Gruppo Nazionale
di Bioingegneria

# Respiration in Extreme Environments

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Ud'A Università degli Studi "G. d'Annunzio"

DNISC Dipartimento di Neuroscienze, Imaging e Scienze Cliniche

Functional Evaluation Lab

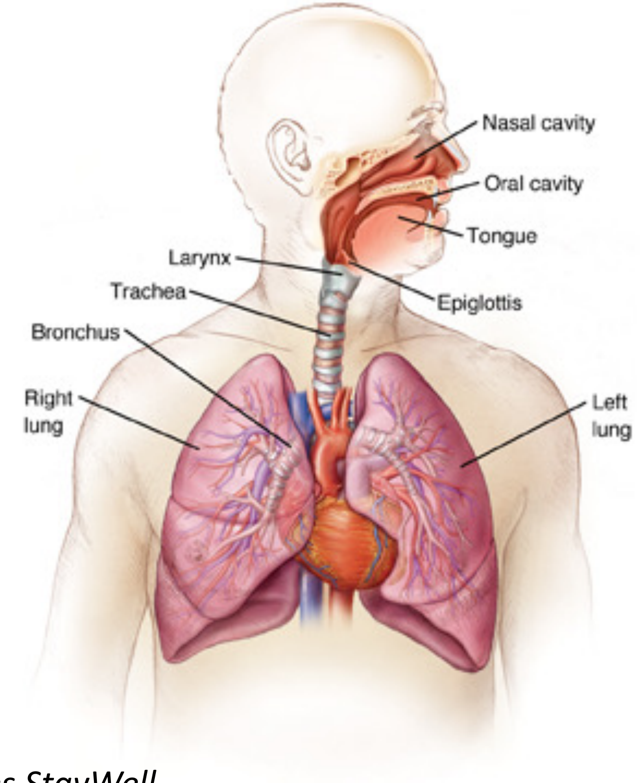
Laboratory of Clinical and Hypoxic Physiology

**WHAT**

Inspired air: Oxygen – 20.95%, Nitrogen – 79.01%, Carbon dioxide – 0.04%
Expired air: Oxygen – 16.40%, Nitrogen – 79.60%, Carbon dioxide – 4.00%

**WHY**

Humans rely on pulmonary ventilation for **oxygen** supply, thereby ensuring life




*Author: Eric Olson*

*Source: https://www.stanfordchildrens.org/*

**HOW**

Every cell needs oxygen, whose delivery is allowed by the pneumodynamic pump, (lungs), hemodynamic pump (cardiovascular system), and hematopoietic system (hemoglobin)

**WHERE**

From the bottom of the sea to the top of the mountains and beyond

# Formulas of respiratory function

$$\dot{V}e = Rf \times VT$$

$$\dot{V}A = \dot{V}e - \dot{V}d$$

$$DO_2 = CO \times [(1.31 \times Hb \times SaO_2 \times 0.01) + (0.0225 \times PaO_2)]$$

$$\dot{V}O_2 = CO \times (CaO_2 - CvO_2)$$

- Ve: ventilation
- Rf: respiratory frequency
- VT: tidal volume
- VA: alveolar ventilation
- Vd: dead-space ventilation
- $DO_2$: oxygen delivery
- CO: cardiac output
- Hb: hemoglobin
- $SaO_2$: arterial hemoglobin saturation
- $PaO_2$: partial pressure of arterial oxygen
- $VO_2$: oxygen consumption
- $CaO_2$: arterial oxygen content
- $CvO_2$: mixed venous oxygen content

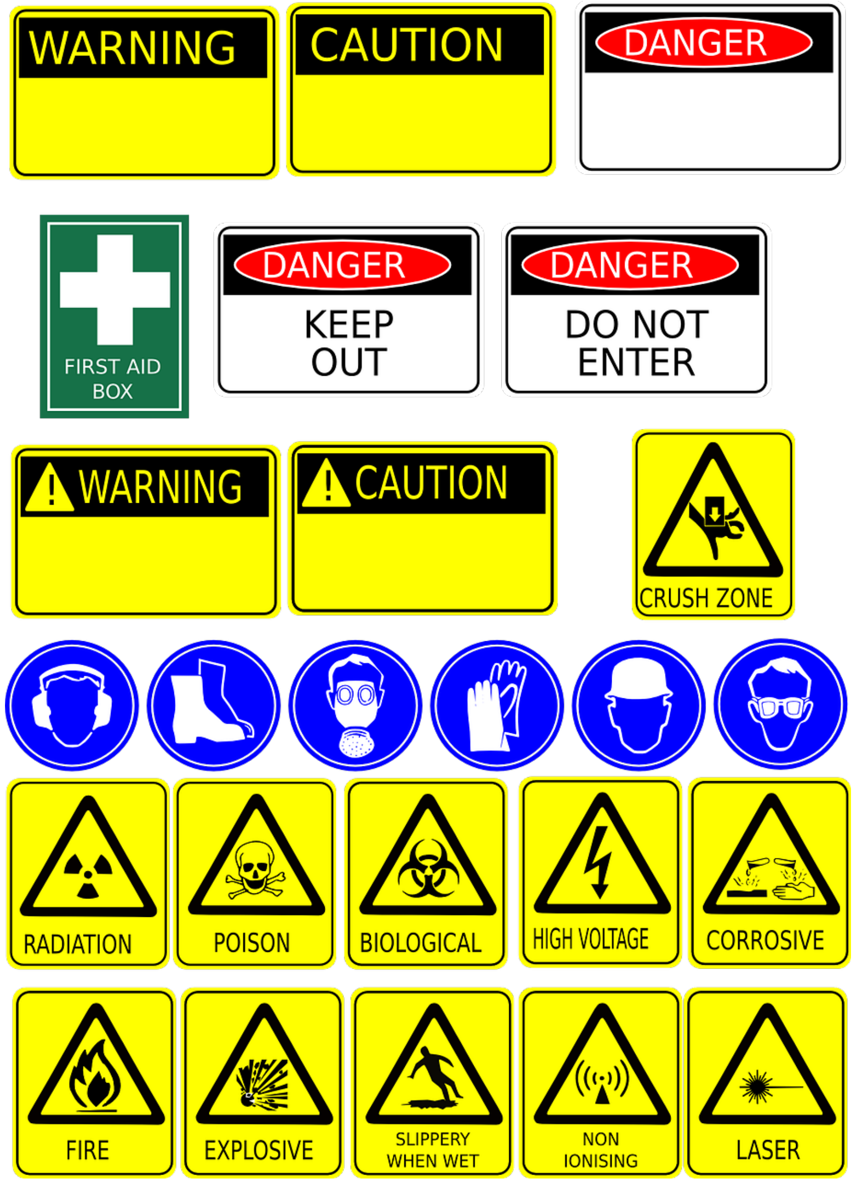
**The oxygen used by tissue on the total amount of oxygen delivered is only 20–30%**

