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Swiss Olympic Medical Day 2025

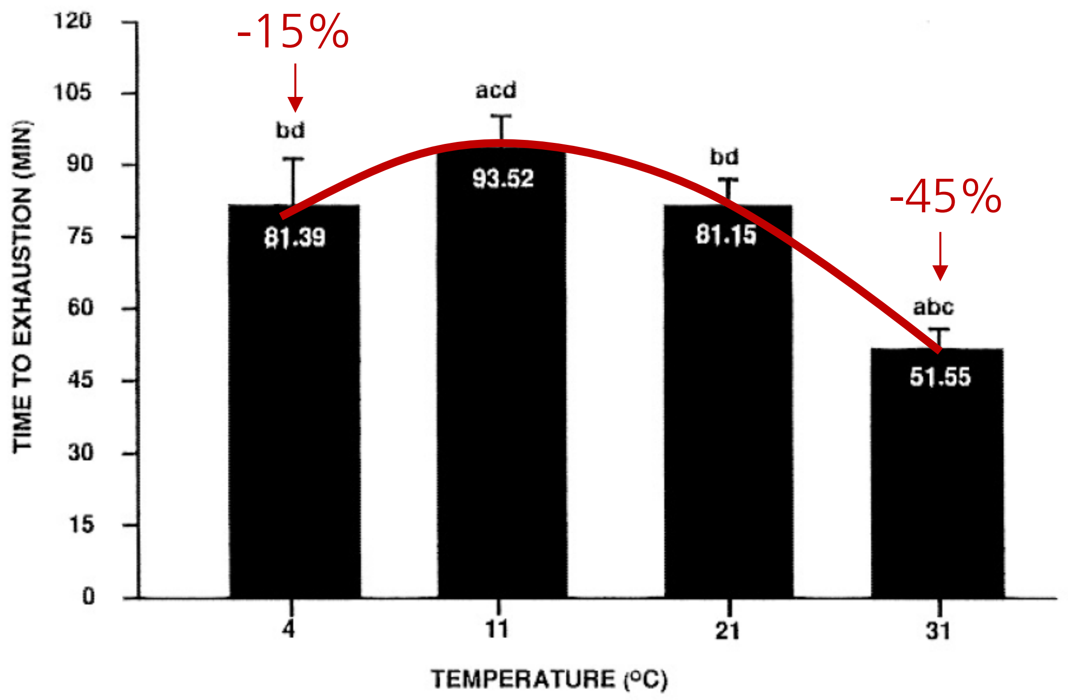
How do I adapt my training before competitions in extreme conditions?

Physiology of altitude, heat and cold. Acclimatisation and effects of training for competitions under normal conditions.

Thomas Steiner, PhD

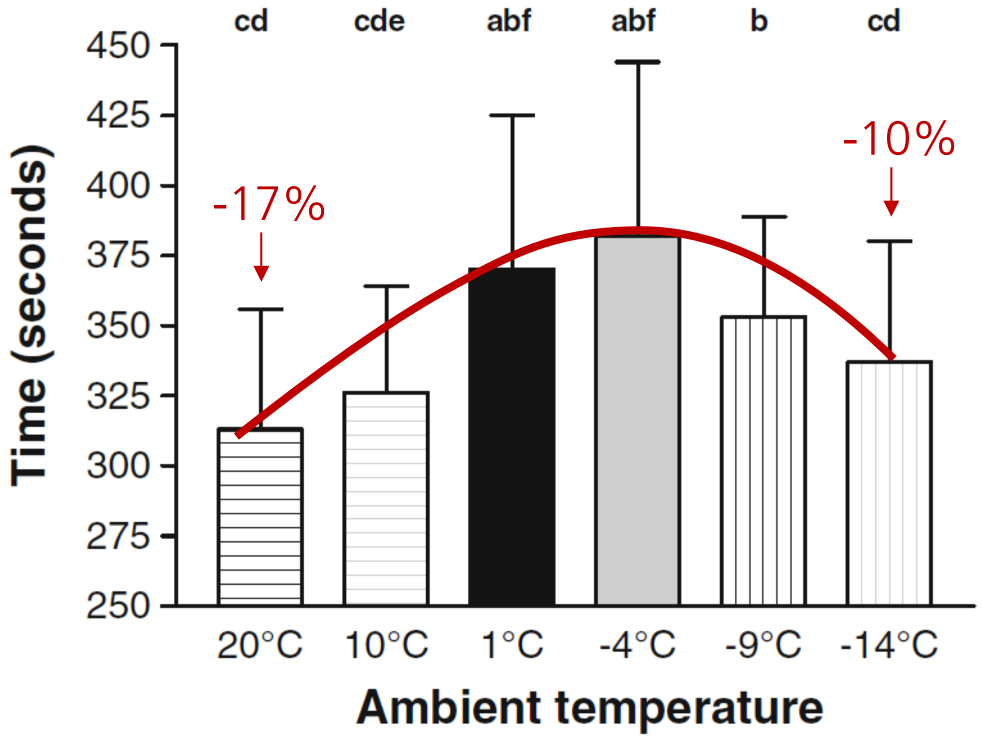
Temperature and exercise performance

Cycle ergometry
70% VO_2max until exhaustion
Clothing: Shorts and T-shirt



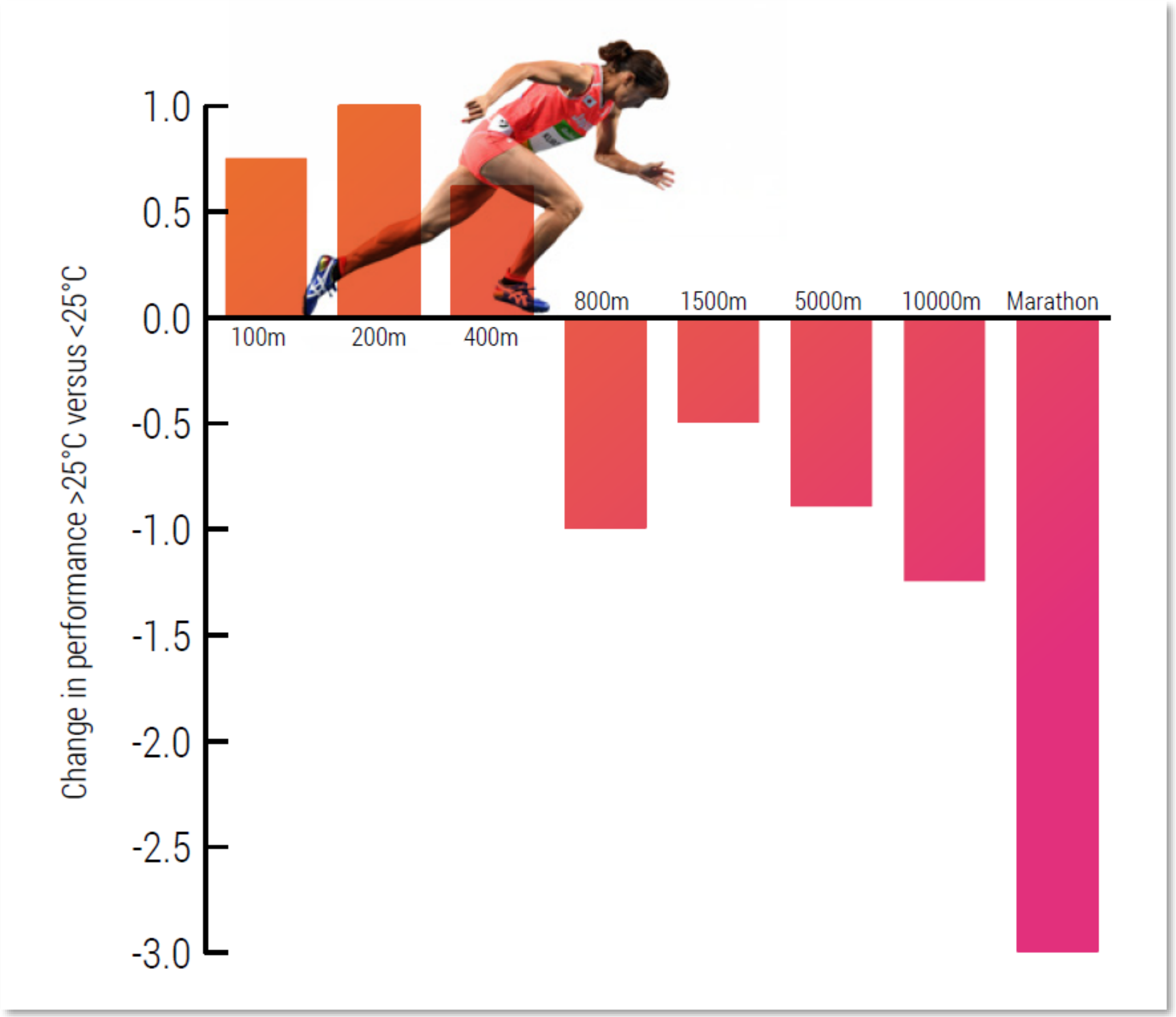
Galloway, S. D., & Maughan, R. J. (1997). Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. *Medicine and Science in Sports and Exercise, 29*(9), 1240-1249.

Treadmill
Submaximal ramp, then to exhaustion.
Clothing: Cross-country clothing (5.0 m/s wind)



Sandsund et al. (2012). Effect of ambient temperature on endurance performance while wearing cross-country skiing clothing. *European Journal of Applied Physiology, 112*(12), 3939-3947.

Temperature and exercise performance



Sprint performance: **Enhanced**
(better contractile functionality)

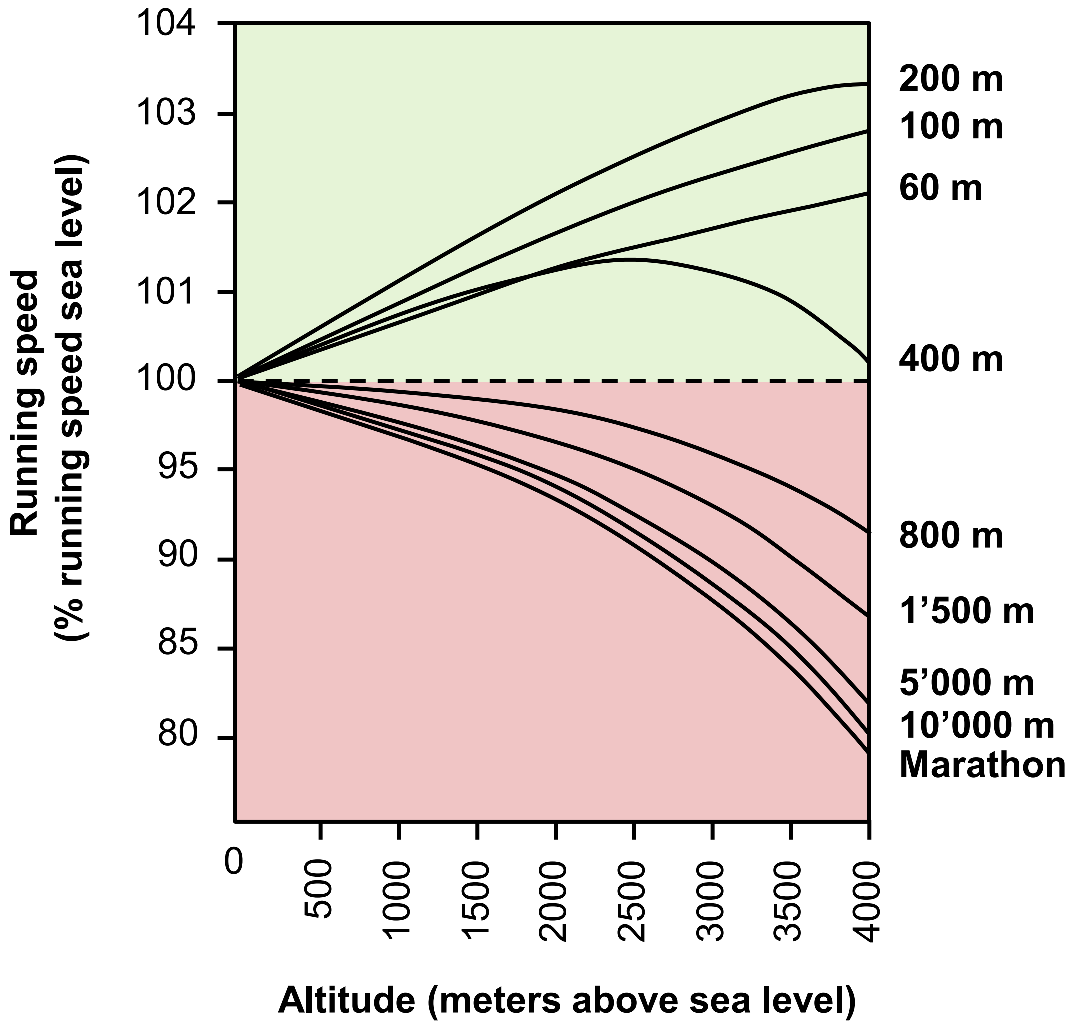
Endurance performance: **Impaired**

"Heat-induced performance decrements can range from **6 to 16% in trained athletes** during endurance and team sport events, …"

Racinais S, Périard JD, Alonso JM, Adami PE, Bermon S. (2018). Beat the heat during the IAAF World Athletics Championships Doha 2019 and the Tokyo 2020 Olympics.

Casadio, J. R., Kilding, A. E., Cotter, J. D., & Laursen, P. B. (2017). From lab to real world: heat acclimation considerations for elite athletes. *Sports Medicine*, *47*(8), 1467-1476.

Altitude and exercise performance



Air density ↓

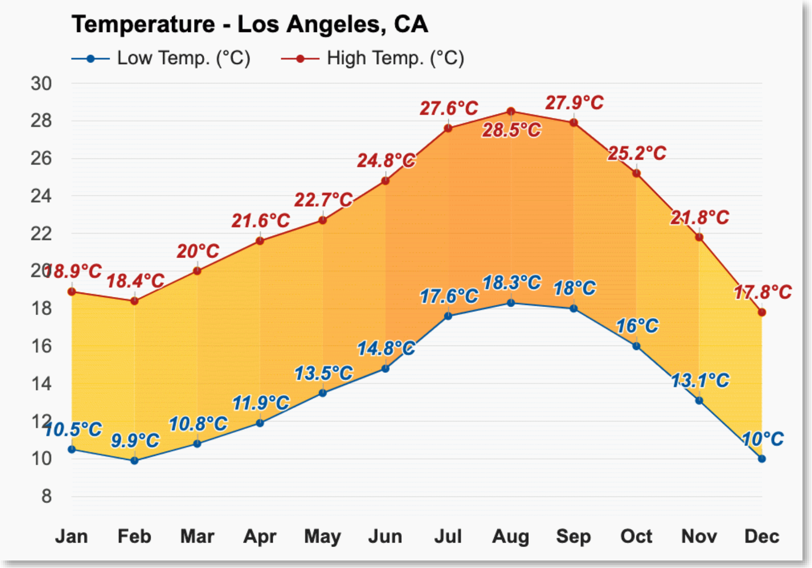
Redrawn from: Wilber, R. (2004). *Altitude Training and Athletic Performance*. Human Kinetics.

