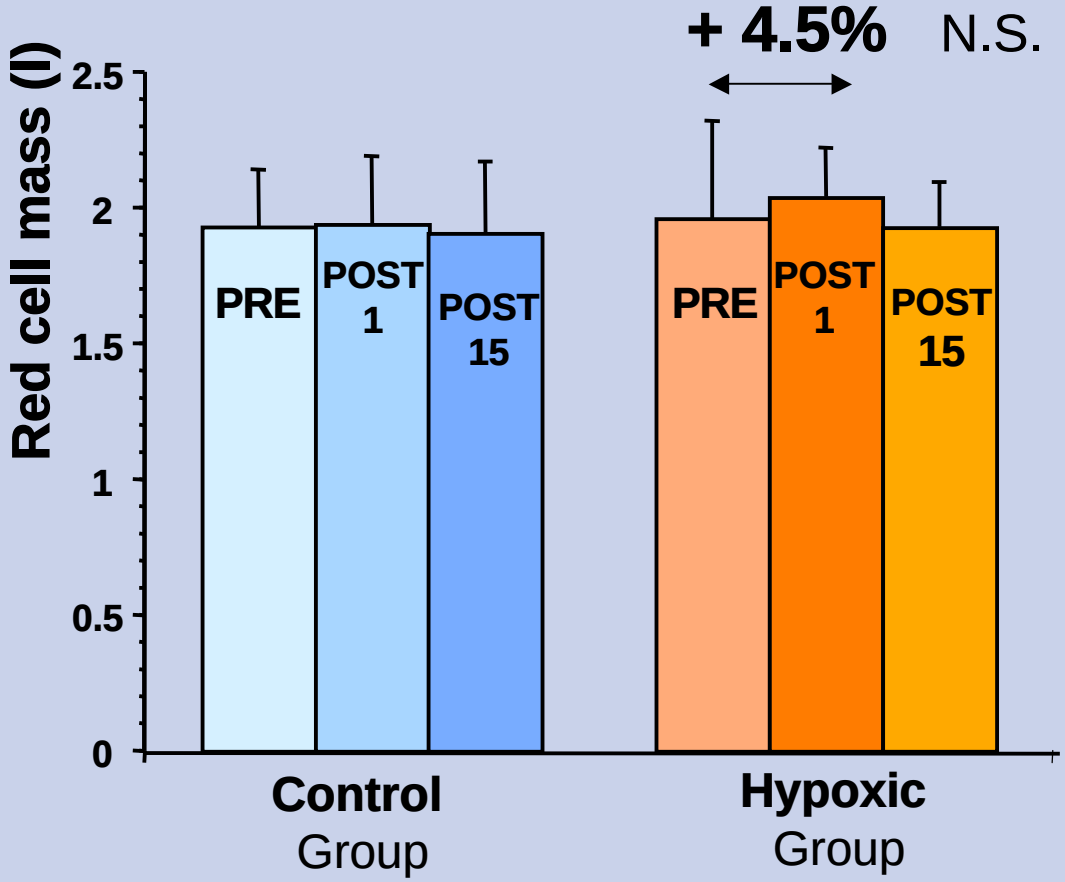
- VO_2max (treadmill)
- field test 10 min at 90% MAS
- Blood sampl., PV
- TFM, TDF
- hypoxic test

