Cycling under heat stress:
Performance implications and mitigation strategies

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Overview

- Human interaction with the environment
  - Thermal environment and thermal indices
    - Link to physiological strain and performance
- Endurance performance in the heat
  - Thermal and cardiovascular strain
    - Maximal/peak aerobic capacity
  - Hydration status
- Heat mitigation
  - Heat acclimation approaches
  - Adaptations kinetics and practical considerations
  - Cooling intervention and practical considerations

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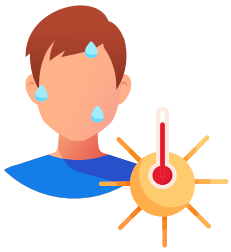
Human interaction with the environment



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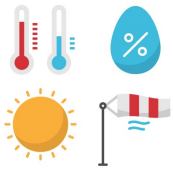
Human thermal environment

Environmental parameters



Task dependent parameters

Environmental characteristics:

- Wet-bulb globe temperature (WBGT)
  - Wet-bulb temperature
  - Dry-bulb temperature
  - Black-globe temperature
- Heat Index, Humidex, Universal thermal climate index (UTCI)

Human heat stress index (HSI)

- Integrates ambient conditions, work rate and clothing
- Partitional calorimetry
- HSI = E_{req}/E_{max}

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Physiological strain and performance

- WBGT: Wet-bulb globe temperature
- T_{wb}: Wet-bulb temperature
- T_{db}: Dry-bulb temperature
- T_{bg}: Black-globe temperature
- Heat Index
- Humidex
- UTCI: Universal thermal climate index
- HSI: heat stress index

UCI CYCLING REGULATIONS

PART 2 ROAD RACES

Version on 13.06.2023

Protocol for discussions regarding extreme weather and the riders' safety during events

The protocol shall be applied in men's events of the UCI WorldTour and UCI ProSeries as well as in women's events of the UCI Women's WorldTour and UCI ProSeries in order to prevent and avoid incidents or problems relating to extreme weather conditions for riders' safety during events. All other road events are equally recommended to refer to the procedures set out in the protocol when appropriate.

Problems

The protocol involves the compulsory convening of a meeting of stakeholders (see the section on "Appointment of representatives" below) when:

- extreme weather conditions are anticipated prior to the start of a stage or race.

The extreme weather conditions that could lead to such a meeting include:

1. Freezing rain;
2. Accumulation of snow on the road;
3. Strong wind;
4. Extreme temperatures;
5. Poor visibility;
6. Air pollution.

TABLE 3. Mean power output, mean and peak T_{gi} and HR, and sRPE and thermal sensation during the six stages of the 2019 TDU.

	Mean Power (W)	Mean T_{gi} (°C)	Peak T_{gi} (°C)	Mean HR (bpm)	Peak HR (bpm)	sRPE	Thermal Sensation
Stage 1	183 ± 72[3,4,5,6]	38.3 ± 0.3	38.9 ± 0.3	140 ± 17[3]	187 ± 11	990 ± 286[3,6]	6.1 ± 1.0
Stage 2	180 ± 59[3,4,5,6]	38.3 ± 0.4	39.1 ± 0.5	131 ± 16[1,3,4,6]	186 ± 10	809 ± 292[1,3,4,5,6]	5.5 ± 0.8[3]
Stage 3	232 ± 61[4]	38.5 ± 0.5	39.4 ± 0.4	147 ± 14	188 ± 9	1668 ± 312	6.2 ± 0.7
Stage 4	249 ± 52	38.4 ± 0.4	39.3 ± 0.4	140 ± 13[3]	181 ± 8[1,3]	1090 ± 273[3,6]	4.5 ± 0.9[1,2,3,6]
Stage 5	225 ± 65[4]	38.2 ± 0.4	39.0 ± 0.4	135 ± 15[3,4]	182 ± 8[3]	1078 ± 246[3]	4.4 ± 0.9[1,2,3,6]
Stage 6	225 ± 68[4]	38.2 ± 0.5	39.3 ± 0.4	137 ± 15[3]	182 ± 8	1315 ± 318[3]	5.2 ± 0.8[1,3]

HR: n = 11–15, power output: n = 15–16, sRPE: n = 19–21, T_{gi}: n = 2–14, thermal sensation: n = 19–21.
[1,2,3,4,5,6]Significantly different from stages 1, 2, 3, 4, 5, and 6, respectively ($P \leq 0.05$).

