**Altitude training and practical solutions.**

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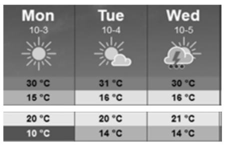
**CAR Sierra Nevada. CSD. Oct 2016.**

*La Alcazaba 3371 m*

*Mulhacen 3479 m*

## Environmental conditions

- ⇓ Atm P. = Hypoxia:
  - SL -Pat 760 mmHg -PiO2 159 mmHg -$SaO_2$ 97-99%
  - 3000m -Pat 523 mmHg -PiO2 100 mmHg -$SaO_2$ 90%
- Temperature:
  - ⇓ 0.5°- 1°C / 100 m
  - Humidity, latitude, wind ...



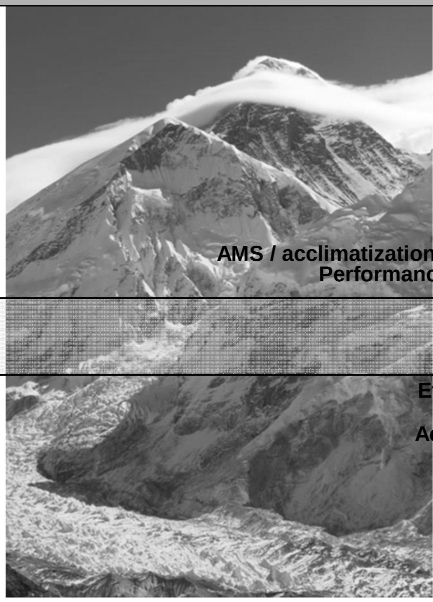

- Low humidity – dehydration.
- Increased radiation.
- Less gravidity and air density.

# Altitude levels

TABLE 1. DEFINITION OF ALTITUDE PROPOSED BY P. BÄRTSCH AND B. SALTIN (2008)

| *Definition* | *Altitude, meters above sea level* |
| --- | --- |
| Near sea level | 0–500 |
| Low altitude | 500–2000 |
| Moderate altitude | 2000–3000 |
| High altitude | 3000–5000 |
| Extreme altitude | Above 5000 |

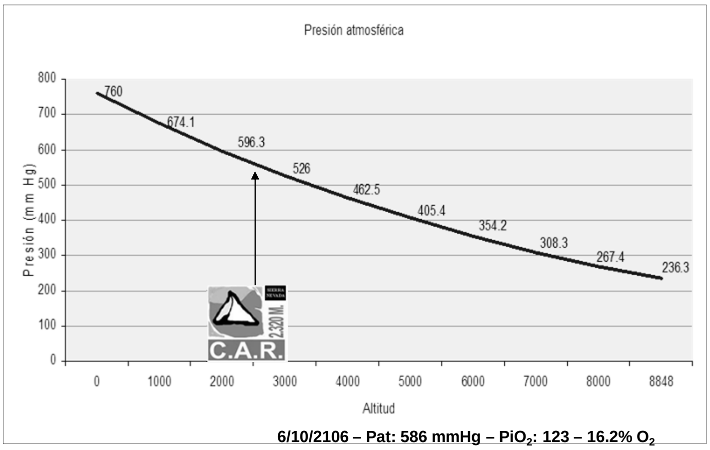
# Altitude levels



| Altitude | Effects |
|---|---|
| **8848 m** | **life impossible?.** |
| **Extreme altitude** | **Permanent life Impossible?.** |
| **5500 m** | |
| **High altitude** | **Rest effects. AMS / acclimatization become clinically relevant. Performance is considerably impaired.** |
| **3000 m – 2000 m** | ***Training area*** |
| **Moderate altitude** | **Effects on aerobic exercise. AMS starts. Acclimatization is important.** |
| **1000 m** | |
| **Low altitude 500-2000** | **Minor impairment in aerobic performance.** |