*(Dunn JO, Mythen M, Grocott M. Physiology of oxygen transport. BJA Educ. 2016;16(10):341-348. doi:10.1093/bjaed/mkw012)*

# Extreme environments

- temperature
- altitude
- level of danger
- lack of external visibility
- lack of space
- specific clothing
- unusual photoperiodicity
- lack of intimacy
- the need for a high-tech life support system
- isolation
- possibility of sudden disaster
- lack of access to food, water, shelter,other resources necessary for safety and comfort

*(Le Roy B, Martin-Krumm C, Pinol N, Dutheil F, Trousselard M. Human challenges to adaptation to extreme professional environments: A systematic review. Neurosci Biobehav Rev. 2023;146:105054. doi:10.1016/j.neubiorev.2023.105054)*



# COLD

- peripheral vasoconstriction
- > $O_2$ consumption
- ve increases slightly less than $VO_2$: drop in ventilatory equivalent ($Ve/VO_2$)

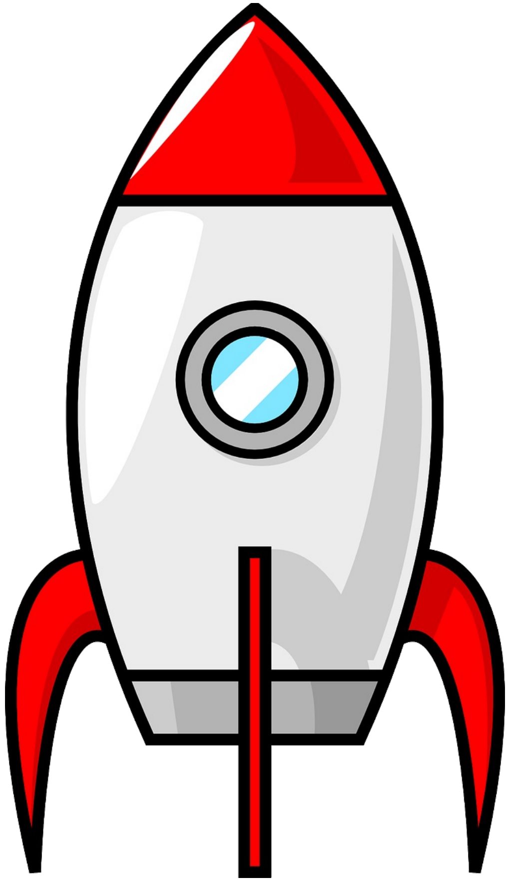
*(Mortola JP, Maskrey M. Metabolism, temperature, and ventilation. Compr Physiol. 2011;1(4):1679-1709. doi:10.1002/cphy.c100008 )*

# HOT

- > evaporation via the respiratory tract to dissipate heat
- higher *Rf* and lower *VT*: thermal tachypnea (in moderate warm conditions)
- lower *Rf* and higher *VT*: thermal hyperventilation (in very hot conditions)

*(Mortola JP, Maskrey M. Metabolism, temperature, and ventilation. Compr Physiol. 2011;1(4):1679-1709. doi:10.1002/cphy.c100008 )*

# "Space analogs" – Antarctic base



- exertional dyspnea
- outdoor airway hyper-reactivity
- reduced forced vital capacity

*(Ancic P, Guzmán M, Oyarzún M. [Respiratory symptoms and pulmonary function in O' Higgins antarctic base residents]. Rev Med Chil. 1993;121(3):247-252)*

# Under the sea

external pressure > by about 1 standard atmosphere (101325 Pa) every 10 m

"DIVING REFLEX": bradycardia, apnea, and increased peripheral vascular resistance

As the depth >, total lung capacity continues to <

# Under the sea

Immersion to the neck exposes individuals to a positive pressure outside the thoracic cage of about 14.7 mmHg (1960 Pa)

- < residual capacity of 50%
- < expiratory reserve of 70%
- > energy cost of breathing of 60%

*(Bonanni R, Brunamonti E, Cacchio M, et al. Adattamenti fisiologici agli ambienti straordinari. In: Fisiologia Umana. Edizioni A.L.E.; 2022 )*