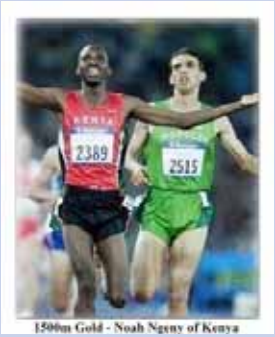




1500m Gold - Noah Ngeny of Kenya

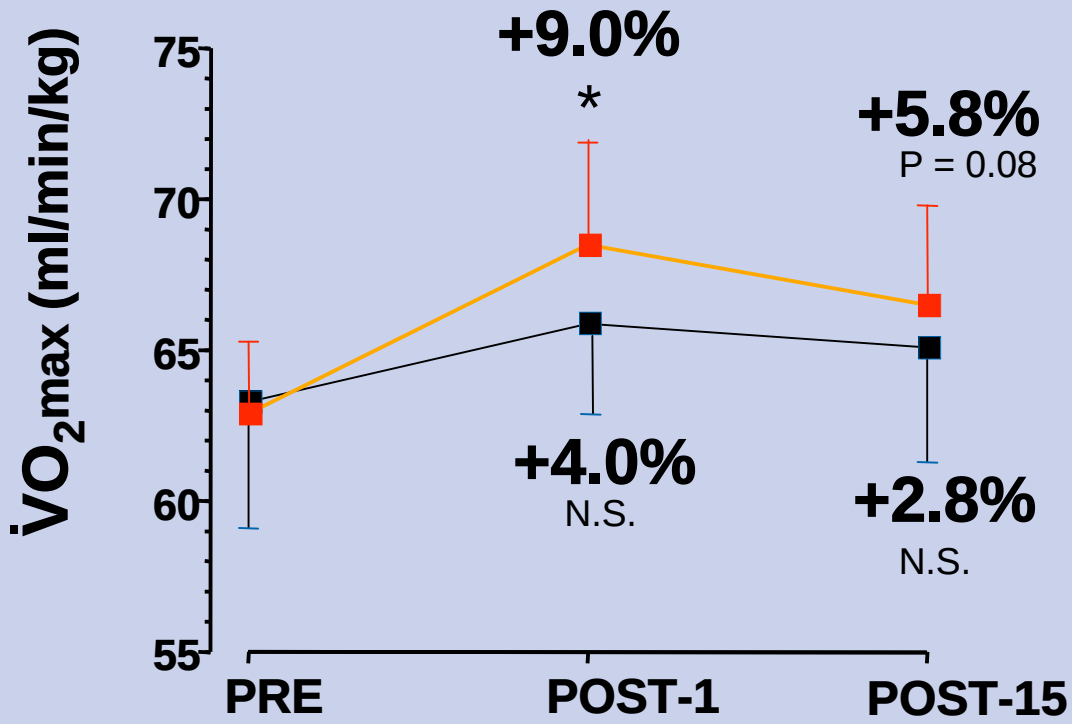
Red cell mass





1500m Gold - Noah Ngeny of Kenya

Performance ($\dot{V}O_2max$)