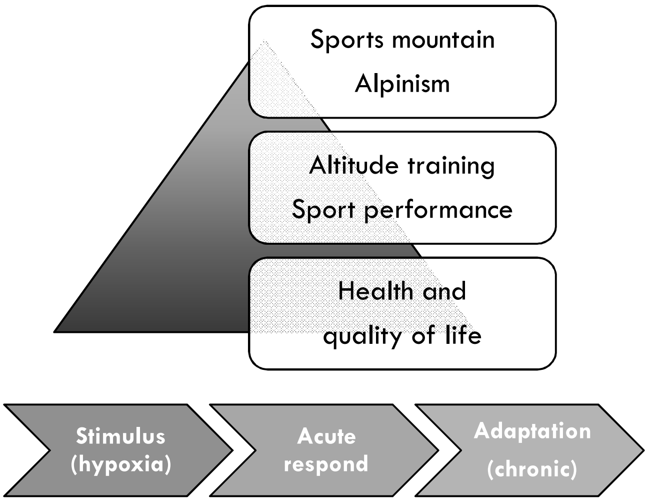
# Altitude

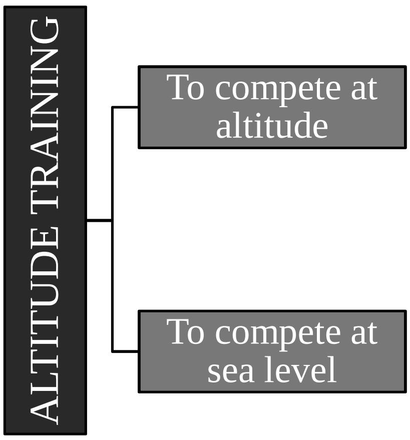
**HYPOXIA**




**6/10/2106 – Pat: 586 mmHg – $PiO_2$: 123 – 16.2% $O_2$**

# WHY ALTITUDE?




- **Controversial results….**

Table 3 Effects of hypoxic training on sea level endurance performance

| Hypoxic stimulus | Altitude (m) | Exposure time (days) | Time tested after altitude (days) | Submaximal improvement | Change in $\dot{V}O_2$ MAX (%) | Control group |
|---|---|---|---|---|---|---|
| *Potentiating effects* | | | | | | |
| CH[42] | 1300–2500 | 28 | 1 | Yes† | +4† | No |
| CH[43] | 1900 | 21 | 1/14 | Yes† | NS/NS | No |
| CH[44] | 2100–2700 | 14 | 2 | Yes† | NS | No |
| CH[45] | 2300 | 23 | 3/21 | Yes† | +8†/+10† | No |
| CH[46] | 2500 | 28 | 7 | ND | +6† | No |
| IH[47] | 3049–4268 | 23 | 3–4 | Yes† | NS | No |
| CH[48] | 3800 | 35 | 14 | ND | +14† | No |
| IH[49] | 4020 | 21/28 | 1 | Yes† | +8‡/+26‡ | No |
| CH[50] | 1250–2500 | 28 | 7 | Yes† | +4† | Yes |
| IH[51] | 2300 | 21–28 | 1 | Yes† | NS | Yes |
| IH[52] | 2300 | 28 | 1–2 | Yes† | ND | Yes |
| IH[53] | 4000 | 70 | 1 | Yes† | NS | Yes |
| *No potentiating effects* | | | | | | |
| CH[45] | 2300 | 14 | 1 | No | NS | No |
| CH[54] | 1695–2700 | 7 | 4 | ND | NS | No |
| CH[55] | 2240 | 20 | 4/22 | ND | +6/+9* | No |
| CH[56] | 2300 | 42 | 4–5 | No | NS | No |
| CH[57] | 2300 | 70 | 5 | ND | NS | No |
| CH[58] | 2800 | 10 | 2–4 | No | +7* | No |
| CH[59] | 3090 | 17 | 1 | ND | NS | No |
| CH[60] | 3110 | 21 | 7 | ND | −5* | No |
| CH[61] | 4000 | 48–63 | 2–15 | No | NS | No |
| IH[62] | 4000 | 21 | 1 | ND | NS | No |
| CH[38] | 2000 | 14 | 6/12 | ND | NS/NS | Yes |
| CH[63] | 1600–1800 | 18–28 | 7 | ND | NS | Yes |
| CH[64] | 1640 | 28 | 20 | No | NS | Yes |
| CH[65] | 1700–2000 | 28 | 7 | No | NS | Yes |
| CH[66] | 2300 | 21 | 1 | No | NS | Yes |
| IH[67] | 2250 | 28 | 1 | ND | +17.5* | Yes |
| IH[67] | 3450 | 28 | 1 | ND | +10.0* | Yes |
| IH[68] | 2500 | 28 | 1 | No | NS | Yes |
| IH[69] | 2500 | 35 | 1 | ND | NS | Yes |
| CH[70] | 2600 | 11 | 1 | ND | NS | Yes |
| IH[71] | 3100 | 19 | 6 | No | NS | Yes |
| IH[72] | 3345 | 42 | 1 | ND | NS | Yes |
| IH[73] | 4020 | 15 | 1 | ND | NS | Yes |
| IH[74] | 4100–5700 | 21 | 1 | ND | NS | Yes |
| CH[75] | 4300 | 28 | 1–5 | ND | NS | Yes |