Descent phase: transient hyperoxia
Ascent phase: transient hypoxia

When $PaO_2$ > 100 mmHg, $SpO_2$ stays at 100% plateau

Need to assess hyperoxia in *$PaO_2$* range of 100-200 mmHg

Oxygen reserve index (ORI) developed by multiwave length pulse co-oximetry analysing both arterial and venous pulsatile blood absorption changes of incident light through finger probes

*(Vos JJ, Willems CH, van Amsterdam K, et al. Oxygen Reserve Index: Validation of a New Variable. Anesth Analg. 2019;129(2):409-415. doi:10.1213/ANE.0000000000003706)*

# Over the mountain

- Hypoxic ventilatory response (HVR): > Ve triggered by hypoxia
- $VO_2$ max < due to < $CaO_2$, < CO, and redistribution of blood flow
- respiratory alkalosis triggered by hyperventilation

# Over the mountain

When altitude > 5000 m, $PaO_2$ usually < 50 mmHg and $PaCO_2$ < 25 mmHg

- > dead space ventilation
- < lung volumes

*(Richard NA, Koehle MS. Differences in cardio-ventilatory responses to hypobaric and normobaric hypoxia: a review. Aviat Space Environ Med. 2012;83(7):677-684. doi:10.3357/asem.3182.2012 )*

Increases in *Rf* and *VT* can both occur in response to hypoxic exposure

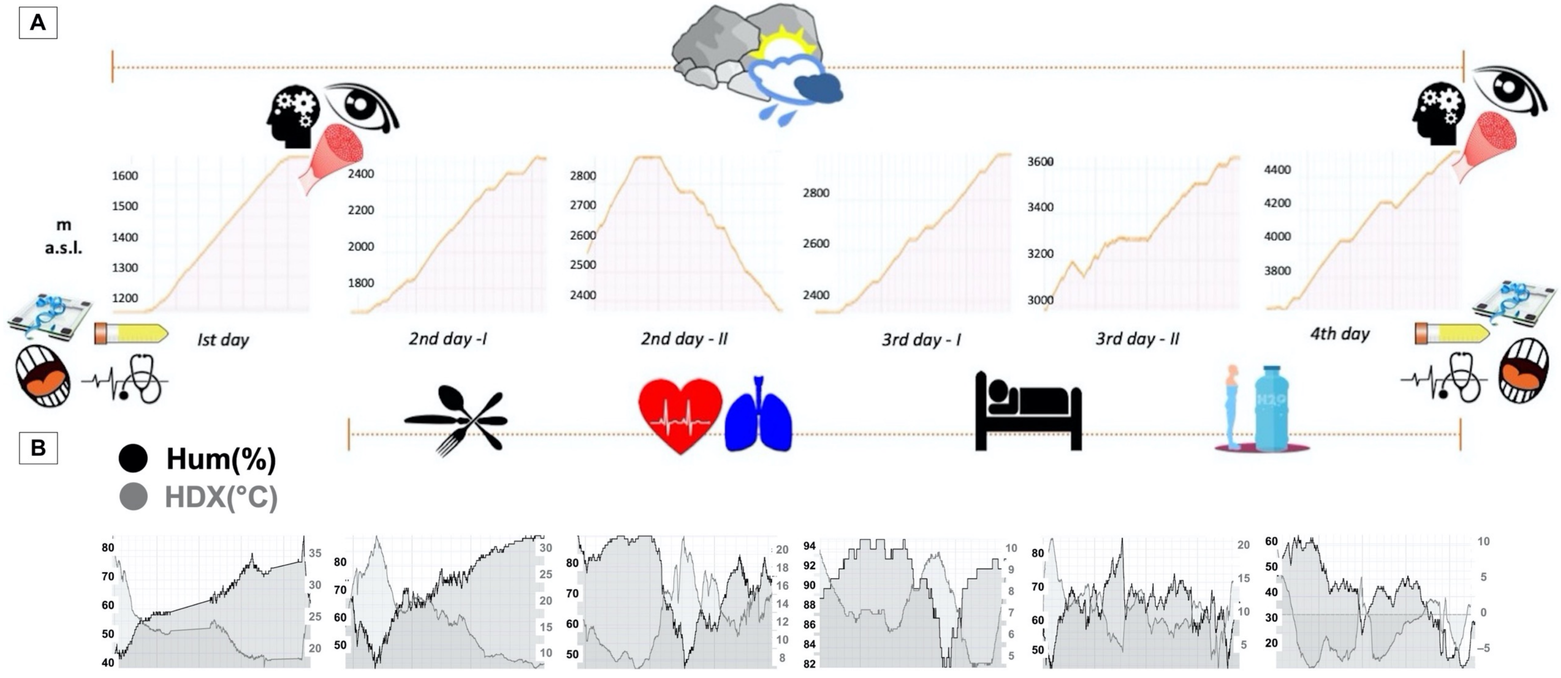
Severe hypoxia: >> increase in *Rf* and < in *VT*.