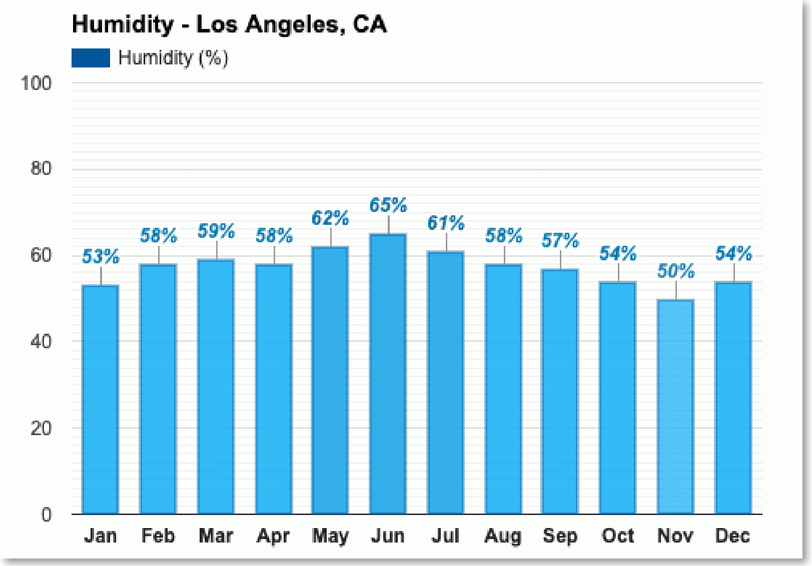
Future major sporting events and extreme conditions

Event	Year	Altitude	Heat	Cold
Summer Olympic Games Los Angeles	2028			
Summer Olympic Games Brisbane	2032			
Summer Olympic Games Qatar?	2036			
Winter Olympic Games Milano-Cortina	2026	Biathlon (Antholz,1600 M.ü.M)		
Winter Olympic Games French Alps	2030	Langlauf (La Clusaz, 1600 M.ü.M)		
Winter Olympic Games Salt Lake City	2034	LL und Biathlon (Soldier Hollow, 1700 M.ü.M)		
FIFA World Cup Canada, USA, Mexico	2026	Mexico City (2300 M.ü.M, Guadalajara 1600 M.ü.M)	Monterrey, Miami, Kansas	
FIFA World Cup Marocco, Portugal, Spain	2030			
FIFA World Cup Saudi Arabia	2034		?	

Acclimatisation imperative / Acclimatisation highly recommended / Acclimatisation recommended

Games of the XXIIIrd Olympiad Los Angeles 1984





Beating The Odds To Reach The Finish | Gabriela Andersen-Schiess' Historic Marathon Race | Eurosport (youtube.com)

FIFA World Cup 2026 Canada, USA and Mexico

Altitude and acclimatisation to moderate altitude

Reduced performance at altitude - why?

2500 masl

$P_IO_2 = 750\ \text{mbar} \times 0.21 \approx 158\ \text{mbar}$

Lower Oxygen
$P_IO_2 \downarrow$

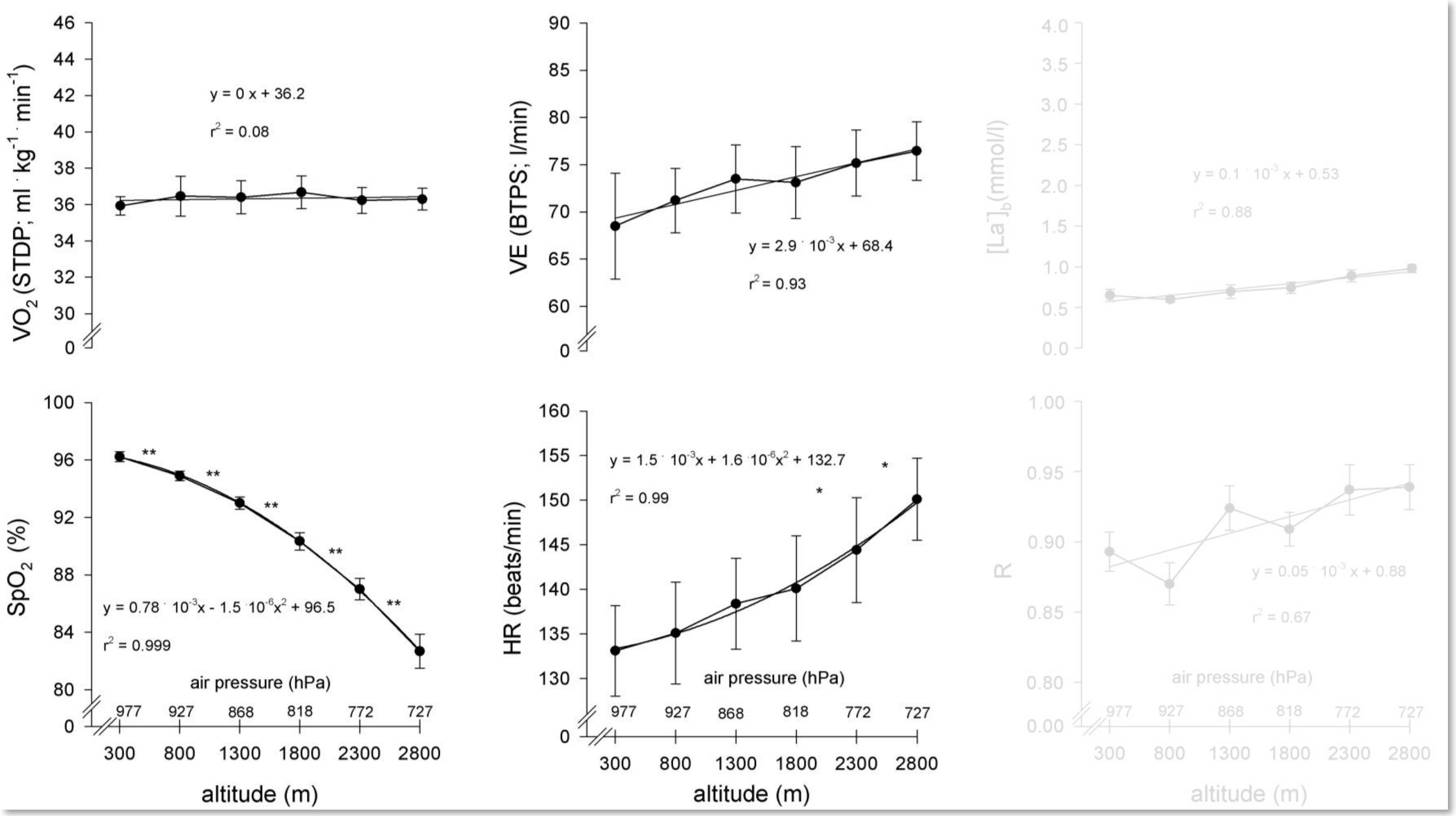
Sea level

$P_IO_2 = 1013\ \text{mbar} \times 0.21 \approx 213\ \text{mbar}$

A decrease in oxygen partial pressure (smaller amount of O_2 molecules in the same volume of air) leads to a decrease in arterial oxygen partial pressure. This is a measure of how much oxygen is available to the tissue after the oxygen has diffused from the alveoli into the bloodstream.

Acute reaction to exercise at altitude

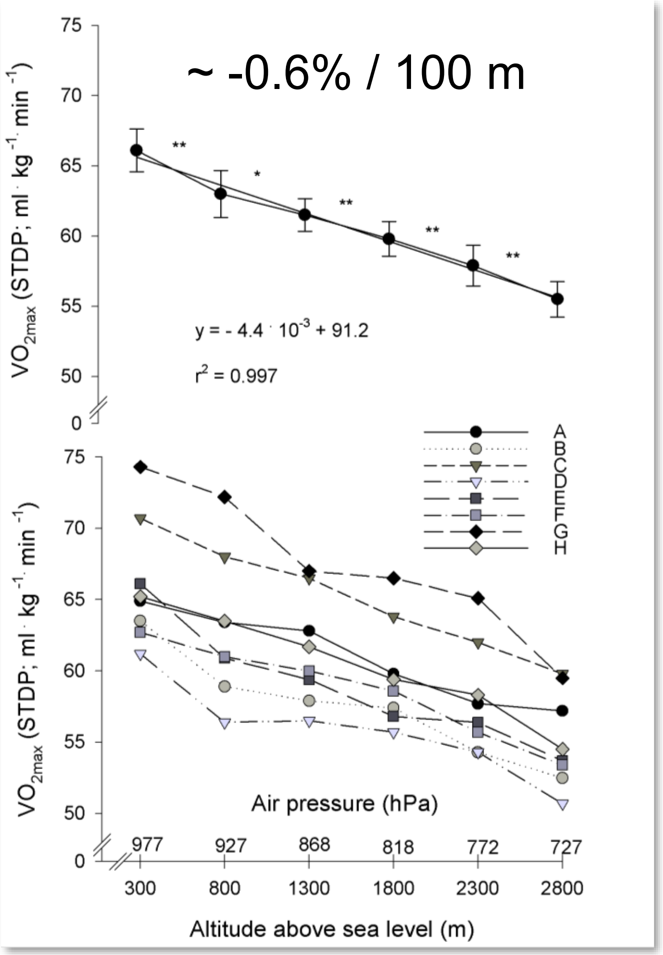
Submaximal exercise approx. 50% of endurance performance capacity

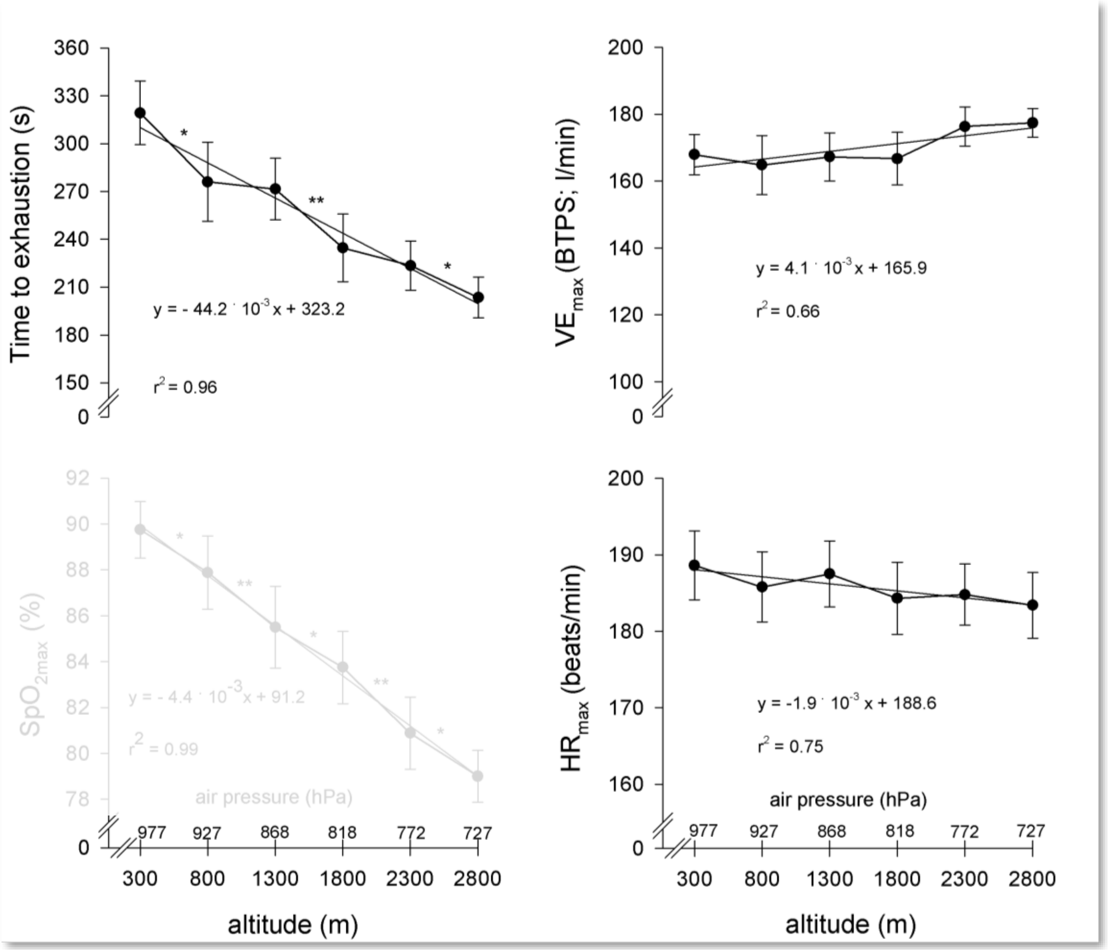


Wehrlin J., Hallén J. (2006). Linear decrease in VO_{2max} and performance with increasing altitude in endurance athletes. *Eur J Appl Physiol.; 96*(4):404-412

Acute reaction to exercise at altitude

Maximal performance capacity





Wehrlin J., Hallén J. (2006). Linear decrease in VO_{2max} and performance with increasing altitude in endurance athletes. *Eur J Appl Physiol.; 96*(4):404-412