CH, Chronic hypobaria; IH, intermittent hypobaria; ND, no data.
* Level of significance not reported .
† Significantly different from pre-altitude value ($P<0.05$).
‡ Significantly different from pre-altitude value ($P<0.01$).
NS, not significantly different from pre-altitude value ($P>0.05$).

*Bailey DM and , Davies B.*
*BJSM 1997.*

- **Controversial results….**

**Table I.** Characteristics of study groups included in the meta-analysis sorted by protocol and first author

| Study | Subjects | Sample size[a] | Design | Competitive level | Training phase | Hypoxic (h/d)[b] | Exposure/ intervention days[c] | Altitude level (m)[d] | Hypoxia device |
|---|---|---|---|---|---|---|---|---|---|
| **Live-high train-high** | | | | | | | | | |
| Bailey et al.[29] | Runners | 8M, 2F; 14M, 5F | C | Elite | ? | 24 | 28 | 1640 | |
| | Runners | 9M, 5F; 6M, 3F | C | Elite | ? | 24 | 28 | 1750 | |
| Burtscher et al.[30] | Runners | 10M; 12M | C | Subelite | ? | 24 | 12 | 2315 | |
| Friedmann et al.[31] | Boxers +Fe[e] | 9M | U | Subelite | Off-season | 24 | 18 | 1800 | |
| | Boxers −Fe[e] | 7M | U | Subelite | Off-season | 24 | 18 | 1800 | |
| Gore et al.[32] | Cyclists | 8M | U | Elite | ? | 24 | 31 | 2690 | |
| Ingjer and Myhre[33] | Skiers | 7M; 7M | U | Elite | Competitive | 24 | 21 | 1900 | |
| Jensen et al.[34] | Rowers | 9M; 9M | C | Elite | Competitive | 24 | 21 | 1822 | |
| Levine and Stray-Gundersen[35] | Runners | 10? | U | Subelite | ? | 24 | 28 | 1200 | |
| | Runners | 9? | U | Subelite | ? | 24 | 28 | 2500 | |
| Levine and Stray-Gundersen[2] | Runners | 9M, 4F; 9M, 4F | C | Subelite | Competitive | 24 | 28 | 2500 | |
| Miyashita et al.[36] | Swimmers | 12M, 8F | U | Elite | Competitive | 24 | 21 | 2300 | |
| Pyne[37] | Swimmers | 14M, 8F | U | Elite | Competitive | 24 | 21 | 2102 | |
| Rusko et al.[38] | Skiers | 14M; 7M | C | Elite | ? | 24 | 22 | 1700 | |
| Saunders et al.[39] | Runners | 10M; 13M | C | Elite | ? | 24 | 20 | 1750 | |
| Svedenhag and Saltin[40] | Runners | 5M; 4M, 2F | C | Elite | ? | 24 | 14 | 2000 | |
| Svedenhag et al.[41] | Skiers | 5M, 2F | U | Elite | ? | 24 | 30 | 1900 | |
| **Live-high train-low** | | | | | | | | | |
| Dehnert et al.[42] | Triathletes | 6?; 10? | C | Subelite | ? | ~18–24 | 13 | 1956/800 | |
| Levine and Stray-Gundersen[2] | Runners | 9M, 4F; 9M, 4F | C | Subelite | Competitive | ~18–24 | 28 | 2500/1200 | |
| Stray-Gundersen and Levine[43] | Runners | 6? | U | Subelite | ? | ~18–24 | 28 | 2500/1200 | |
| Stray-Gundersen et al.[8] | Runners | 8F, 14M | U | Elite | Competitive | ~18–24 | 27 | 2500/1200 | |
| Wehrlin et al.[44] | Orienteers | 5M, 5F | U | Elite | Pre-season | ~18–24 | 24 | 2456/1000 | |
| Witkowski et al.[45] | Runners | 8M, 4F | U | Subelite | ? | ~18–24 | 28 | 1780/1250 | |
| | Runners | 8M, 4F | U | Subelite | ? | ~18–24 | 28 | 2085/1250 | |
| | Runners | 8M, 4F | U | Subelite | ? | ~18–24 | 28 | 2454/1250 | |
| | Runners | 8M, 4F | U | Subelite | ? | ~18–24 | 28 | 2805/1250 | |