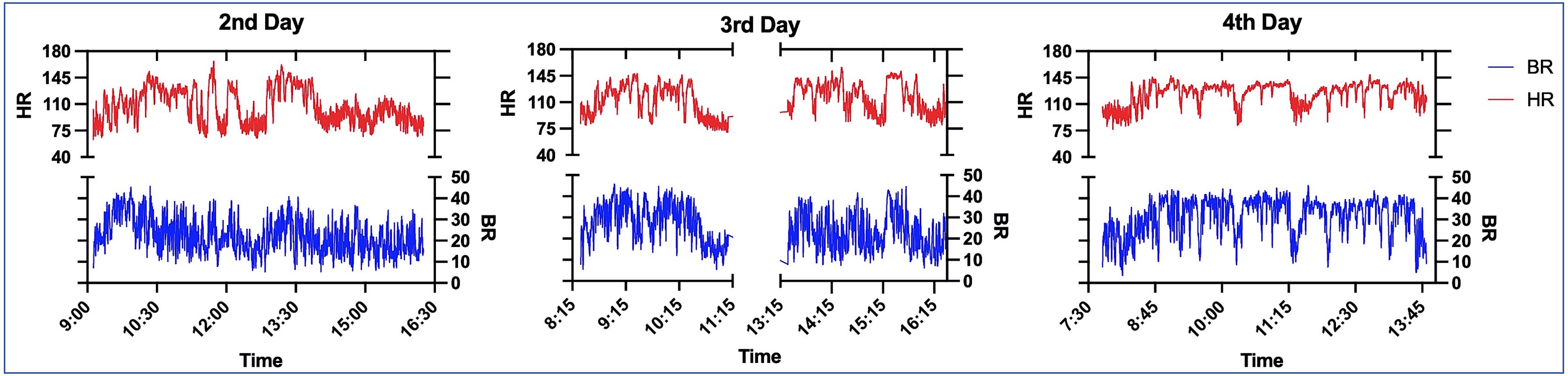
Elite high-altitude climbers: slower *Rf* with a larger *VT* during maximal exercising tests

Individuals susceptible to AMS have > *ƒ*R and < *VT* at rest in acute hypoxia and increase *Ve* by a prominent increase in *Rf*

> *Ve* mainly via *VT* than *Rf* on exposure to hypoxia is a good response

*(Tipton MJ, Harper A, Paton JFR, Costello JT. The human ventilatory response to stress: rate or depth? J Physiol. 2017;595(17):5729-5752. doi:10.1113/JP274596 )*

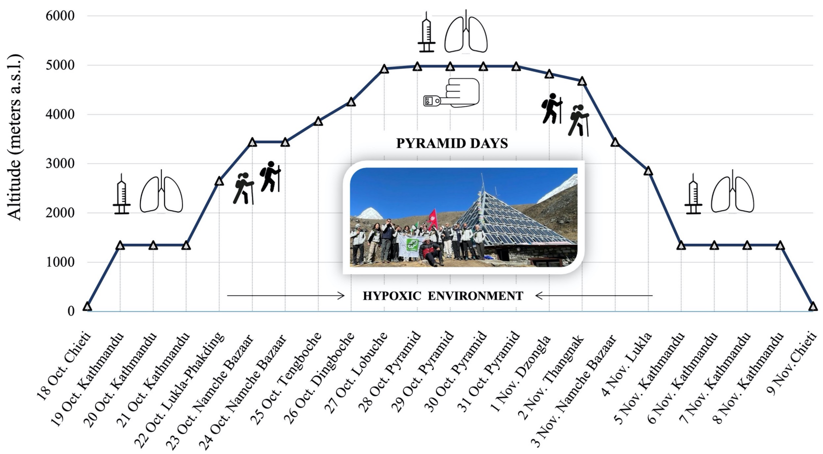


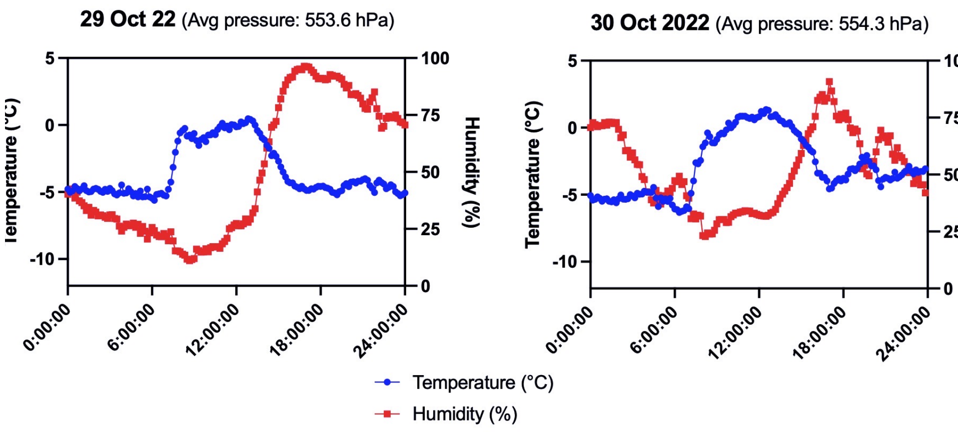




Bondi D, Lobefalo L, Ciampini F, et al. Clinical features and health-threatening conditions of the trek to Capanna Margherita. *J Sports Med Phys Fitness*. 2023;63(8):927-933. doi:[10.23736/S0022-4707.23.14859-6](https://doi.org/10.23736/S0022-4707.23.14859-6)