Périard et al. (2023) *Med Sci Sport Exerc*

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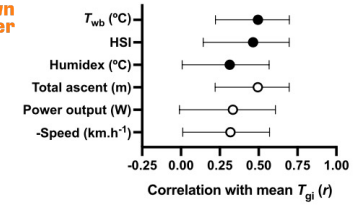
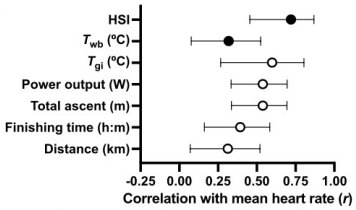
Physiological strain and performance





Repeated-measures correlation
- Thermal indices (●)
- Independent factors (○)

"-" Negative correlation

- HSI was integrative index most strongly associated with both mean T_{gi} & HR
- T_{gi} correlated with HSI … but not WBGT (widely used in sport)

Périard et al. (2023) *Med Sci Sport Exerc*

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Endurance performance in the heat

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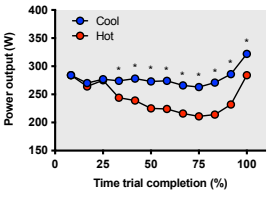
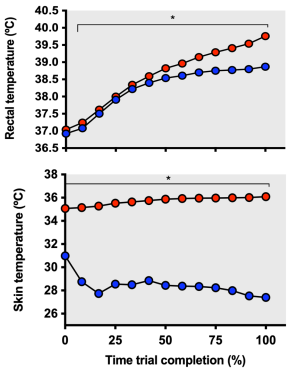
Endurance performance in the heat

40 km cycling time trial
HOT: 35°C, 60% RH
COOL: 20°C, 40% RH





Périard et al. (2011) *Exp Physiol*

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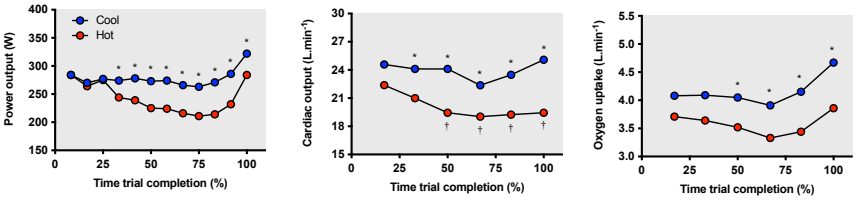

↑ Thermal strain → ↑ Cardiovascular strain (↓VO_{2peak}) → ↓ Sustainable power output

Périard et al. (2011) *Exp Physiol*

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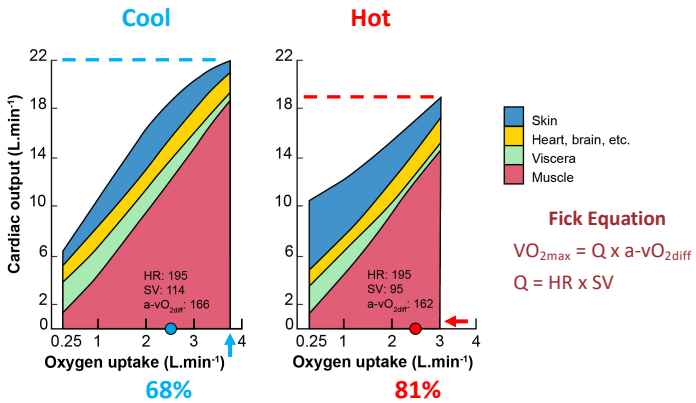
Maximal oxygen uptake – heat stress