*Bonetti DL and Hopkins WG.*
*Sports Med 2009.*

- **Controversial results….**

| Effect | Natural altitude protocols | | Artificial altitude protocols |
|---|---|---|---|
| | live-high train-high | live-high train-low | live-high 8–18 h/d, continuous, train-low |
| **Effect of mean protocol[a] (%); ±90% CL[b]** | | | |
| Elite | (1.6; ±2.7) | **4.0; ±3.7** | (0.6; ±2.0) |
| Subelite | (0.9; ±3.4) | **4.2; ±2.9** | **1.4; ±2.0** |
| **Effect of enhanced protocol[c] (%); ±90% CL** | | | |
| Elite | **5.2; ±4.1** | **4.3; ±4.1** | (4.0; ±5.5) |
| Subelite | **4.5; ±4.1** | **4.6; ±3.3** | **4.8; ±5.3** |

*Bonetti DL and Hopkins WG.*
*Sports Med 2009.*

# ALTITUDE TRAINING

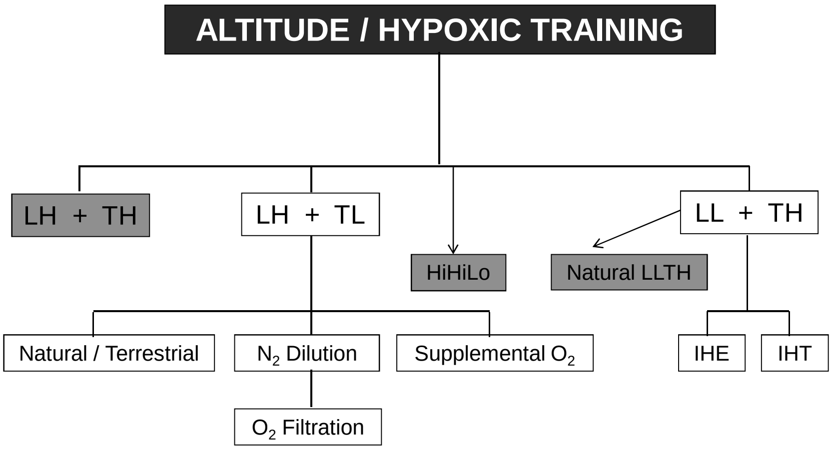
"Elite athletes have used altitude/hypoxic training for several years. Although the efficacy of altitude/ hypoxic training relative to sea-level performance remains controversial from a research perspective, athletes continue to use it in preparation for elite level competition".