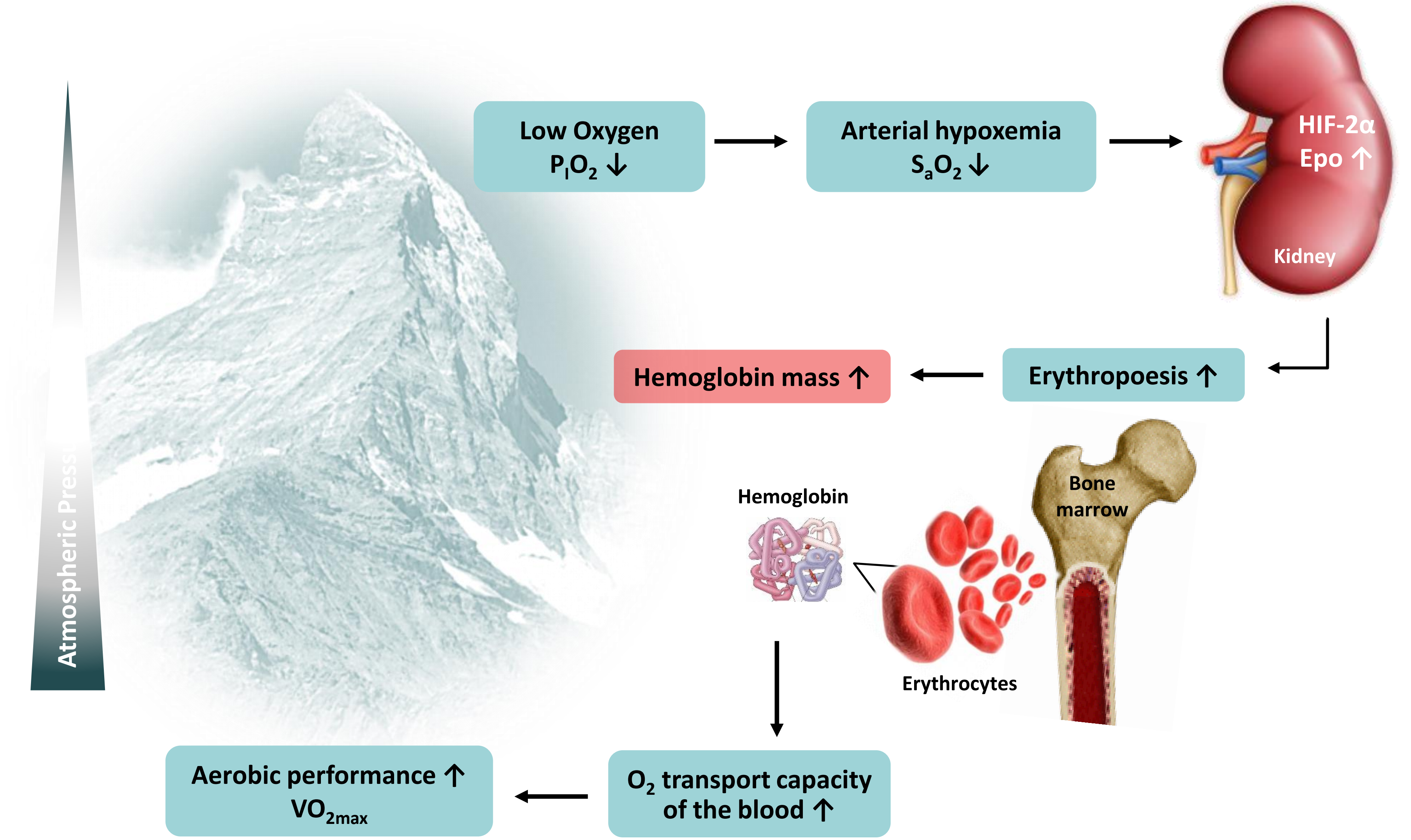
Specific effects in team sports (e.g. football)

- Reduction in aerobic performance at altitude
- Reduction in anaerobic performance (repeated sprints)
- Deterioration in movement (playing) technique due to changed aerodynamic conditions (neuromuscular adaptations).
- Due to lower air resistance, the ball flies further and has less rotation.

Similarly, a ball that carries about 30 m through the air at sea level will carry about 2.95 m further at 1000 m, 5.9 m further at 2000 m and 8.9 m further at 3000 m. On a play by play basis, it becomes harder to judge exactly where the ball will go. This makes it

Levine, B. D., Stray-Gundersen, J., & Mehta, R. D. (2008). Effect of altitude on football performance. *Scandinavian Journal of Medicine & Science in Sports*, *18*, 76-84.

Altitude training – what is the goal?



Levine & Stray-Gundersen, 2005

Preparing for competitions at altitude

1. Directly (1 day) from sea level to the competition at altitude (only possible if 1 competition)

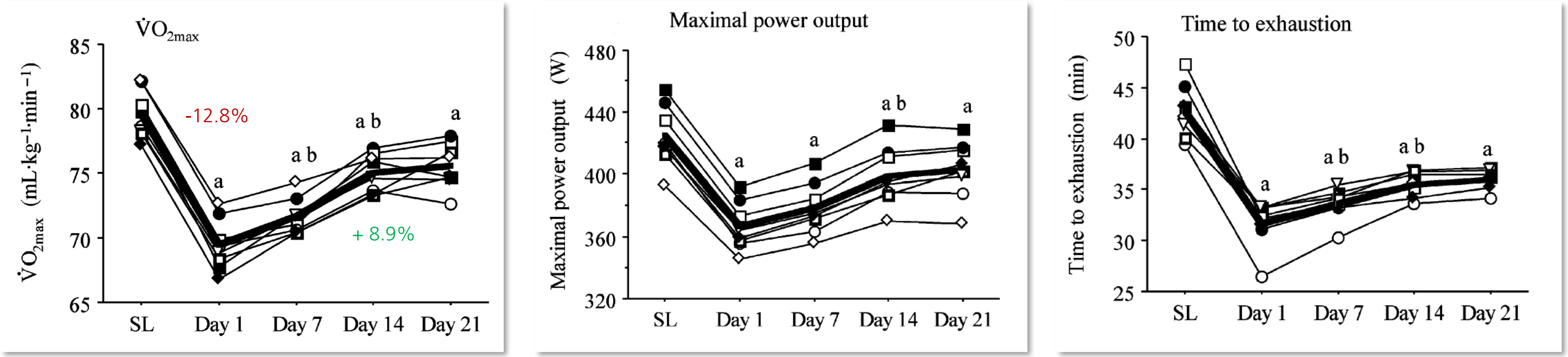
2. Acclimatisation to the target altitude (at least 10 days, preferably 14 days) → Stay at the target altitude, if necessary single trainings at a lower altitude

3. Acclimatisation combined with altitude training camp (at least 3, preferably 4 weeks) → Altitude of residence 2500 m (effect on haemoglobin mass); training at target altitude (with single intensive sessions at lower altitudes)

→ In team sports (e.g. football), do not neglect the technical aspect due to changes in the characteristics of the equipment.

→ **NO GO in endurance sports:** Too short (2-7 days) acclimatisation to the target altitude! Otherwise, it is better to go directly to the competition.

Consequences of acclimatisation effects on endurance performance at 2340 m

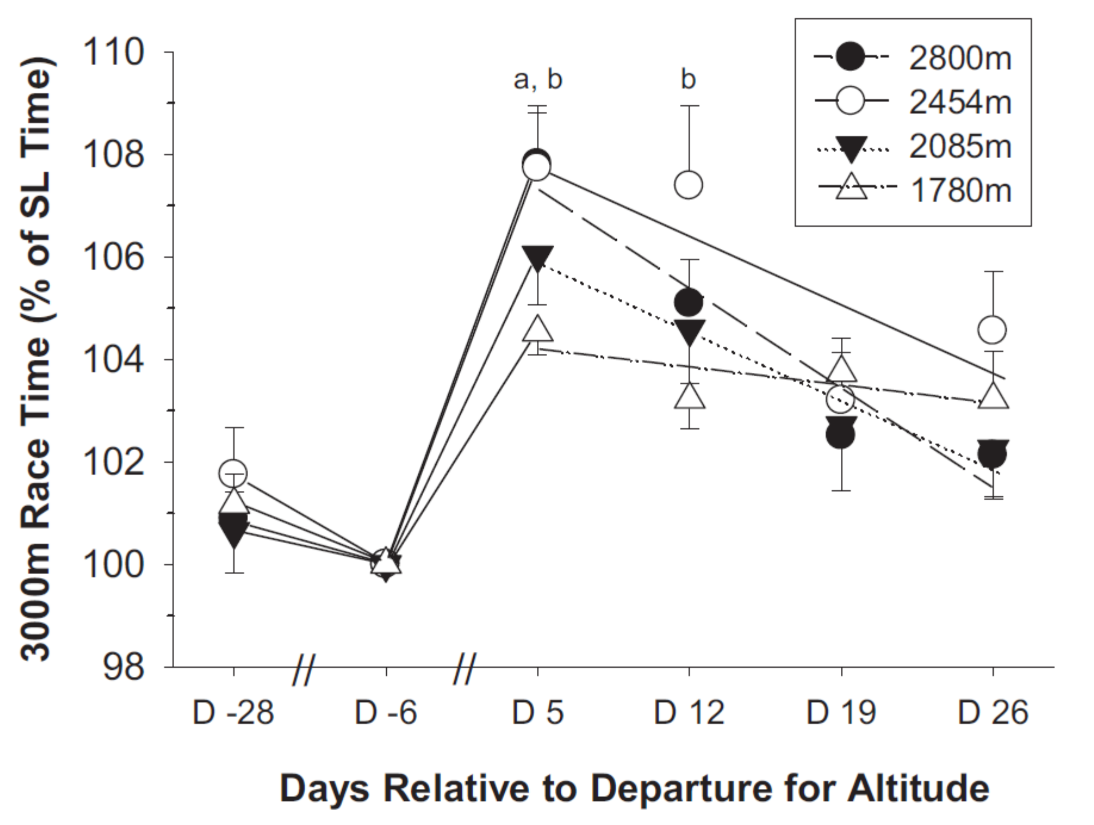


Over 21 days: - 5% compared to sea level

…athletes who plan to compete at 2340 m altitude are advised to expose themselves to this altitude **for at least 14 days before the competition.**

Schuler, B., Thomsen, J. J., Gassmann, M., & Lundby, C. (2007). Timing the arrival at 2340 m altitude for aerobic performance. *Scandinavian Journal of Medicine & Science in Sports*, *17*(5), 588-594.

Do I have to go higher than the altitude of the competition venue?



Trainings at same altitude and location (between 1,250 and 3,000 m), regardless of the subjects' assigned living altitude.

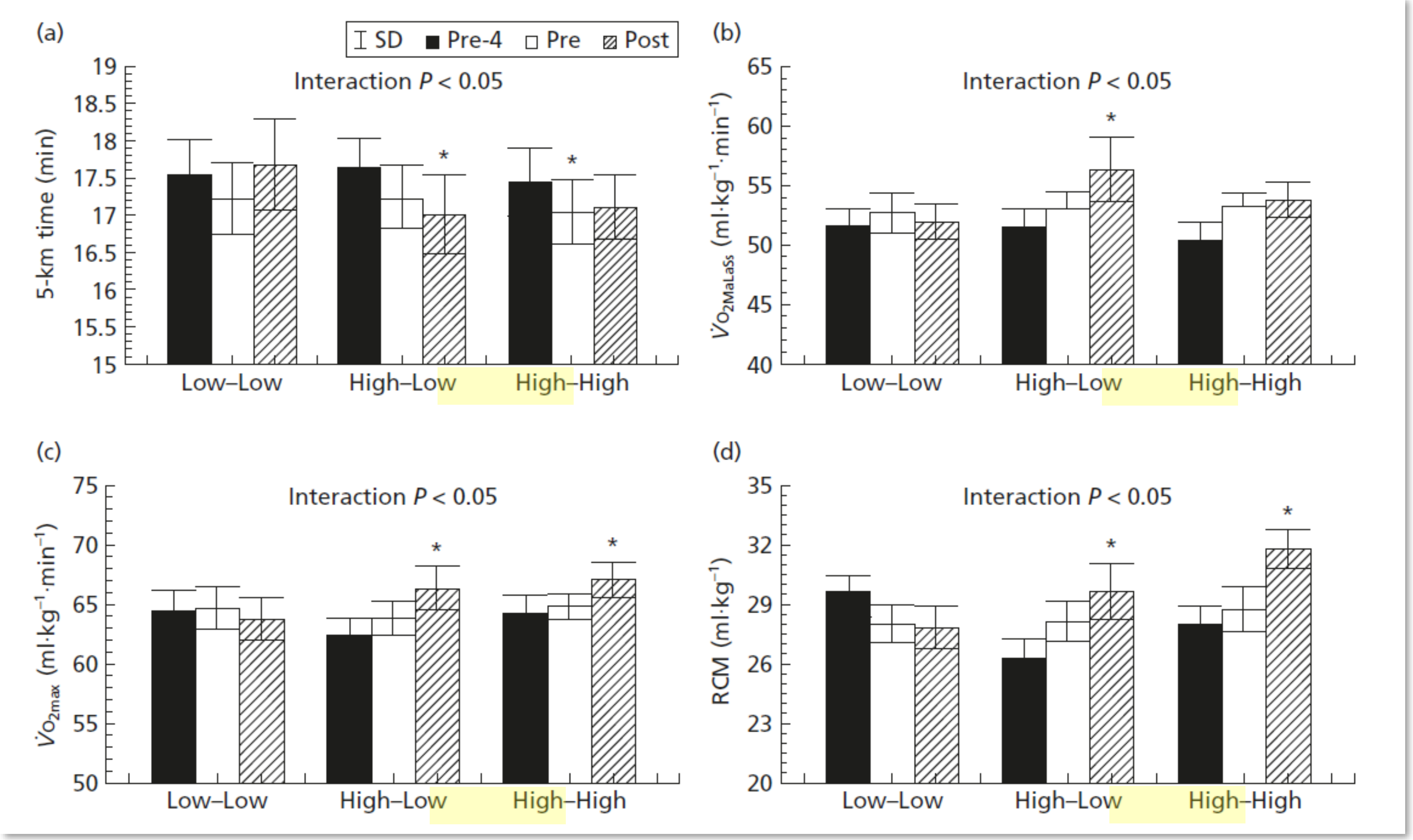
…we recommend that sea level based athletes, who must compete at or near this altitude, **live at the same altitude as the competition for a minimum of 5 days**, with longer exposures resulting in small performance improvements (0.4% per week)…

….should circumstance or strategy (i.e., attempting to enhance the erythropoietic effect of chronic altitude exposure) require the athlete to live higher than the competition altitude, our data suggest that 19 days of altitude residence or more is recommended to minimize the altitude mediated performance decrement..

Chapman, R. F., Karlsen, T., Ge, R. L., Stray-Gundersen, J., & Levine, B. D. (2016). Living altitude influences endurance exercise performance change over time at altitude. *Journal of Applied Physiology, 120*(10), 1151-1158.

Altitude training for competitions at sea level

Altitude training to prepare for competitions at sea level – Live high – train low



"Live high, train low offers both the acclimatisation effect (increased red cell mass (RCM) and VO_2max at sea level) and the training effect at sea level (improvement of maximum lactate steady state at sea level and performance at sea level)."