68%

81%

Fick Equation

$VO_{2max} = Q \times a\text{-}vO_{2diff}$

$Q = HR \times SV$

- Same absolute work rate (e.g. 200 W = 2.5 L.min^{-1})
- Greater relative intensity (%VO_{2max})

Rowell (1974) *Physiol Rev*

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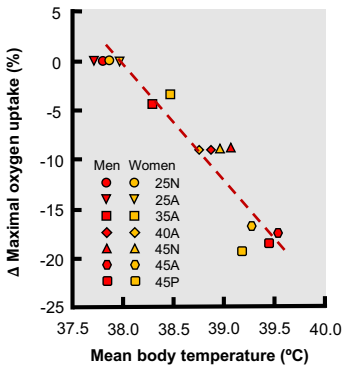
Maximal oxygen uptake – heat stress



25N: 25°C without warm-up
25A: 25°C with a 20-min warm-up
35A: 35°C with warm-up (35A)
40A: 40°C with warm-up
45N: 45°C without warm-up
45A: 45°C with warm-up
45P: 45°C with passive heating to core temperature of 45A

- Proportional relationship between mean body temperature and VO_{2max} in both men and women exercising in the heat

Arngrimsson et al. (2004) *Eur J Appl Physiol*

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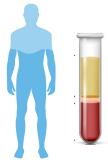
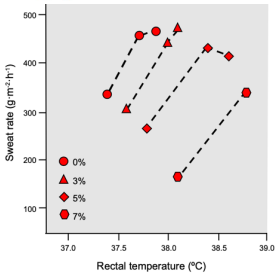
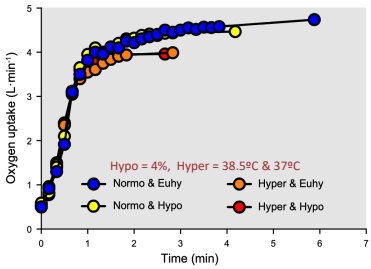
Maximal oxygen uptake – heat & hydration



↓ Plasma volume
↑ Plasma [Na^+]

↓ systemic and regional perfusion & O_2 delivery
↑ glycogenolysis and anaerobic metabolism





- Hydration strategy dictated by:
  - Nature of the task (intensity & duration)
  - Ambient conditions and fluid availability
  - An understating of fitness and acclimation status

Sawka et al. (1985) *J Appl Physiol* Nybo et al. (2001) *J Appl Physiol*

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Heat mitigation

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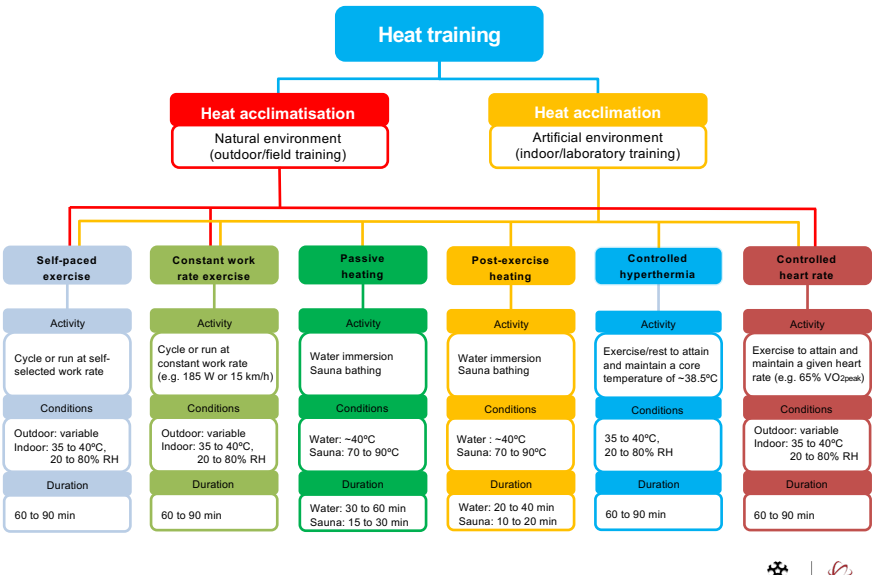
Heat training protocols