- **Control (n=6)**
- **Hypoxic (n=6)**

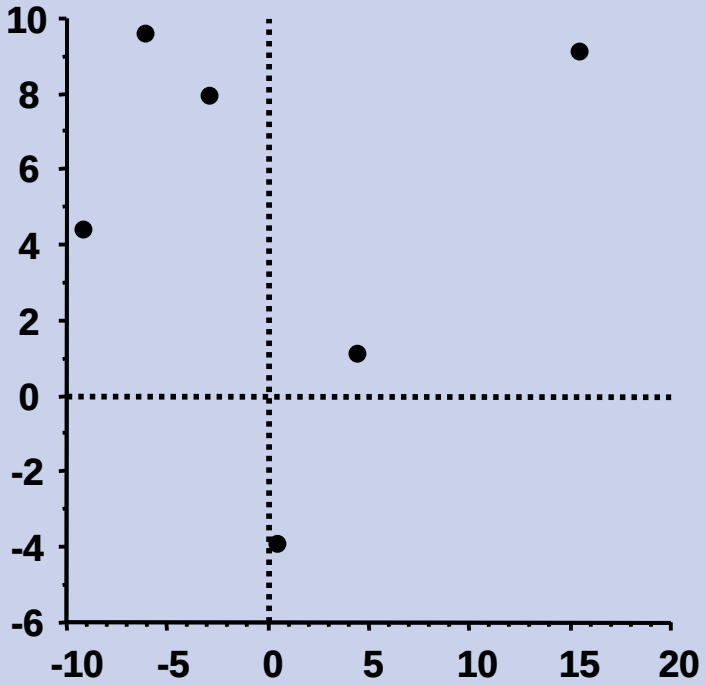
* P<0.05 vs PRE

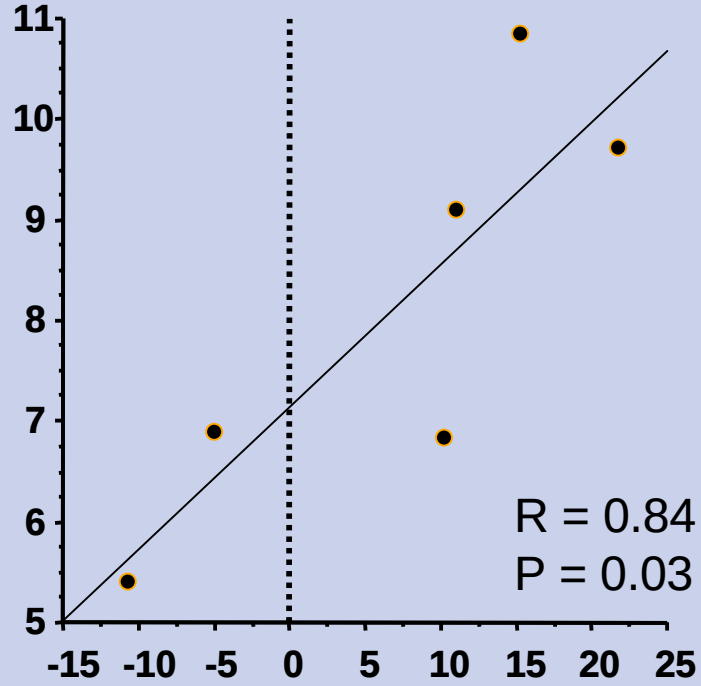
Variations of performance vs hemoglobin

Control group

Hypoxic group

$\Delta \dot{V}O_2max$ (%) (POST1 – PRE)