(According to: Levine & Stray-Gundersen 1997.)

In: Rusko et al. (2003). *Handbook of Sports Medicine and Science - Cross Country Skiing.* Blackwell Science.

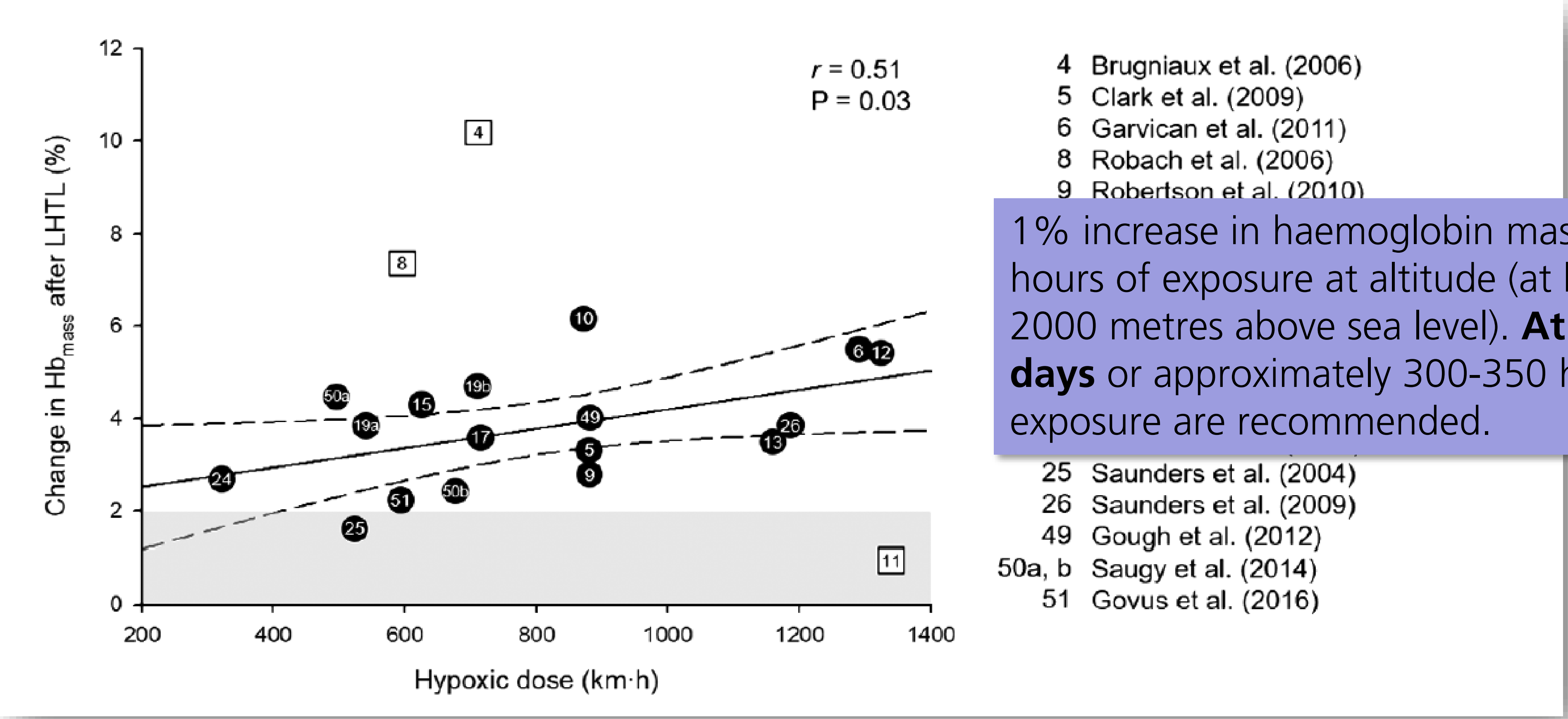
Normobaric (NH) vs. hypobaric Hypoxia (HH)

NH

HH

Bernina: Training possible in Tirano (IT) at 441 m (1 hour drive).

Hypoxic dose – the higher and longer the duration, the better!



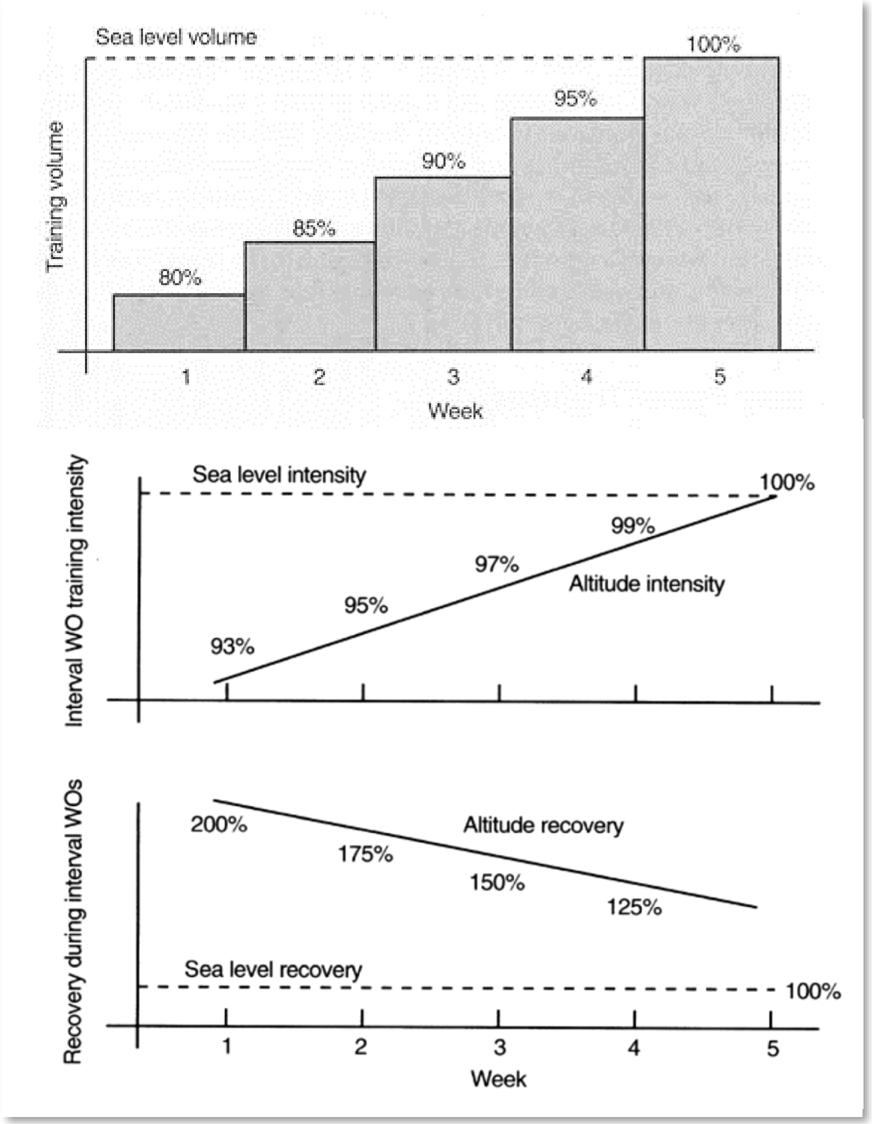
1% increase in haemoglobin mass per 100 hours of exposure at altitude (at least 2000 metres above sea level). **At least 21 days** or approximately 300-350 hours of exposure are recommended.

Millet GP, Chapman RF, Girard O, Brocherie F. *Br J Sports Med*, 2017

Adapt your training and recovery at altitude!

General recommendations (must be adapted to individual needs)

- **Training volume:**
  At least 20% lower at the start. Increase gradually.
- **Training intensity:**
  5-7% lower than training at sea level, significantly longer breaks during interval training
- Avoid high intensities in the first 5-7 days (acclimatisation phase)
- Increase gradually



Wilber (2004). *Altitude Training and Athletic Performance*. Human Kinetics.

Altitude training – dos and don'ts

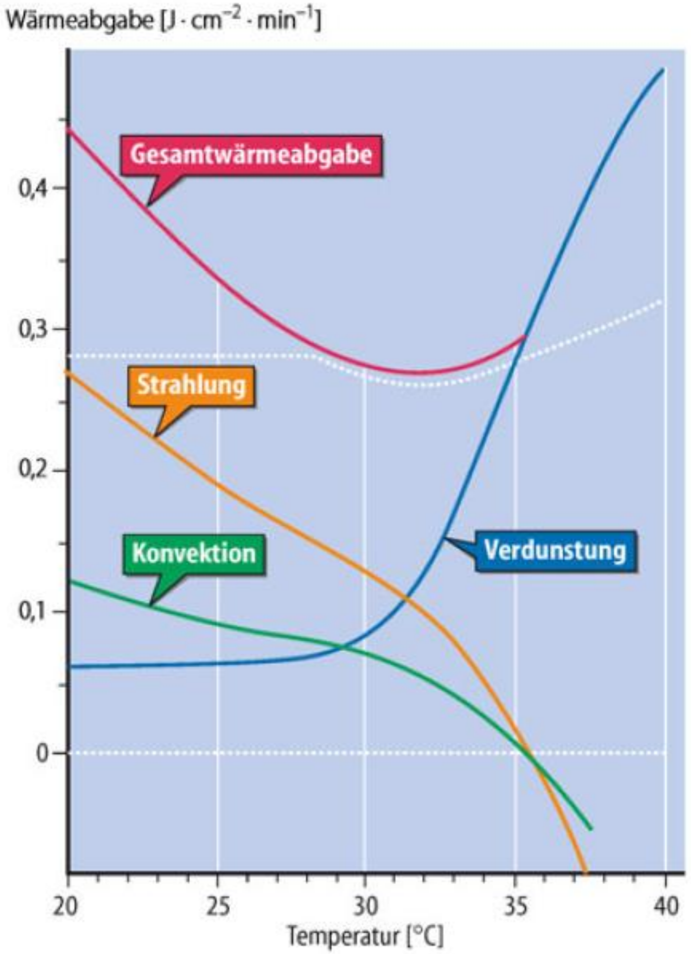
- High enough (same altitude as competition or ~ 2500 m for LHTL)
- Long enough, at least 10-14 days LHTH, more is better; > 21 days and > 300 hours (>12-15 hours per day) for LHTL.
- Always start an altitude training block healthy and rested. Infectious risk increased (2-3x!) at altitude.
- Promote and increase recovery (time).
- Increase food intake and fluid intake.
- Supplement iron (~100 mg per day) and vitamins early enough (pre-camp).
- Monitor physiological parameters (HR, RPE, [La], SpO2, ...), sleep quality, physical fatigue and state of mind
- Individualise all of the above points.
- Try everything out before planning altitude training for a target competition. Never try an altitude training block for the 1st time before a major event.

Heat and acclimatisation to heat

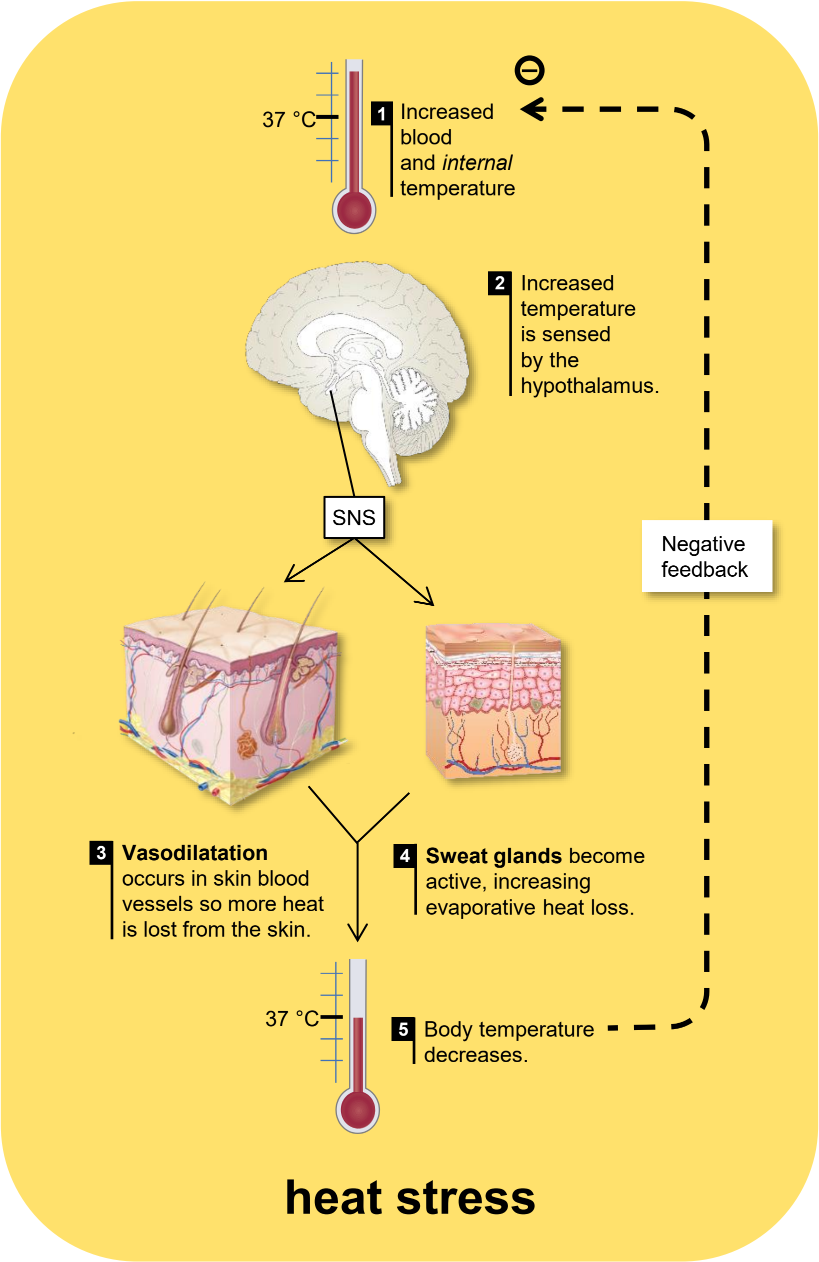
Thermoregulation – Heat loss and gain

Mechanism	Description
Radiation (R) (Strahlung)	• Energy transfer via **infrared radiation** (electromag. waves) • **Temperature gradient** nescessary • Most important mechanism in room temp.
Conduction (K)	• Transfer of heat via **direct contact** • Energy conduction rate is function of temperature difference (**temperature gradient**) and material (**water >> air**)
Convection (C) (Konvektion)	• Heat transfer due to **movement of fluids** (e.g. blood flow, air flow, water flow) • High with **wind speed** («wind chill factor»)
Evaporation (E) (Verdunstung)	• **Sweat**: Water phase change on skin (liquid → gaseous) transfers energy • Only effective heat loss mechanism when **air temp. > body temp.** • Attenuated with high **humidity** of ambient air

Interaction with temperature:



Schmidt, R. F., & Lang, F. (2007). Physiologie des Menschen mit Pathophysiologie.