***WILBER, R. L. Application of Altitude/Hypoxic Training by Elite Athletes. Med. Sci. Sports Exerc., Vol. 39, No. 9, pp. 1610–1624, 2007***

"….Enhancing protocols by appropriate manipulation of study characteristics produced clear effects with all protocols (3.5–6.8%) in subelite athletes, but only with LHTH (5.2%) and LHTL (4.3%) in elite athletes.

*BONETTI DL, Hopkins WG. Sea-level exercise performance following adaptation to hypoxia: a meta-analysis. Sports Med. 2009;39(2):107-27.*

**Some clues**




Wilber RL. Application of altitude/hypoxic training by elite athletes.
Med Sci Sports Exerc 2007 Sep; 39 (9): 1610-24

# Altitude training

- 1- Altitude / Hypoxia clearly affects human body
- 2- Hypoxia + Exercise = more hypoxia.
- 3- The stimulus of hypoxia associated with the training stimulus seemed to induce:

  a) erythropoietic changes: EPO, RBC, Hb mass….

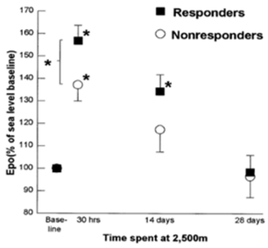
  b) non-erythropoietic changes:
  - Ventilatory acclimatization (decreased cost of ventilation)
  - Glucose metabolism
  - Improved mitochondrial efficiency
  - pH regulation and buffer capacity
  - Improvements in tolerance and kinetics of lactate
  - Angiogenesis
  - Stress adaptgenesis
  - Mechanical efficiency

(GORE, C. J., S. A. CLARK, and P. U. SAUNDERS. Nonhematological Mechanisms of Improved Sea-Level Performance after Hypoxic Exposure. Med. Sci. Sports Exerc., Vol. 39, No. 9, pp. 1600–1609, 2007).

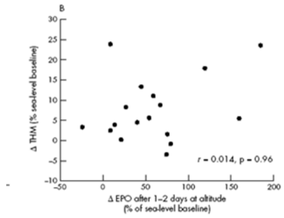
# Altitude training

- 4- Great individual variability.
- 5- Genetic factors:
  - -Altitude natives.
  - -Individual gene polymorphism.
  - -KEY POINT: hypoxia inducible factors (HIF).

¿responders or not responders?




*"Individual variation in response to altitude training"* Champman et al. J Appl Physiol 1998; 85(4):1448.




*"Individual variation in the erythropoietic response to altitude trraining in elite junior swimmers" Friedman, et al Br. J. Sports Med 2005; 39; 148-153.*

# ALTITUDE TRAINING

**Where?**

**When?**

**How?**

**How long?**

**Any risk?**

Med Sci Sports Exerc. 2007 Sep;39(9):1590-9.
**Effect of hypoxic "dose" on physiological responses and sea-level performance.**
Wilber RL[1], Stray-Gundersen J, Levine BD.

J Appl Physiol (1985). 2014 Mar 15;116(6):595-603. doi: 10.1152/japplphysiol.00634.2013. Epub 2013 Oct 24.
**Defining the "dose" of altitude training: how high to live for optimal sea level performance enhancement.**
Chapman RF[1], Karlsen T, Resaland GK, Ge RL, Harber MP, Witkowski S, Stray-Gundersen J, Levine BD.

Eur J Appl Physiol. 2013 May;113(5):1199-211. doi: 10.1007/s00421-012-2536-0. Epub 2012 Nov 9.
**The effects of classic altitude training on hemoglobin mass in swimmers.**
Wachsmuth NB[1], Völzke C, Prommer N, Schmidt-Trucksäss A, Frese F, Spahl O, Eastwood A, Stray-Gundersen J, Schmidt W.

Sports Med. 2009;39(2):107-27. doi: 10.2165/00007256-200939020-00002.
**Sea-level exercise performance following adaptation to hypoxia: a meta-analysis.**
Bonetti DL[1], Hopkins WG.