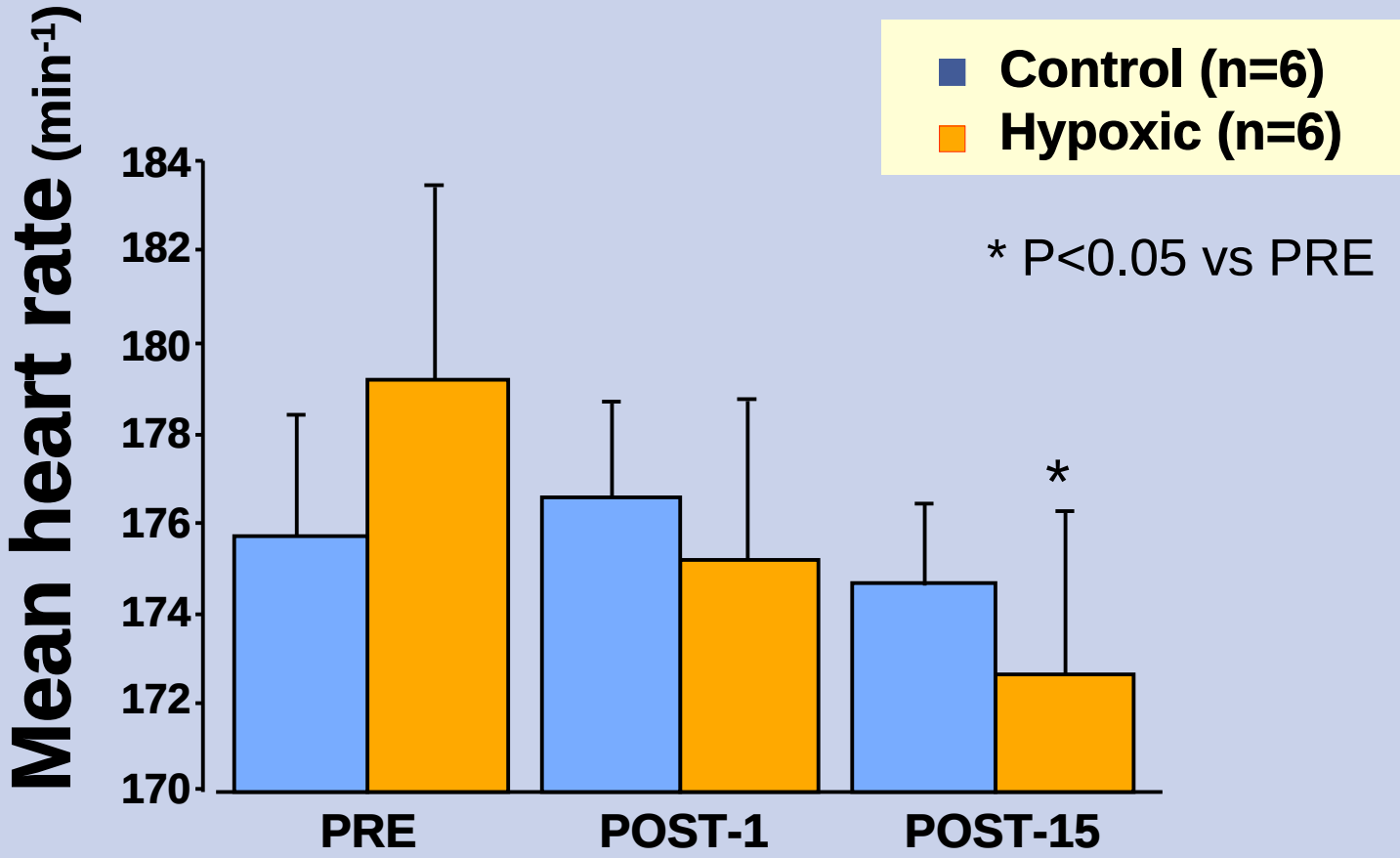




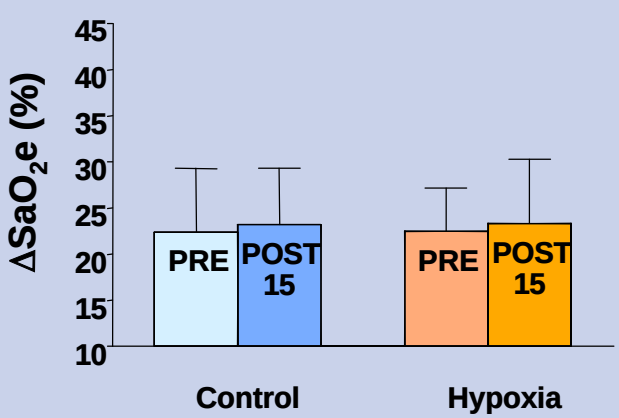
ΔnHb (%) (POST1 – PRE)

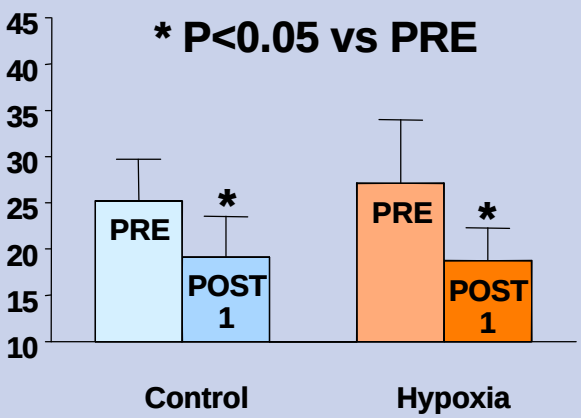
1500m Gold - Noah Ngeny of Kenya

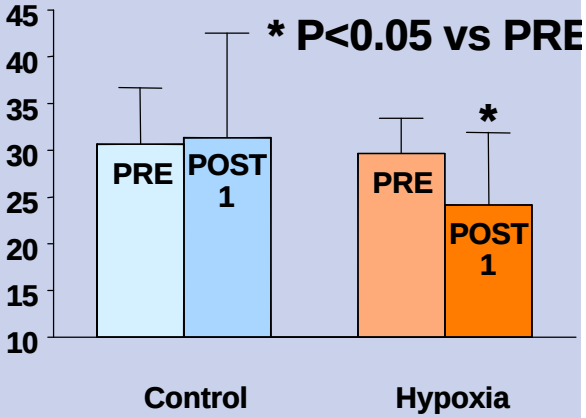
Field test: 10 min at 19.5 km/h
(≈ 90% of maximal aerobic speed)



Hypoxic exercise- induced desaturation (ΔSaO_2e)