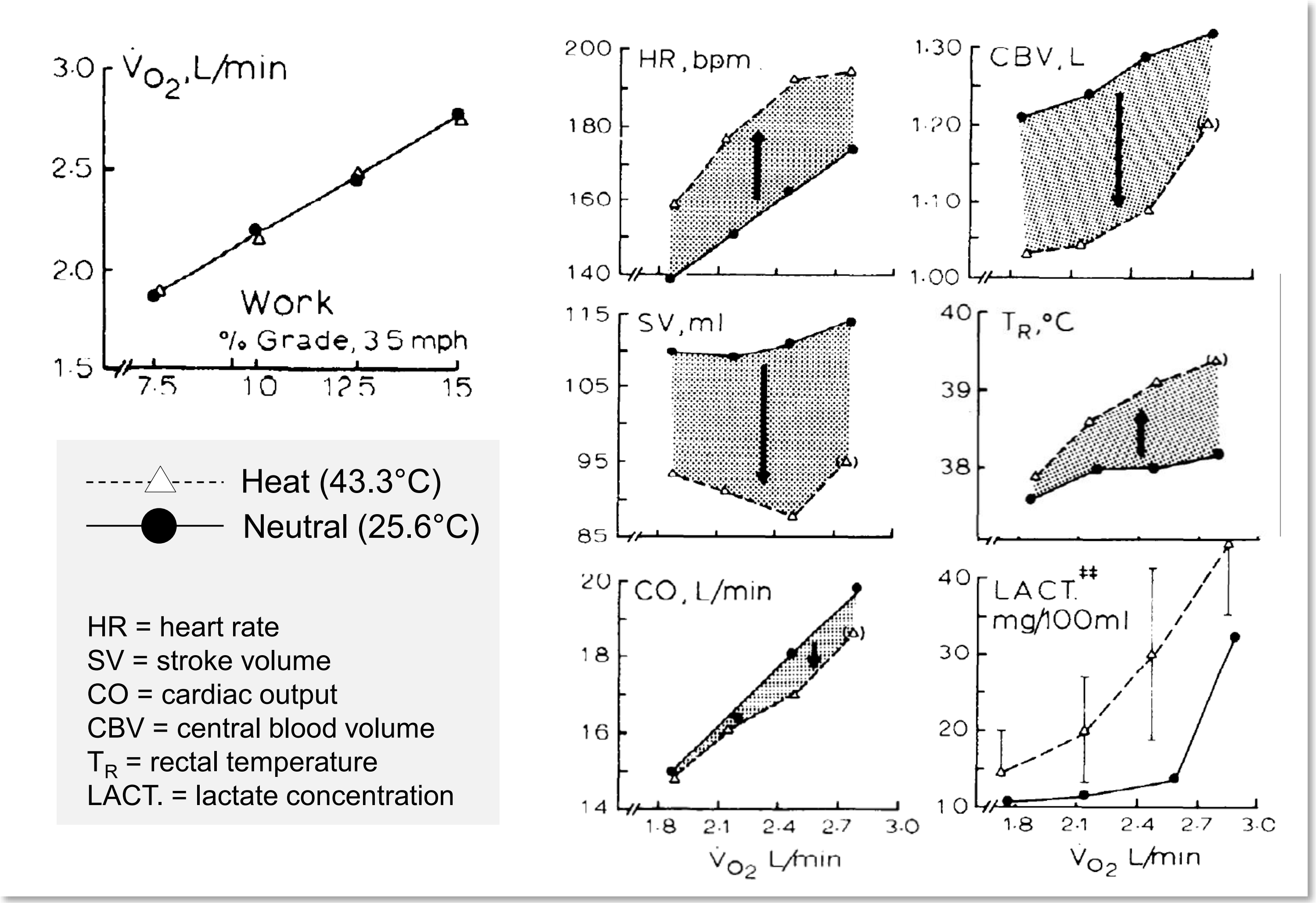


Thermoregulation of the human body

Adapted from: Kenney, W. L., Wilmore, J. H., & Costill, D. L. (2015). *Physiology of sport and exercise*. Human kinetics.

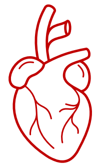
Performance decrease - why?

submaximal



maximal

$\downarrow \dot{V}O_2max = \dot{Q}_{max} \downarrow \cdot$ a-v O_2 $diff_{max}$



$Hf_{max} \cdot SV_{max} \downarrow$

$\uparrow$

EDV $\downarrow$

$\uparrow$

Venous Return $\downarrow$

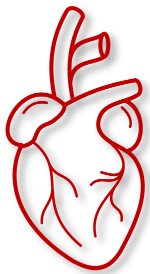
Simplistic: Blood is used for **sweat**, not for **oxygen transport** (…)

Rowell, L. B. (1974). Human cardiovascular adjustments to exercise and thermal stress. *Physiological reviews*, *54*(1), 75-159.

Effects of heat during physical exercise

↑ Skin- and core temperature

Increased cardiovascular stress

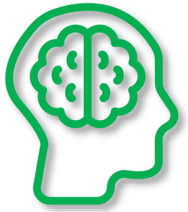


- ↑ Skin blood flow
- ↓ Plasma volume
- ↓ Stroke volume
- ↑ Heart rate
- ↓ Arterial pressure

Changes in brain / nervous system

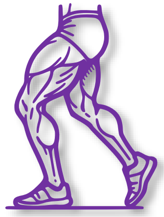
- ↑ Central fatigue
- ↓ Neurotransmitter (Dopamine)
- ↓ Coordination

Mental challenges



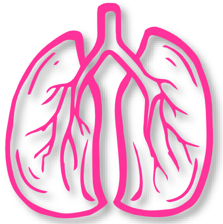
- ↑ Discomfort
- ↓ Technical / tactical ability
- ↓ Motivation

Impaired muscle function



- ↓ Oxygen delivery
- ↑ Anaerobic metabolism
- ↑ Increased utilisation of carbohydrates/glycogen
- ↑ Lactate and H+
- ↑ Feedback from thermoreceptors

Ventilatory changes



- ↑ Hyperventilation
- ↓ CO_2 in the blood
- ↓ Brain blood flow

Heat - Possible solutions

Longer lasting (~14 days) adaptation to environmental conditions of the venue

Acclimatisation on-site (competition venue) preparation

Acclimation in heat chambers / artificially induced

*"…while acclimation and acclimatisation share **similar physiological adaptations**, training outdoors is more specific to the competition setting as it allows athletes to experience the **exact nature of the heat stress**." Racinais 2015*

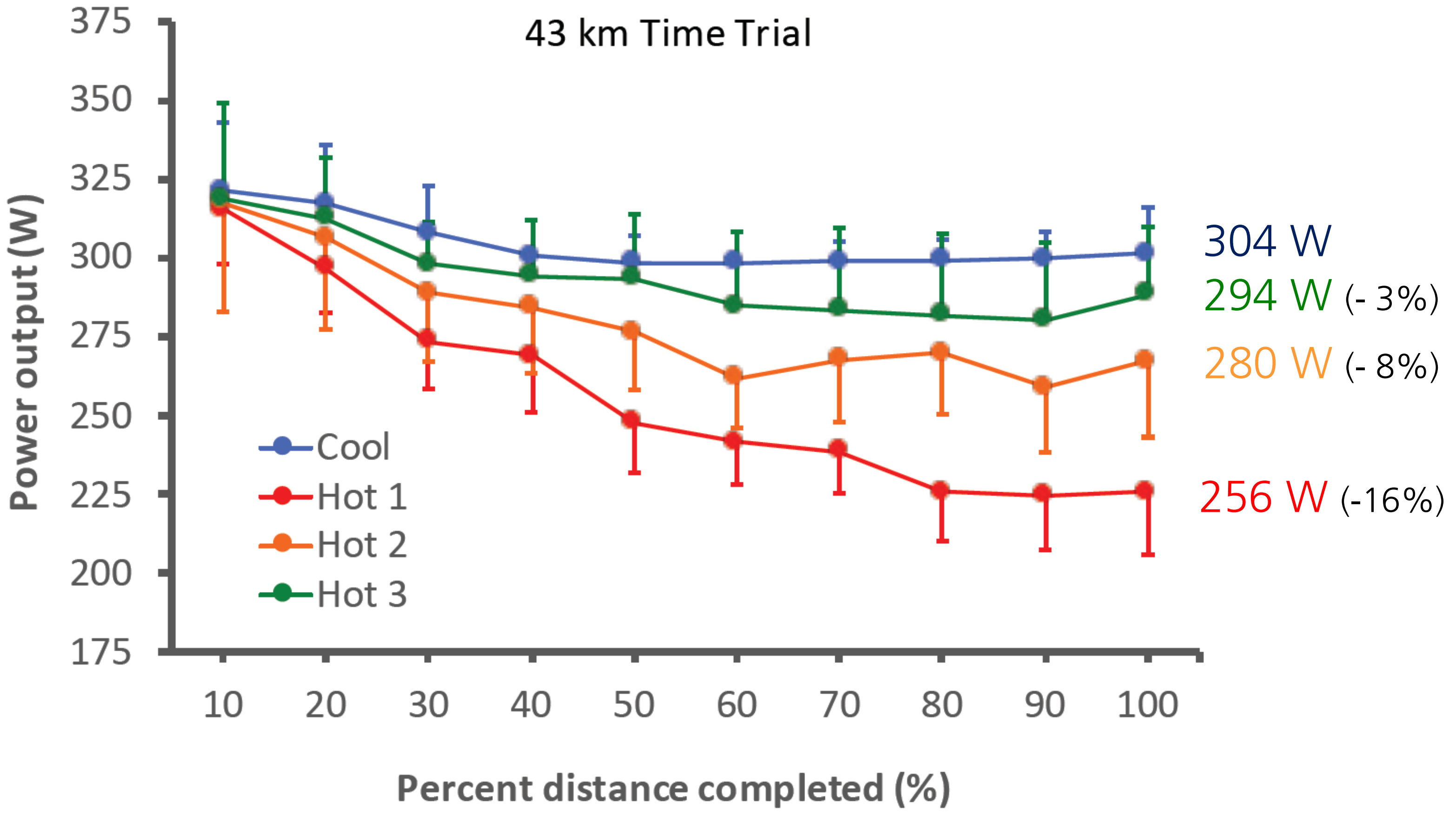
Immediate possibilities on the day of the competition

PRE-cooling (before competition). Idea: later increase of core temperature.

PER-cooling (during competition). Idea: Slowing the core-temperature rise.

Hydration Hypohydration → reduced performance. Aim for euhydrated state.

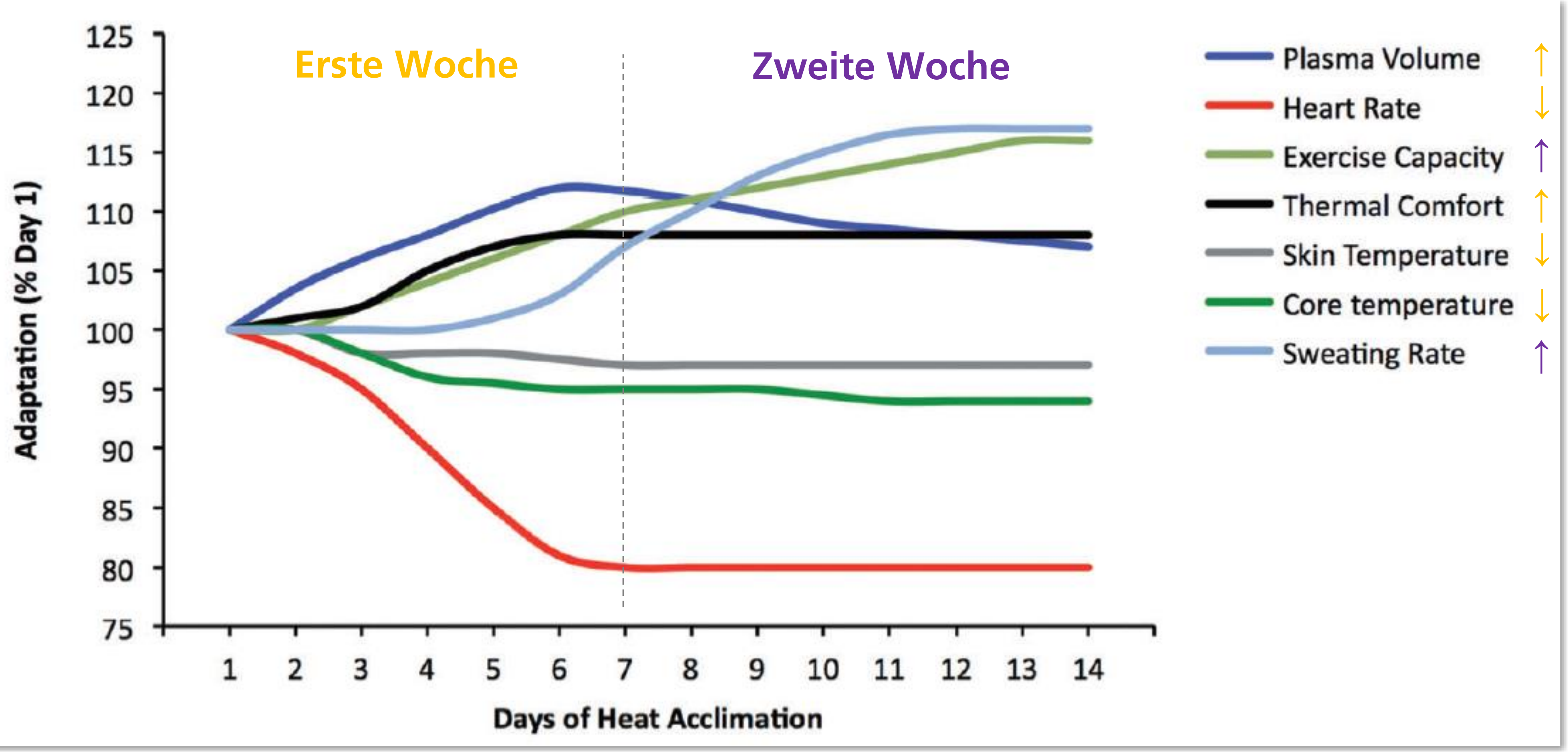
Heat acclimat(isat)ion



Power output during a 43 km cycling time trial in cool conditions (8°C) and after 2 days (Hot 1), 1 week (Hot 2) and 2 weeks (Hot 3) of training in 37°C outdoor conditions in <u>high-level cyclists.</u>

Racinais, S., Périard, J. D., Karlsen, A., & Nybo, L. (2015). Effect of heat and heat acclimatization on cycling time trial performance and pacing. *Medicine and Science in Sports and Exercise*, *47*(3), 601.