Scand J Med Sci Sports. 2012 Feb;22(1):95-103. doi: 10.1111/j.1600-0838.2010.01145.x. Epub 2010 Jun 18.
**Time course of the hemoglobin mass response to natural altitude training in elite endurance cyclists.**
Garvican L[1], Martin D, Quod M, Stephens B, Sassi A, Gore C.

Med Sci Sports Exerc. 2015 Sep;47(9):1965-78. doi: 10.1249/MSS.0000000000000626.
**Altitude Training in Elite Swimmers for Sea Level Performance (Altitude Project).**
Rodríguez FA[1], Iglesias X, Feriche B, Calderón-Soto C, Chaverri D, Wachsmuth NB, Schmidt W, Levine BD.

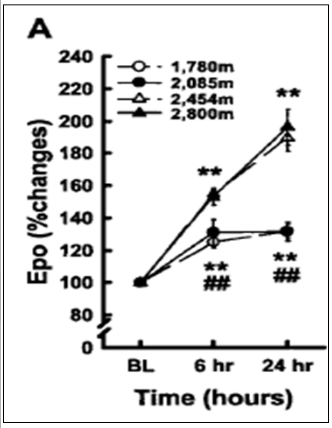
# Altitude training. Some clues

- **What is the optimal altitude?**
  - 2000 m - 2500 m
- **How long?**
  - 2 - 4 weeks
  - for > 22 hours/day or > 300 h
- **Is simulated altitude as effective as natural altitude?**

There is evidence that N2 dilution and O2 filtration are effective if provided the "hypoxic dose" is attained. It appears that fewer hours of hypoxic exposure (12-16 hr), but at a higher simulated elevation (2500 - 3000 m) is required to achieve similar erythropoietic effects vs. natural/terrestrial altitude (> 22 hr/d).
*(Wilber 2007)*

# The altitude-induced increase in EPO is “dose” dependent

Altitude




Days

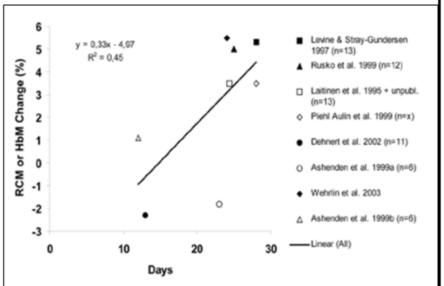



**Fig. 3.** Percentage changes (%) in the mean total red cell volume (RCM) or haemoglobin (HbM) mass during HiLo in relation to the number of days of the HiLo period.

*“Determinants of EPo release in response to short-term hypobaric hypoxia”*
*Ri-Li Ge et al, JAP 2002*

*“Altitude and endurance training”*
*Rusko et al., JSS 2004*

# When come back?

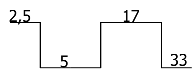
J Appl Physiol (1985). 2014 Apr 1;116(7):837-43. doi: 10.1152/japplphysiol.00663.2013. Epub 2013 Dec 12.
**Timing of return from altitude training for optimal sea level performance.**
Chapman RF[1], Laymon Stickford AS, Lundby C, Levine BD.

Table 1. *Recommendations of top coaches and applied sport scientists on when to compete after return from altitude training*

| Authors (Reference) | Recommended best time to compete after return from altitude training | Recommended times to avoid competition after return from altitude training |
|---|---|---|
| Bueno (9) | *Day 17* “prime date for best performances” | |
| Dick (20) | After *Day 15* | |
| IAAF technical publication (6) | After *Days 12–14* | |
| Mann (personal communication) | Within the first 48 h; after 10 days | *Days 3–9* |
| Popov (37) | *Days 18–21* “80% of best performances” | |
| Suslov (47) | *Days 3–7; Days 14–25* | *Days 8–13* |

± 2 weeks

Sports Med. 2009;39(2):107-27. doi: 10.2165/00007256-200939020-00002.
**Sea-level exercise performance following adaptation to hypoxia: a meta-analysis.**
Bonetti DL[1], Hopkins WG.