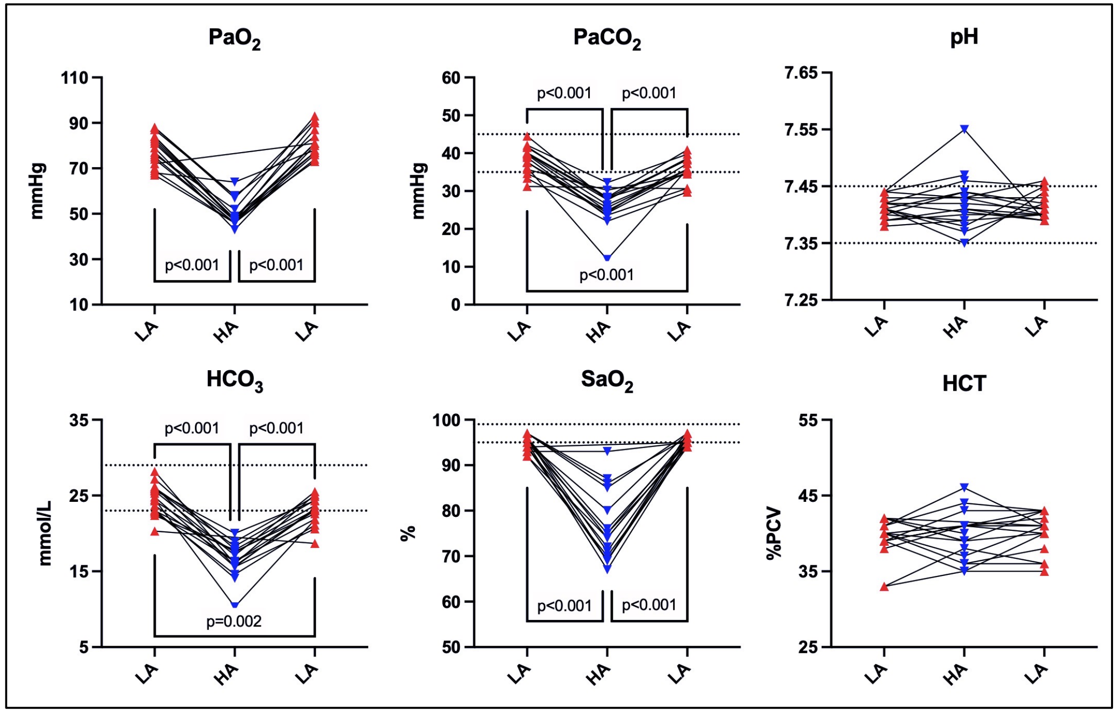
MONTE ROSA
EXPLORATION & PHYSIOLOGY
Ud'A

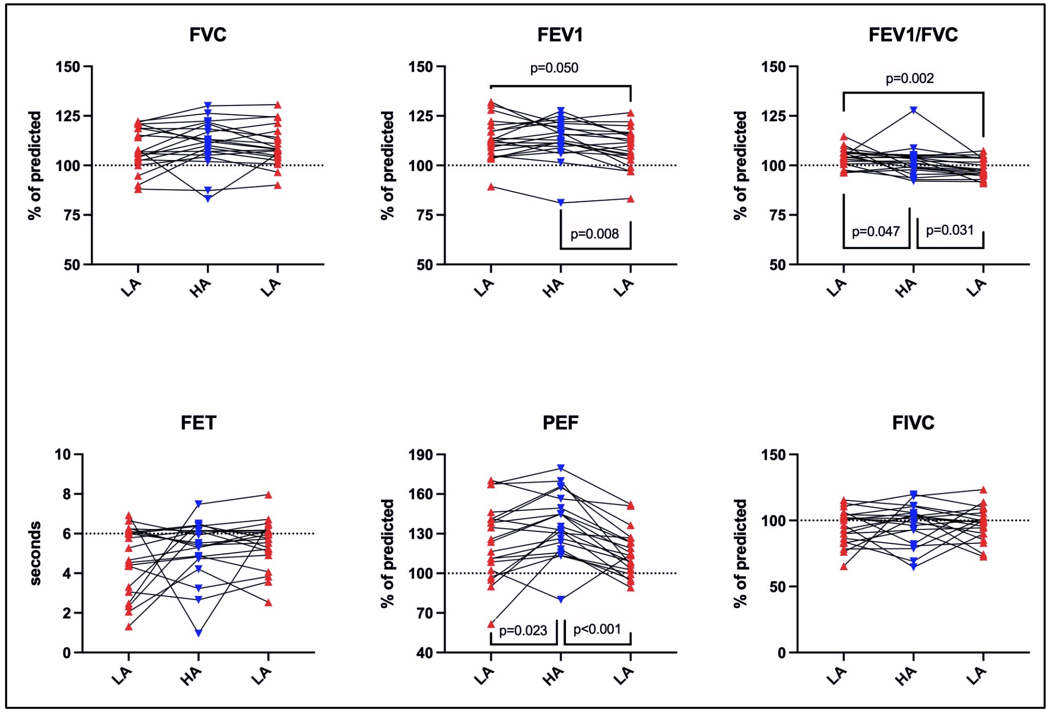
*Data acquired by the chest strap BioHarness 3.0 by Zephyr*