Heat acclimat(isat)ion - effects



Périard, J. D., Racinais, S., & Sawka, M. N. (2015). Adaptations and mechanisms of human heat acclimation: applications for competitive athletes and sports. *Scandinavian journal of medicine & science in sports*, *25*(S1), 20-38.

Heat training modality

Heat-Lab

Heat-Tent

Heat-Suit

Competition venue
(or similar climate)

> "In conclusion, daily training sessions conducted either in ambient 35 °C, while wearing thermal clothing in temperate conditions or while wearing thermal clothing combined with hot water immersion are equally effective for improving exercise performance in the heat."

Lundby, C., Svendsen, I. S., Urianstad, T., Hansen, J., & Rønnestad, B. R. (2021). Training wearing thermal clothing and training in hot ambient conditions are equally effective methods of heat acclimation. *Journal of Science and Medicine in Sport*, *24*(8), 763–767. https://doi.org/10.1016/j.jsams.2021.06.005

Heat acclimat(isat)ion I

«Best Practice» recommendations:

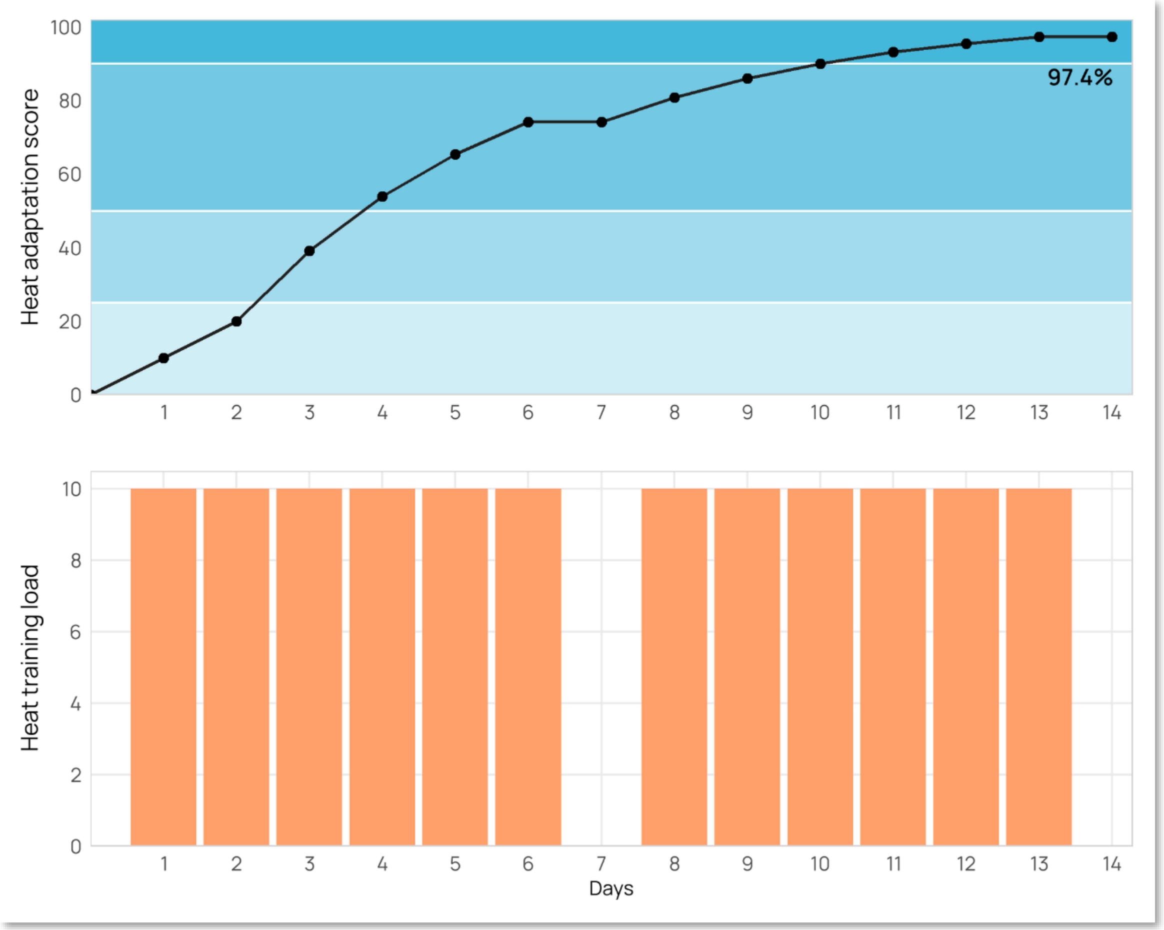
1 to 2 weeks

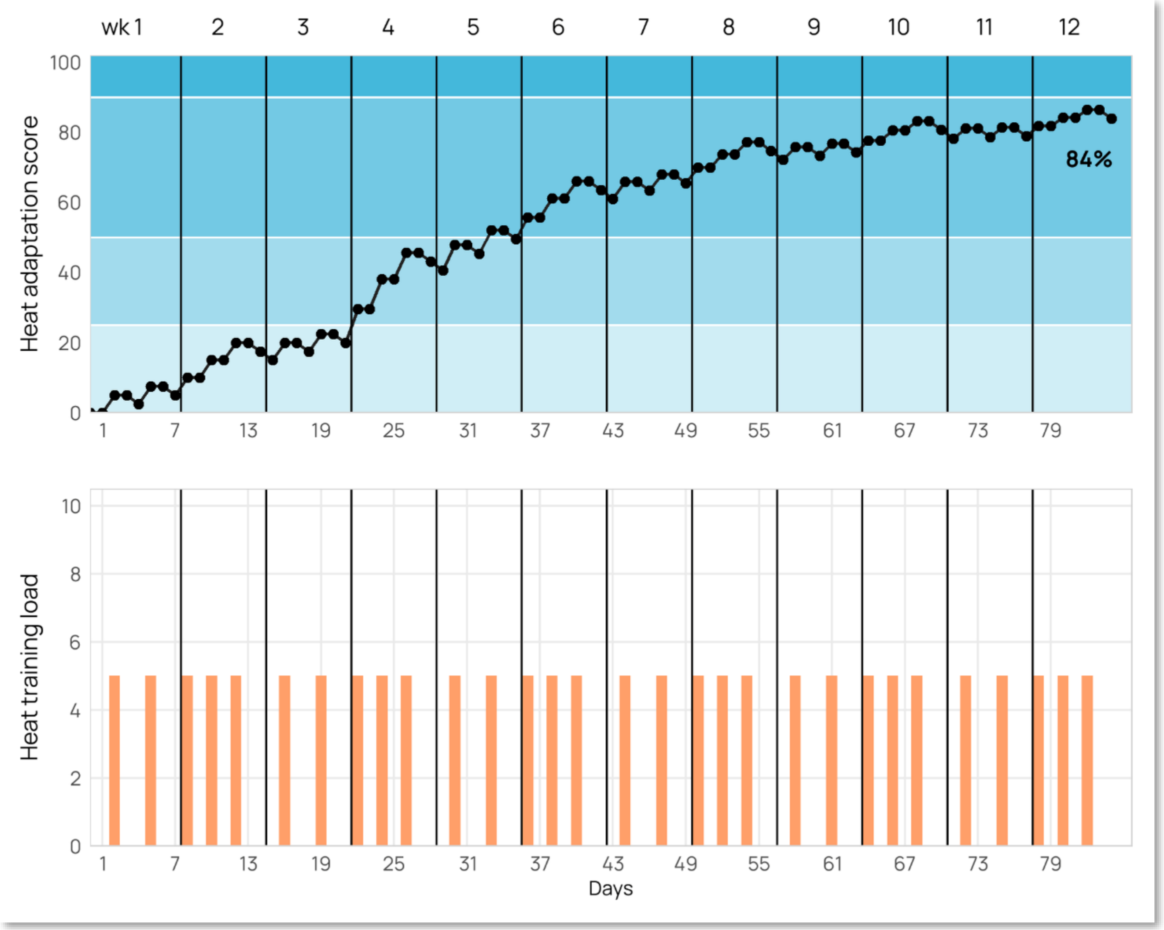
As close as possible to climate of competition

Daily, competition-specific training > 60 min

- start carefully
- control by HF instead of power/speed
- core body temperature at the end 38.5-39.0 °C, sweat rate about 1.5 L/h

CORE's heat adaptation score



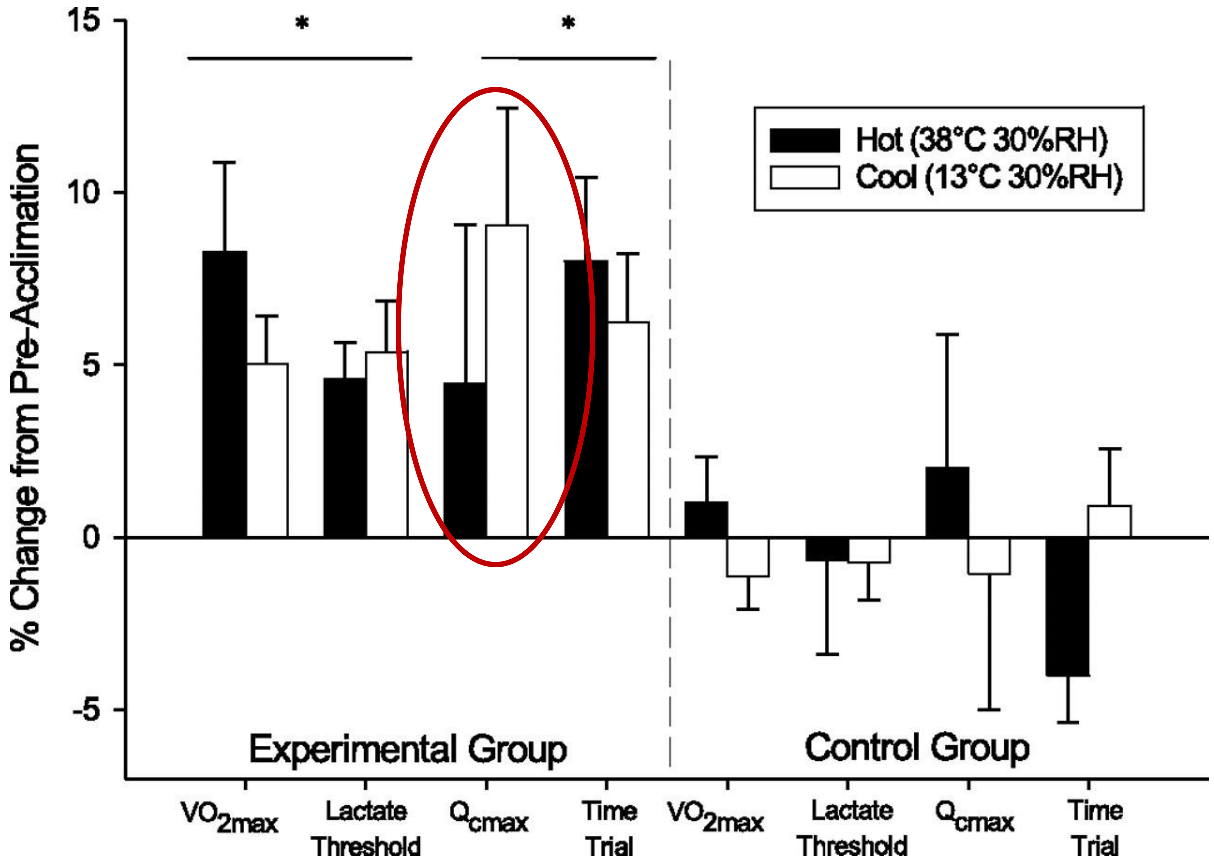


The CORE Heat Adaptation Score is a percentage value in the CORE app that quantifies an athlete's degree of heat adaptation. It ranges from 0% to 100% and uses an evidence-based formula to best estimate progress and potential for heat training and performance in hot conditions.
The value is calculated based on the athlete's physiological response to heat (depending on the cumulative time spent with a Heat Strain Index / in a Heat Zone).