# When come back?

- Performance

……..A change in Hb-mass by 1 % changed performance by 1.8 points. Participation at an ATC tended to decrease performance by 11 points until 14 days after return, had no effect the following 10 days, and significantly improved performance by 23 points 25–35 days after return. Illness reduced swimming performance by 25 points and injury by 16 points.

*(Wachsmuth et al, EJAP 2013)*

Eur J Appl Physiol

**Table 4** Factors influencing competition performance

| Factor/covariate | Competitions (count) | Significance $p\leq$ | Effect (points) | CL (95 %) |
|---|---|---|---|---|
| Altitude influence | | 0.014 | | |
| No altitude influence | 759 | | 0 | 0 |
| 0–14 days after return | 80 | (0.06) | −11 | −21/0 |
| 15–24 days after return | 38 | (0.52) | −4 | −17/8 |
| 25–35 days after return | 17 | 0.016 | +23 | 4/42 |
| Health status | | 0.003 | | |
| No problems | 829 | | 0 | 0 |
| Injured | 37 | 0.020 | −16 | −30/−3 |
| Sick | 28 | 0.011 | −25 | −44/−6 |
| ΔHb-mass | | | | |
| 1 % of Hb-mass | 894 | 0.001 | 1.8 | 0.8/2.8 |

Presented are the results of an analysis of covariance for 726 competitions performed by 39 athletes. The effect on performance is expressed as difference in points from the mean of all individual competition results (world record at recent Olympic games = 1,000). A change of e.g. 42 points corresponds to a difference in swimming time by 0.65 s (2.7 %) for 100 m freestyle (men). Injured and sick indicate appropriate problems within 2 weeks before the competition lasting for at least one week. ΔHb-mass indicates the influence of a 1 % change of the individual Hb-mass on performance. $CL$ = 95 % confidence limits. The factor sex and the covariate age had no influence on performance and are not demonstrated here

± 3 weeks

# When come back?

The recommendation of when to compete after completing an altitude training sojourn may ultimately be dependent on the individual responses to altitude training and acclimatization, altitude deacclimatization, as well as the training response that occurs within the first several days postaltitude.

……Future research should simultaneously explore in detail the time course of the changes in red blood cell mass, ventilatory acclimatization, biomechanical and/or neuromuscular factors, and performance in elite endurance athletes after return to sea level. We believe the interaction between these variables will strongly influence the ideal time to compete after altitude training. Each athlete may display his or her own signature of deacclimatization with sea level residence, and knowledge of personal decay rates may allow for individualized prescriptions of when best to complete postaltitude camp.

*(Chapman RF et al, JAP 2014)*

Consider:

- Post altitude training.
- Combining other hypoxic methods.
- Other factor (travel, nutrition, temperature….)

# How to train?

## Altitude/Hypoxic Training Phases

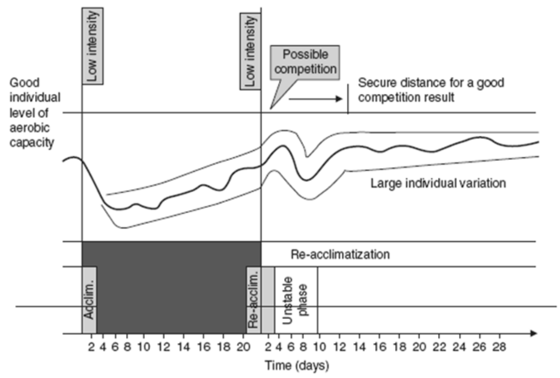



Fig. 2. Schematic view of the development of the aerobic capacity during and after 'live-high train-high' (LHTH) training (adapted from Fuchs and Reiss[3]). Acclim. = acclimatization.

# But ……..altitude is much more

- **Other objectives:**
  - To increase sports training capacity.
  - Socialization / Team Building / Psychological aspects.
  - Training environment (mild temperature, clear air…).
  - To recover (train while resting) – “The resting value”.
  - To obtain a record.
  - To mask or disguise the use of exogenous EPO.
  - Alternative to doping.
  - To imitate champions.
- **Other strategies:**
  - Short stages more frequent.
  - Combine methods.
  - Strength training.
  - RSH or RST.
  - Altitude + heat.
  - Respiratory training
  - …….