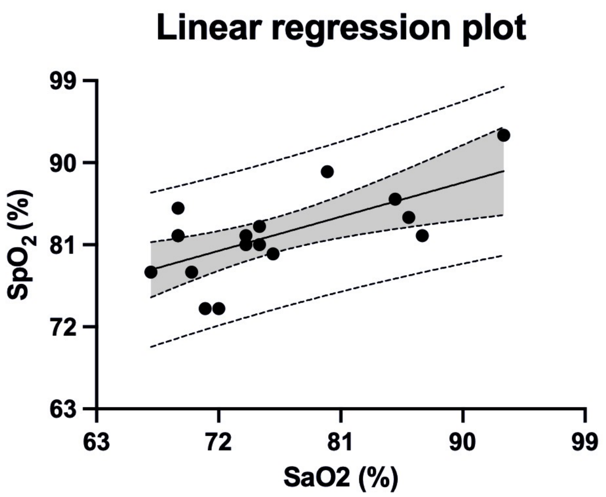


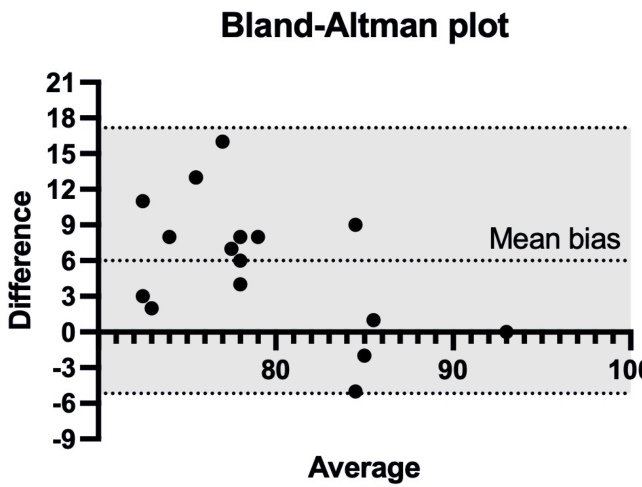




Prosperi P, Verratti V, Taverna A, et al. Ventilatory function and oxygen delivery at high altitude in the Himalayas. *Respiratory Physiology & Neurobiology*. 