Heat training for competitions in temperate conditions

Heat training and performance in ambient conditions

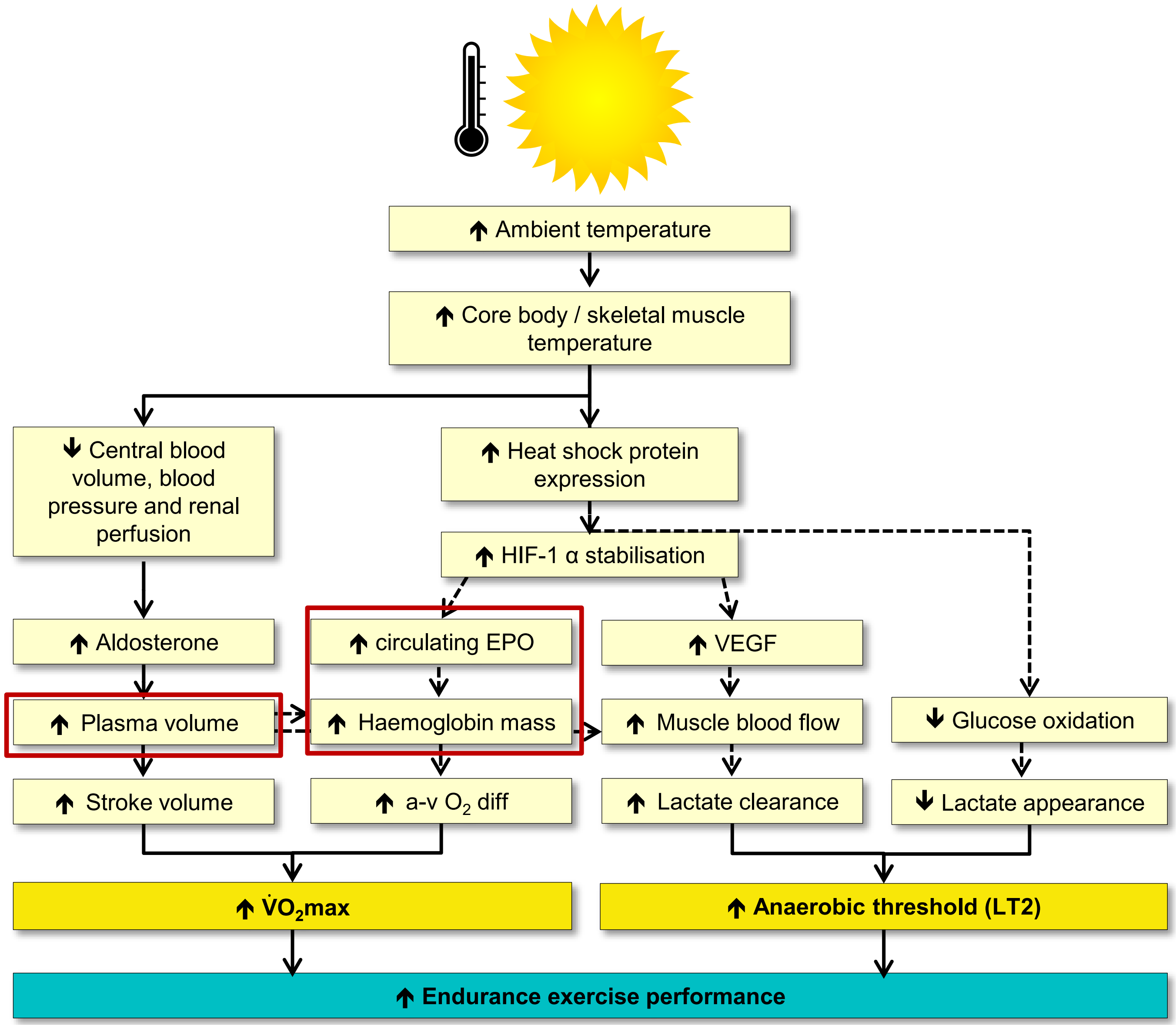
First study to investigate the positive effects of heat acclimatisation on aerobic performance in ambient conditions



Cardiorespiratory and performance changes as a percent change from the preacclimation trials in both environmental conditions. *$P < 0.05$ vs. preacclimation within environmental condition. There was no difference in the variables displayed for the control group. Values are means ± SE for 12 heat acclimation **(10 days)** subjects (VO_2max ~67 mL min^{-1} kg $^{-1}$) and 8 controls (VO_2max ~67 mL min^{-1} kg $^{-1}$). Q_{cmax}, maximal cardiac output.

Lorenzo, S., Halliwill, J. R., Sawka, M. N., & Minson, C. T. (2010). Heat acclimation improves exercise performance. *Journal of Applied Physiology, 109*(4), 1140–1147. https://doi.org/10.1152/japplphysiol.00495.2010

Mechanisms for increasing endurance performance with heat training at temperate conditions



→ Established and evidence-based relationship

- - -> Limited evidence of the relationship

Baranauskas, M. N., Constantini, K., Paris, H. L., Wiggins, C. C., Schlader, Z. J., & Chapman, R. F. (2021). Heat versus altitude training for endurance performance at sea level. *Exercise and Sport Sciences Reviews*, *49*(1), 50-58.

Heat training recommendations - updated

- **Sufficient duration:** non-hematologic adjustments may indeed be achieved with short-term protocols (within days). To elicit additional hematologic adaptations, a heat block duration of 4-5 weeks is needed (with at least 5 weekly sessions) → Frequent exercise over an extended period of time.

- **Training Load:** there does not appear to be a need for very long or maximal exercise sessions in the heat. Recommendation: about one hour, RPE moderately hard (Borg 13-14), core body temperature at the end 38.5-39.0 °C, sweat rate about 1.5 L/h, in a heat room, tent or with sweat-impermeable clothes (heat-suit training)

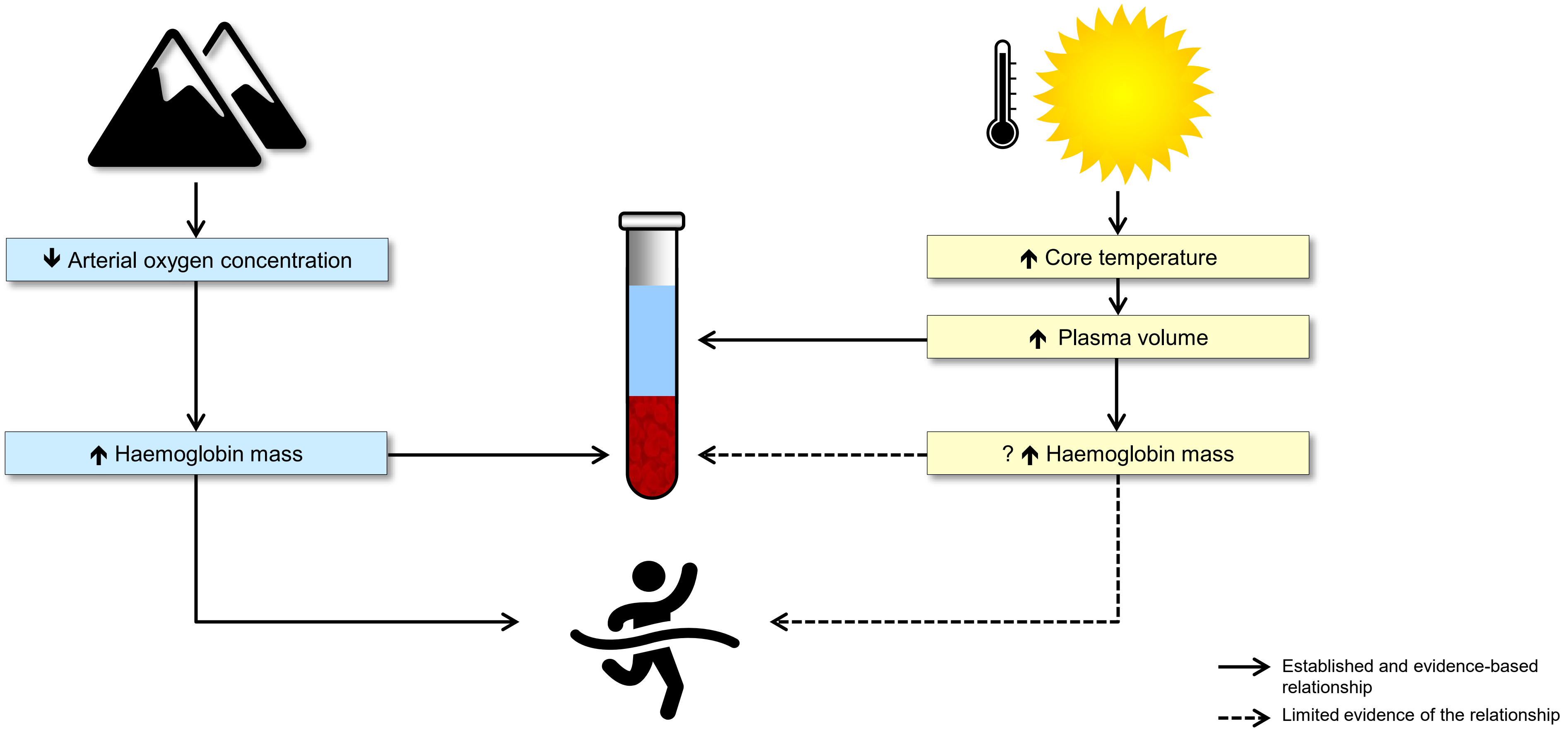
- **Maintain adaptations:** after heat acclimatization well possible with few heat training units (2-3/week; or passive measures (hot bathes) if reduced training/tapering exclude high training volumes) → Advantage over altitude training, where the hematological adaptations "decay" relatively quickly...

Based on: Nybo, L., Ronnestad, B., & Lundby, C. (2022). High or Hot - Perspectives on altitude camps and heat acclimation training as preparation for prolonged stage races. *Scand J Med Sci Sports.* https://doi.org/10.1111/sms.14268

Combining heat training and altitude training – additive training effect?

Combining heat training and altitude training

Objective: Combination of hypoxia-induced stimulation of erythropoiesis with heat-induced plasma volume expansion (and a possible associated increase in haemoglobin mass).



Possible combination forms

Simultaneously

Heat training at altitude during high-altitude stays, combined altitude and heat training in climate chambers, passive heat training followed by hypoxic training (RSH).

Concurrently

morning afternoon

High-altitude training with individual heat training sessions. Endurance training in the heat and RSH alternating between morning and afternoon or on different days.

Sequentially

3 weeks (1 week) 3-5 weeks

LHTL altitude training block followed by a heat training block.

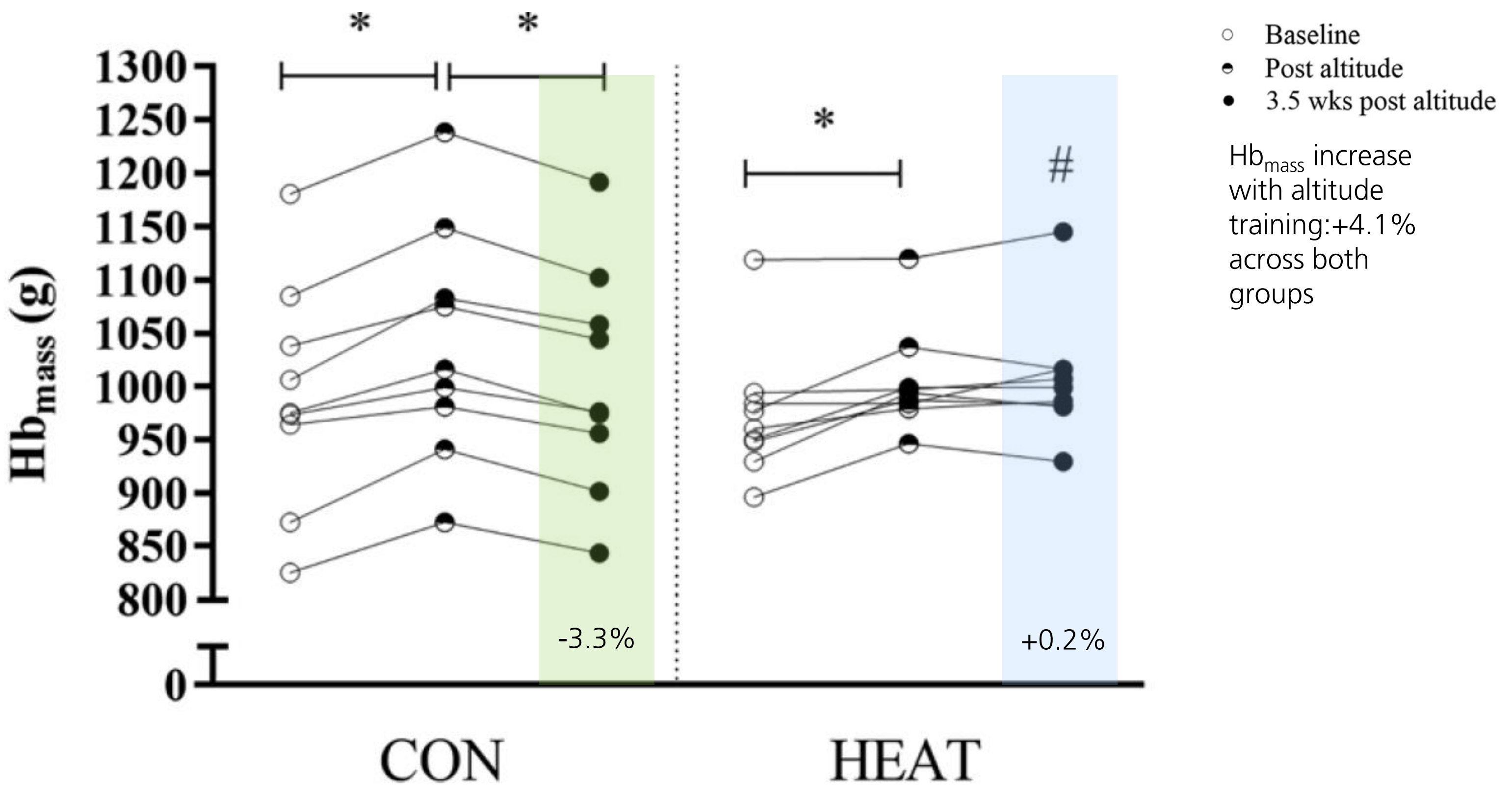
Blocks with altitude and heat training can also be done several times in different training periods.

In combined training blocks, the performance gain is not greater than when focusing on one form of training alone!

Adapted from: Girard, O., Peeling, P., Racinais, S., & Périard, J. D. (2024). Combining Heat and Altitude Training to Enhance Temperate, Sea-Level Performance. *International Journal of Sports Physiology and Performance, 1*(aop), 1-6.

Heat training (heat suit) after high altitude training

Sequentially



Individual values of total Hb$_{mass}$ before (baseline), at day 2 after altitude camp (post altitude), and 3.5 wk post altitude for the group that performed the heat suit maintenance protocol (HEAT) and the control group (CON). * $P < 0.05$, within-group difference between time points. # $P < 0.05$, between-group difference.