## So …… altitude training should be planned

- **Depending on:**
  - Aim of the stage.
  - Moment of the season.
  - Net altitude.
  - Resources (technological, medial, sports facilities…)
  - Sport.
  - Age and sports experience.
  - Previous stages.
  - Health status, morphological and physiological characteristics……

## Risk of altitude training

- Environmental factors
- Overload
- Slower recovery
- Dehydration
- Nutritional deficits
- ....

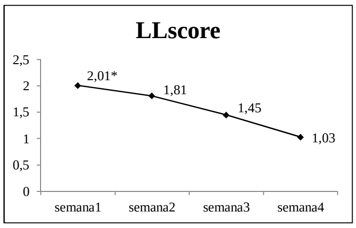
**Altitude patology**

**AMS**

**Lower performance**
**Risk of accidents and sickness**
**Weight lost**
**De-training**
**Overtraining**
**Biomechanical aspects**

## AMS

| | % subjects |
|---|---|
| LL1 - headache | 89.65 |
| LL2 - GI symptoms | 72.41 |
| LL3 - fatigue / weakness | 93.10 |
| LL4 - dizziness | 68.96 |
| LL5 - difficulty sleeping | 82.76 |
| **LL score** | 100 |




## Clinical symptons in altitude training

| Periodo altura (3 sem.) | Hi | | Lo | | Total | | p |
|---|---|---|---|---|---|---|---|
| Síntomas | n | % | n | % | n | % | |
| Generales | 5 | 17,24 | 2 | 18,18 | 7 | 17,5 | 1 |
| Respiratorios | 10 | 34,48 | 3 | 27,27 | 13 | 32,5 | 1 |
| Digestivos | 5 | 17,24 | 2 | 18,18 | 7 | 17,5 | 1 |
| Cardiovasculares | 0 | 0 | 0 | 0 | 0 | 0 | - |
| Musculoesqueléticos | 8 | 27,59 | 0 | 0 | 8 | 20 | 0,08 |
| Alteraciones estado ánimo | 4 | 13,79 | 0 | 0 | 4 | 10 | 0,56 |

**Optimizing Altitude Training**

## Control training and loads assimilation

- Subjective parameters:
  - Fatigue, feeling, appetite, sleep pattern….
- Physiological/biological parameters
  - Weight lost
  - HR (rest, submaximal)
  - Analytical test: HB (Hb mass), leukos, CK, urea, etc
  - SaO2
  - HRV
  - VO2 - load
  - Lactate curve shift
  - RPE/lactate

*Training diary*

>

# Basic advice for coaches

1. AT should be introduced in the annual program as an special or additional stimulus.
2. AT should be individualized.
3. Long term approach- Cumulative effect.
4. Proper Planning:
   - 2-4 weeks
   - Adaptation phase
   - Quality workouts at low level
   - Take care after the descent
5. Progression:
   - Longer stages, more frequently, more volume and/or intensity
6. Control training load and assimilation.

# Basic advice for coaches

7. Health, hydration and nutrition (iron stores).
8. Recovery:
   - More sleep hours (9+1).
   - More recovery intra-microcycle.
   - Massage, Contrasts, Jacuzzi, sauna.
9. Combining methods:
   - Allows more quality workouts.
   - When it is not possible to train in altitude.
   - "Around" altitude training: Before /after.
10. Evaluation of results:
    - Analytics: Improvements in the red series.
    - Practice: how is training the athlete.
    - Final: performance improvement, competitions.

# Conclusions

- **Altitude training is still in force.**
- **HiHiLo is probably the best.**
- **To take care in altitude training:**
  - Proper planing
  - Good physical fitness and health
  - Medical and Physiological control
  - Nutrition and hydration
  - Physiotherapeutic treatments
- **Try new things without risks.**
- **Take advantage of new techniques.**
- **Team work – study – learn.**

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***Thanks***