2023;314:104086. doi:10.1016/j.resp.2023.104086



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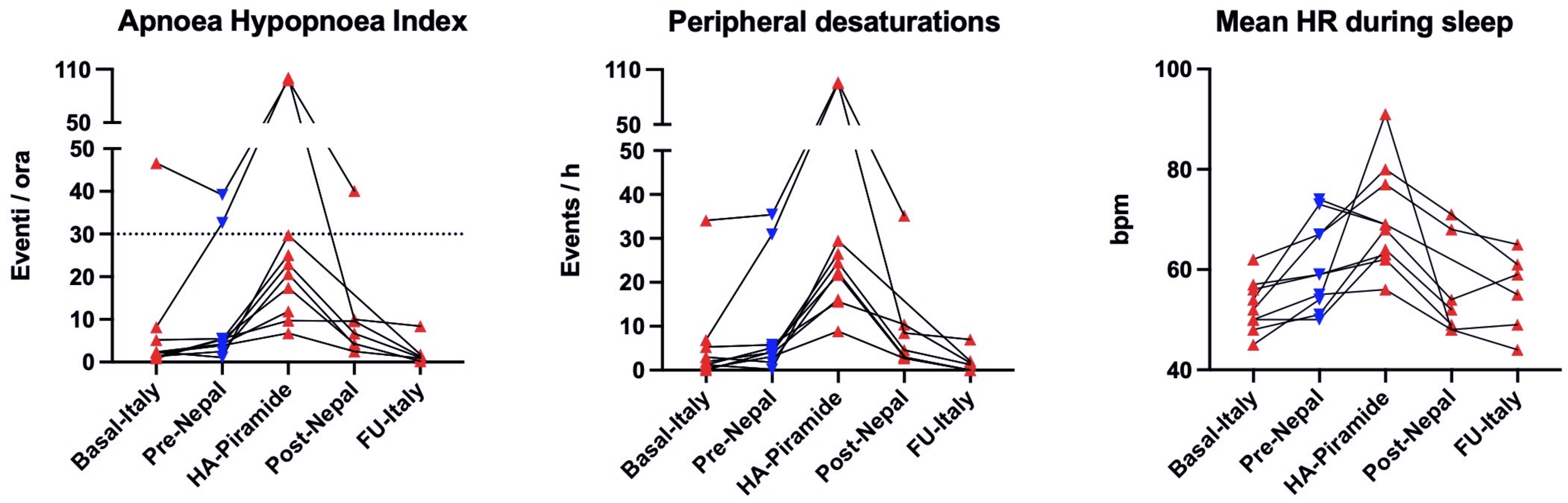
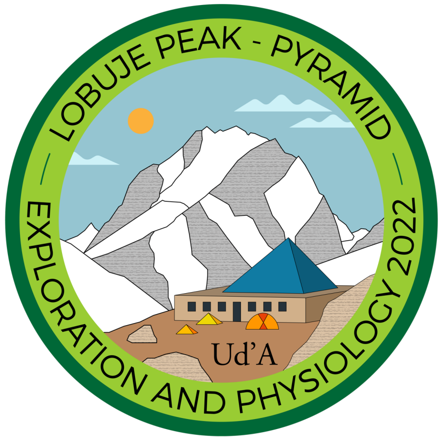
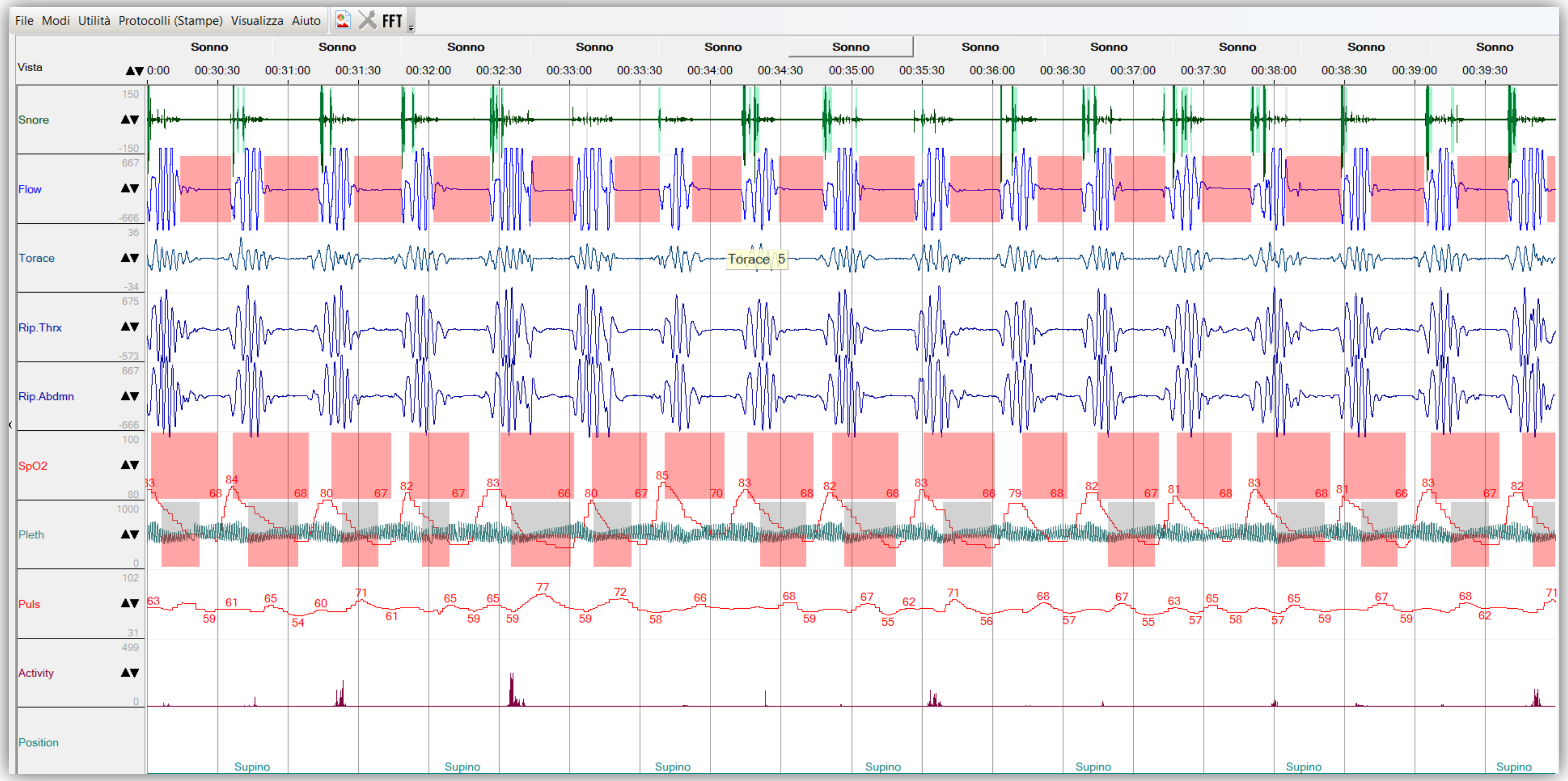