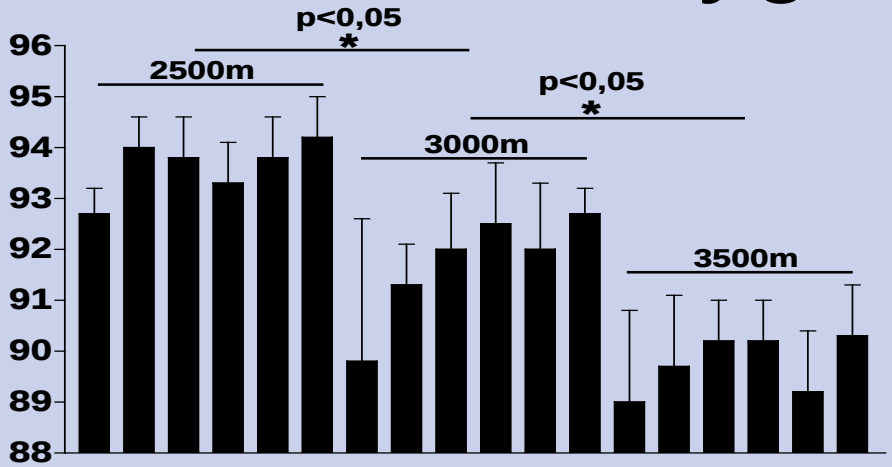


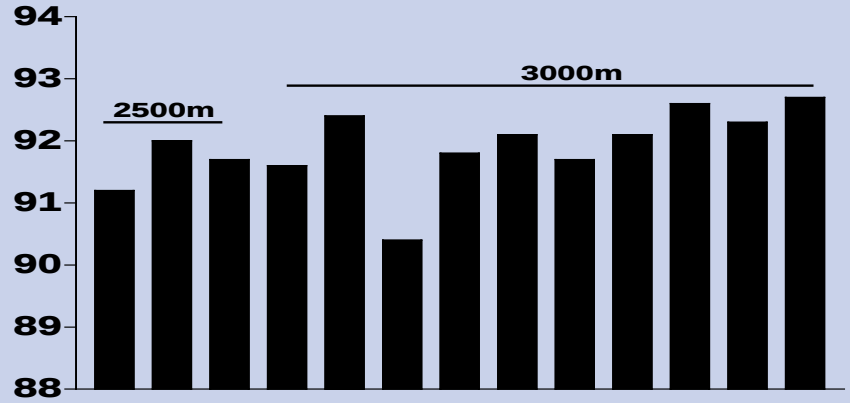


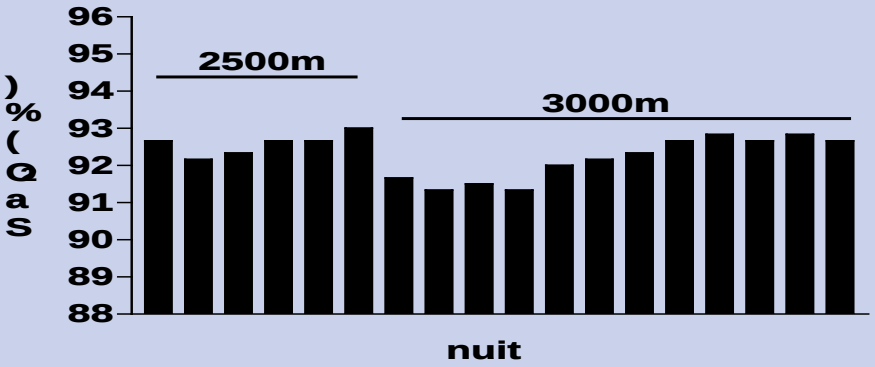


Lesser desaturation at exercise (ΔSaO_2e) at the end of the training session = sign of ventilatory acclimatization at exercice in hypoxia.

Nocturnal oxygen saturation (SaO_2)