- 3 weeks of live high-train high (Livignio, 2100 metres above sea level)
- Training at 1800-2200 metres above sea level
- Heat: 3 heat training sessions per week for 3.5 weeks, 11 sessions in total
- Heat sessions: Heat participants completed 150 minutes (3 x 50 minutes) of their low intensity training in a week wearing a heat suit (wool base layer, wool hat, down jacket and nylon suit with poor evaporation capacity).
- CON and HEAT underwent the same training throughout the test phase.
- Rectal temperature ~38.5°C and fluid loss ≥ 1.5 L per 50 minutes measured 1–3 minutes after training

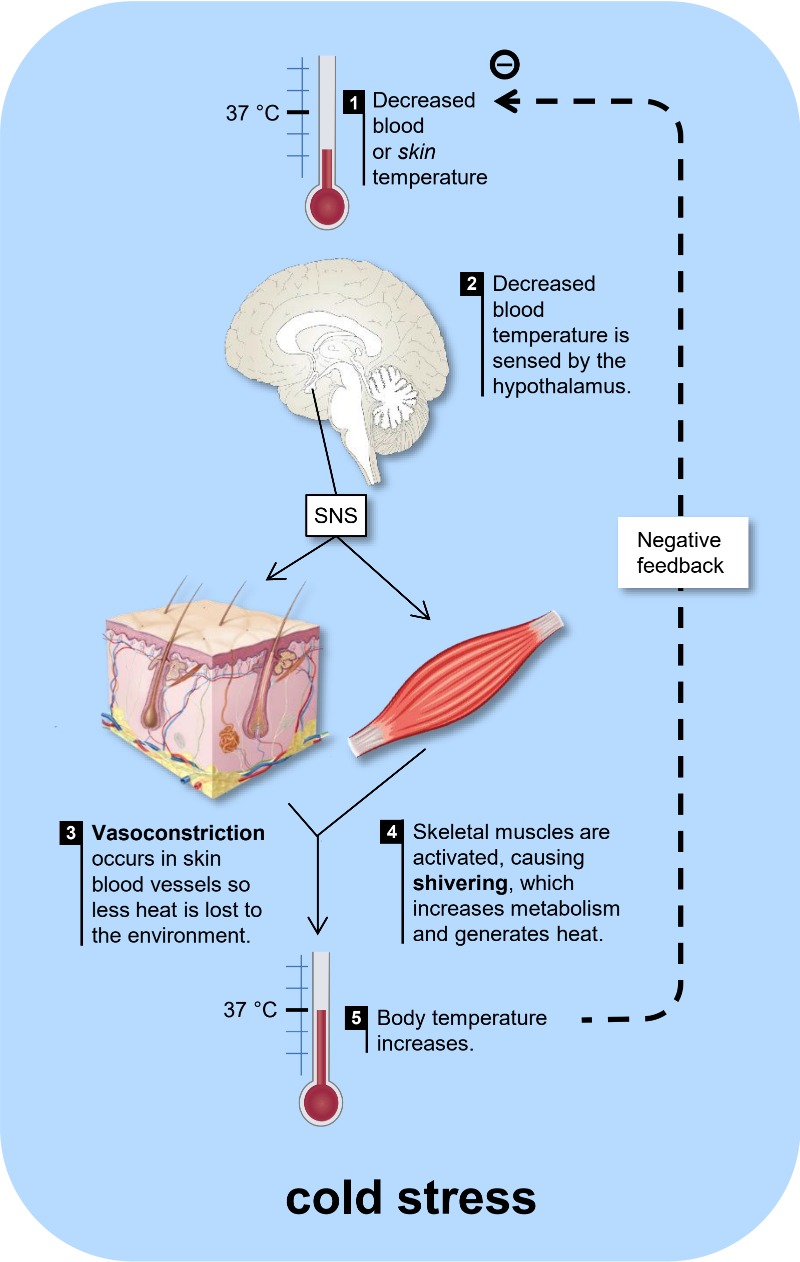
Rønnestad, B. R., Odden, I., Urianstad, T., Hansen, J., Mølmen, K. S., & Cardinale, D. A. (2025). Heat Suit Training Preserves the Increased Hemoglobin Mass after Altitude Camp in Elite Cyclists. *Medicine and Science in Sports and Exercise, 57*(1), 81-87.

Combining heat and high altitude training?

- Adaptations (haemoglobin mass during altitude training and plasma volume during heat training) appear to be difficult to combine simultaneously. In combined training blocks, the performance gain is not greater than when focusing on one form of training alone.
- The risk of accumulated fatigue is greater than with heat or altitude training alone.
- Individual athletes may benefit more from a particular measure (heat or altitude) than others.
- Analyse individual reactions during an initial (non-combined) heat or altitude camp → then optimise measures individually.
- A heat block after an altitude block may, under certain circumstances, prolong the effects of altitude training.

- Nybo, L., Ronnestad, B., & Lundby, C. (2022). High or Hot - Perspectives on altitude camps and heat acclimation training as preparation for prolonged stage races. *Scand J Med Sci Sports.* https://doi.org/10.1111/sms.14268
- Girard, O., Peeling, P., Racinais, S., & Périard, J. D. (2024). Combining Heat and Altitude Training to Enhance Temperate, Sea-Level Performance. *International Journal of Sports Physiology and Performance, 1*(aop), 1-6.
- Rønnestad, B. R., Odden, I., Urianstad, T., Hansen, J., Mølmen, K. S., & Cardinale, D. A. (2025). Heat Suit Training Preserves the Increased Hemoglobin Mass after Altitude Camp in Elite Cyclists. *Medicine and Science in Sports and Exercise, 57*(1), 81-87.

Cold and acclimatisation to cold temperatures

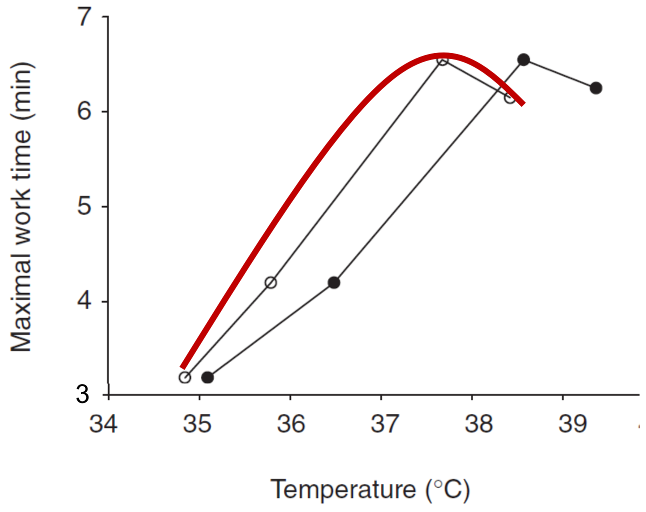


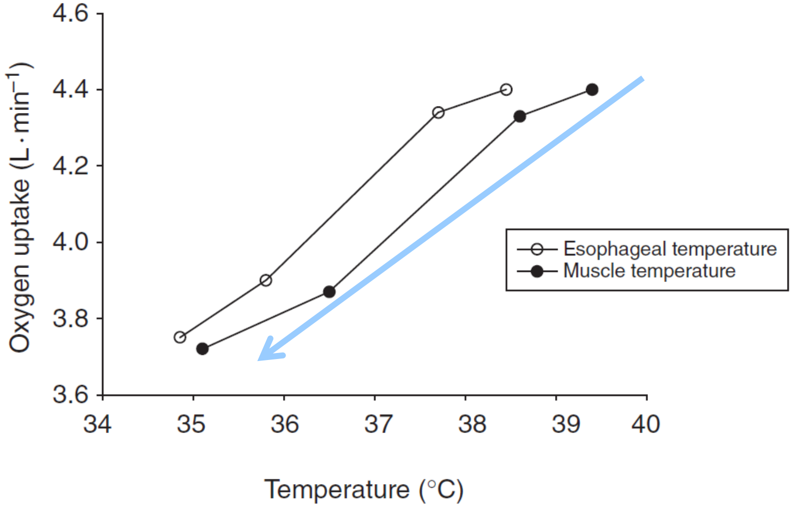
Thermoregulation of the human body

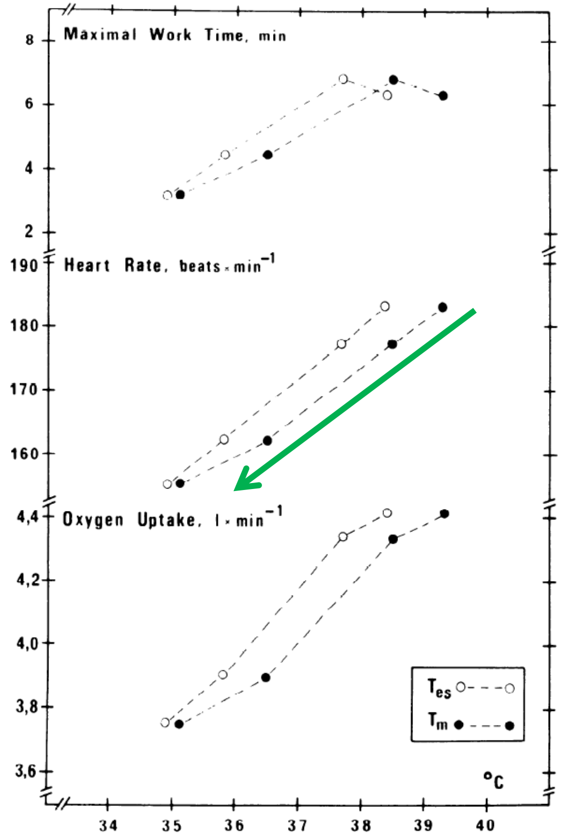
Adapted from: Kenney, W. L., Wilmore, J. H., & Costill, D. L. (2015). *Physiology of sport and exercise*. Human kinetics.

Muscle temperature and performance / $\dot{V}O_2max$

5-6% decrease of VO_2max per 1°C fall

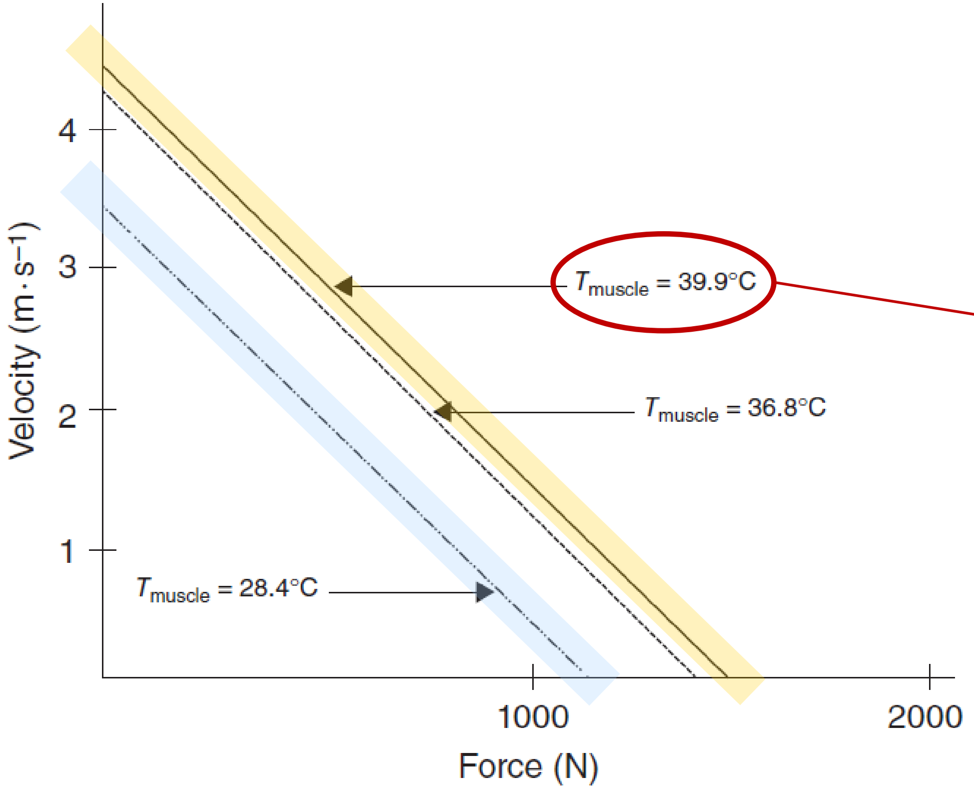






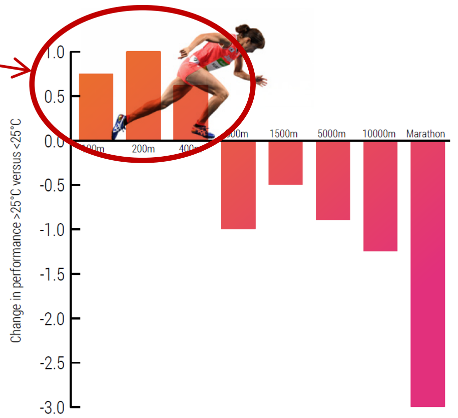
Bergh, U., & Ekblom, B. (1979). Influence of muscle temperature on maximal muscle strength and power output in human skeletal muscles. *Acta Physiologica Scandinavica*, *107*(1), 33-37.

Decrease in muscle strength with lower muscle temperature



Leistung Veloergometer

- 31% Abnahme der Peak Power
- 44% Abnahme der mittleren Leistung



Davies, C. T., & Young, K. (1983). Effect of temperature on the contractile properties and muscle power of triceps surae in humans. *Journal of Applied Physiology*, *55*(1), 191-195.

Reduced aerobic performance in the cold – why?

Simplistic: Reduced muscle blood flow → **decreased muscle temperature**, less muscle force, lower maximal HR → lower VO_2max, higher lactate levels and higher glycogen loss, reduced economy. Increased energy expenditure due to shivering.

Note: Hardly any acclimatisation to the cold
«Habituation» (less shivering) after cold acclimatisation. Less energy consumption to produce heat → efficiency ↑

Castellani, J. W., & Tipton, M. J. (2015). Cold stress effects on exposure tolerance and exercise performance. *Compr Physiol*, *6*(1), 443-469.

Cold - Possible solutions

Hardly any adaptations, only behavioural strategies!

Cold acclimatisation: long-term strategies

- Optimisation of individual warm-up procedures & pacing strategies at different temperatures
- Increased basal metabolic rate requires the creation of individualised nutrition strategies
- Establishing a clothing strategy for different & changing environmental conditions

Cold acclimatisation: short-term strategies

- Keeping clothing ready for optimal maintenance of core and especially muscle temperature
- Adapting warm-up procedures & pacing strategies to environmental conditions with particular attention to the early stages of the race
- Plan treatment for athletes with asthmatic symptoms (risk from high ventilation in cold, dry conditions)

So what? Take Home Messages

- **Acclimatisation is key** for competitions at altitude and in hot and humid conditions. At least 10-14 days are necessary for both interventions (at target altitude / climate of competition venue).
- Try to keep the **exercising muscles as warm as possible** in the cold (without heating up the body). Optimise behavioural strategies.
- For competitions on sea level: **Do it right or don't do it at all.** Altitude block (long enough, high enough, HIT training at low altitudes, etc.) - Heat block (measuring sweat output, core body temperature, monitoring conditions, etc.).
- **Heat or altitude for competitions on sea level?** When in doubt, choose altitude. Altitude training has the most clearly positive effects for endurance-trained athletes competing at low altitudes. Prevent the decline in Hb_{mass} with a subsequent heat intervention. But **be careful** when combining heat and altitude.
- Factors such as **the athlete's psychology, the environment**, the dose of stimuli and the training condition should be taken into account when incorporating heat or hypoxia as part of an athlete's training programme.