*Data acquired with SOMNOtouch™ RESP, SOMNOmedics, Germany*

# High altitude-triggered periodic breathing

*Data acquired with SOMNOtouch™ RESP, SOMNOmedics, Germany*



# ISSUES

- Operating and transport ranges for temperature and humidity
- Zinc-air batteries can suffer from atmospheric gas alterations
- Equations to impute $PaO_2$ from $SpO_2$ should be adapted to $FiO_2$-fixed settings
- Update estimation of $SpO_2$

$$SpO_2 = 103.3 - (altitude \times 0.0047) + Z$$

being Z = 0.7 in males and 1.4 in females

*(Lorente-Aznar T, Perez-Aguilar G, García-Espot A, et al. Estimación de la saturación arterial de oxígeno en función de la altitud. Med Clínica. 2016;147(10):435-440. doi:10.1016/j.medcli.2016.07.025)*

**IN-DEPTH BOX: PULSE OXIMETRY**

Pulse oximetry accuracy declines in the cold environments and when $SpO_2$ falls below 80%; measurements at high altitudes are prone to inaccuracy. The predictive power of $SpO_2$ has acceptable accuracy in participants exhibiting moderate to severe AMS

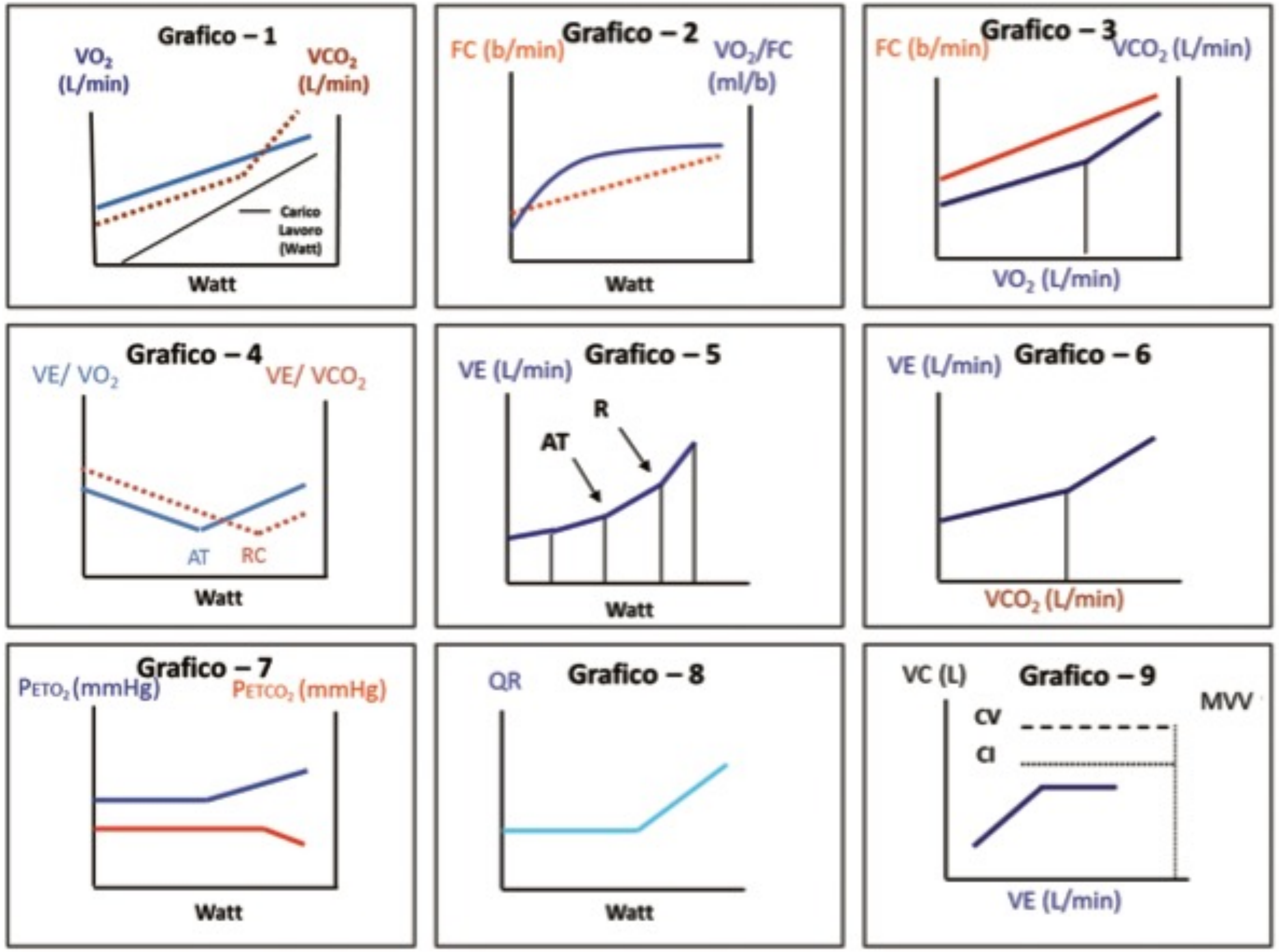
Possible causes of unreliable $SpO_2$ readings:

- excessive movement
- poor probe positioning
- excess ambient light
- cold-induced vasoconstriction
- skin pigmentation
- nail polish
- overestimation due to possible carbon monoxide poisoning

Keep the person silent and gentle breathing for several minutes, extend the measurements over a few minutes, and register the mode

*(Prosperi P, Verratti V, Bondi D, Spacone A. On pulse oximetry and hypoxia. Respiratory Physiology & Neurobiology. 2023;315:104111. doi:10.1016/j.resp.2023.104111; Dünnwald T, Kienast R, Niederseer D, Burtscher M. The Use of Pulse Oximetry in the Assessment of Acclimatization to High Altitude. Sensors. 2021;21(4):1263. doi:10.3390/s21041263)*

# Introducing the challenge: OXYNET




*(CPET - Il test da sforzo Cardiorespiratorio, Interpretazione dei 9 grafici di Wasserman, Edizione 2015; Sponsored by COSMED srl)*

- Aim of the tool: «The objective determination of the first and second thresholds from CPET»
- «First example of a deep learning algorithm trained with crowdsourced data in the field of CPET automatic interpretation»
- Rationale: «breaking points and changing patterns in CPET time-series demarcate the metabolic rates above which: (1) anaerobic metabolism is activated without metabolic acidosis (first threshold) and (2) anaerobic metabolism takes over and metabolic acidosis develops (second threshold)»
- Conclusion: «the web-based applications presented here might provide low-cost and time-efficient universal access to CPET interpretation and trigger new opportunities for collaborations between experts in the field of exercise physiology»

*(Zignoli A, Fornasiero A, Gilli F, Pellegrini B, Schena F. How the Oxynet web applications are used to crowdsource and interpret cardiopulmonary exercising tests data. Biomedical Signal Processing and Control. 2023;85:104836. doi:10.1016/j.bspc.2023.104836)*

CPET INTERPRETER

OXYNET

The assignment consists of the analysis of a cardiopulmonary exercising test.

In particular the data to be analyzed referred to a test registered with the wearable metabolic system COSMED K5, and exported as an Excel by the software OMNIA, associated to the system. The maximal incremental exercise testing is commonly used to determine peak and submaximal physiological and metabolic variables and parameters. Oxygen consumption is usually reported as milliliters of oxygen and possibly converted in kcal or Joule as follows:

1 L O2 ≃ 5 Kcal

1 L O2 ≃ 21 KJ

The same test will be provided in five different version; only one is the correct one that the web app is capable of adequately process.

The system requires a prior calibration related to flow (to compute ventilation), ambient air (usually close to 20.9%, to set the Fraction of Inspired Oxygen: FiO2), and a reference gas calibration (to set the readings with a gas of a known composition). Data required for the inference include oxygen uptake (VO2), exhaled CO2 (VCO2), minute ventilation (VE), end tidal O2 (PetO2) and CO2(PetCO2), and ventilatory equivalents (VEVO2 and VEVCO2).

Ventilation (VE) is the product of Respiratory frequency (Rf) × Tidal Volume (VT).

The total score is 10.

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