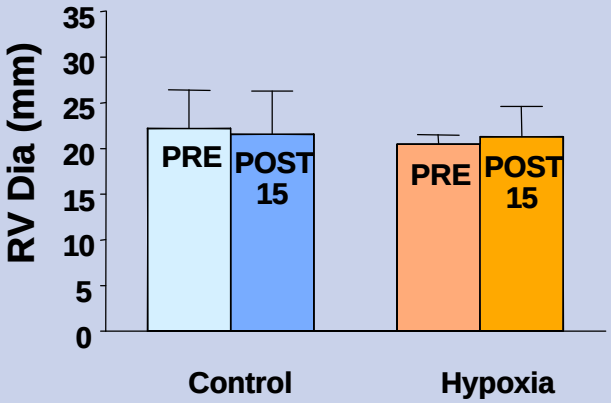


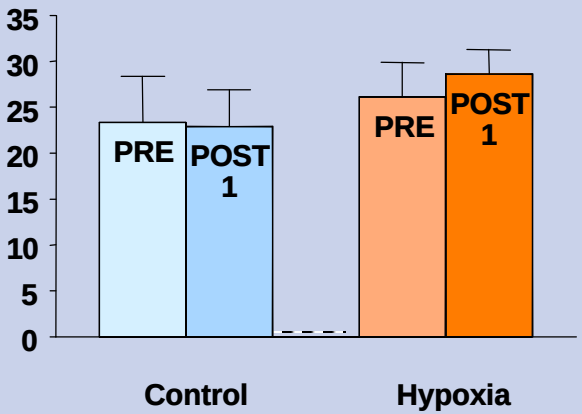


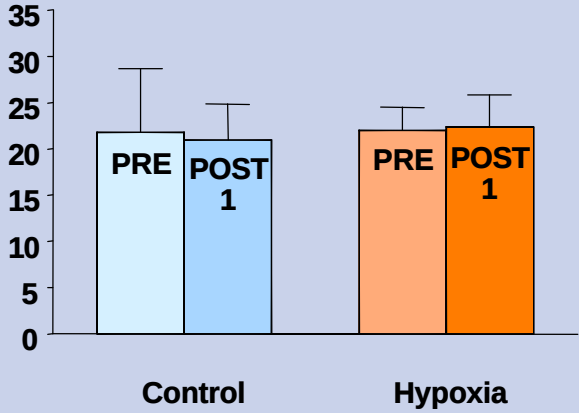


Sleep in hypoxic chambers induces episodes of desaturation, without apparent consequences on athlete's health

Right ventricule diameter in diastole (RVdia)

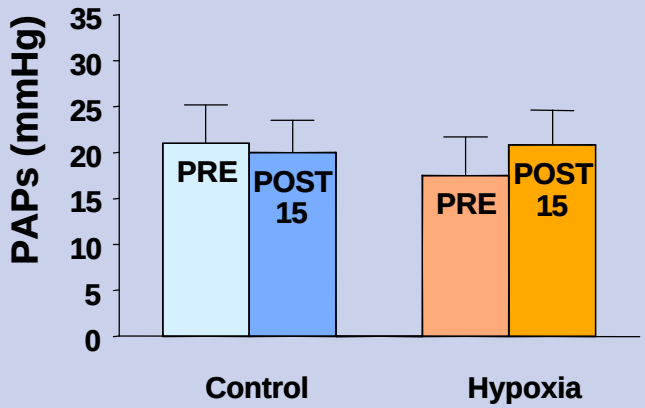


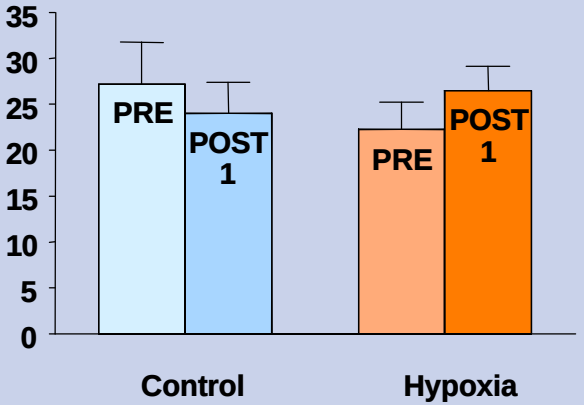




No right ventricular dilatation, classical marker of RV overload due to pulmonary hypertension

systolic Pulmonary artery pressure (PAPs)





PAPs does not vary significantly:
no pulmonary hypertension

Tolerance and acclimatization

« Live high – train low » (3000/1200)

- does not induce symptoms of Acute Mounatin Sickness.
- may induce sleep perturbations and fatigue (if ≥ 3500m and training load not reduced)
- may induce sleep apneas in some subjects, without apparent clinical consequences during the day.

Tolerance and acclimatization

« Live high – train low » (3000/1200)

- is not dangerous for the health of the athlete
- induces a ventilatory acclimatization (lower desaturation at exercise in hypoxia) that fades away 15 days after the training session

Recommendations for « live/sleep high - train low »

Altitude: 2500 - 3000
Duration: 3 weeks
Daily hypoxic exposure: 12-14 hours
Reduce training load during the first 3 days
Control nocturnal O_2 saturation
Control training post hypoxic exposure