Périard et al. (2021) *Physiol Rev*

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Heat adaptations and functional consequences

Adaptation	Consequence
Core temperature	Reduced
Rest - Decreased	
Exercise - Decreased	
Sweating	Improved
Onset threshold - Decreased	
Rate - Increased	
Sensitivity- Increased	
Skin temperature	Reduced
Exercise - Decreased	
Skin blood flow	Improved
Onset threshold - Decreased	
Sensitivity- Increased	
Fluid balance	Improved
Thirst - Improved	
Electrolyte losses - Reduced	
Total body water - Increased	
Plasma volume - Increased	
Cardiovascular stability	Improved
Heart rate - Lowered	
Stroke volume - Increased	
Cardiac output - Better sustained	
Blood pressure - Better defended	
Skeletal muscle metabolism	Improved
Muscle glycogen - Spared	
Lactate threshold - Increased	
Muscle and plasma lactate - Lowered	
Muscle force production - Increased	
Whole-body metabolic rate	Lowered
Acquired thermal tolerance	Increased
Heat shock proteins expression - Increased	
Cytoprotection – Improved	

Périard et al. (2021) *Physiol Rev*

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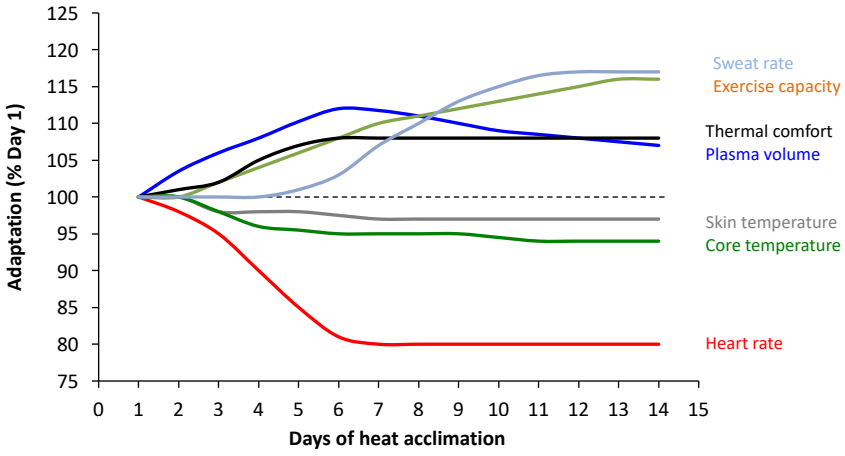
Heat acclimation – Adaptations



Périard et al. (2015) *Scand J Med Sci Sports*

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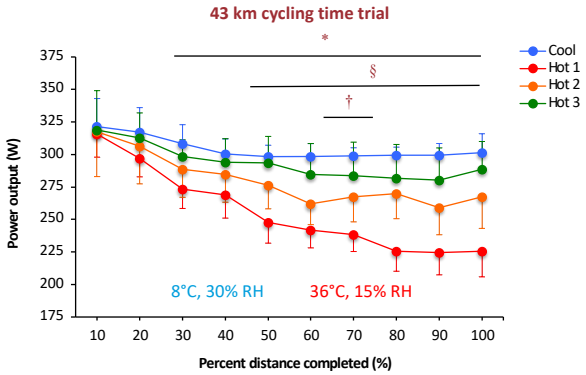
Heat acclimatisation – cycling performance



Racinais et al. (2015) *Med Sci Sports Exerc*

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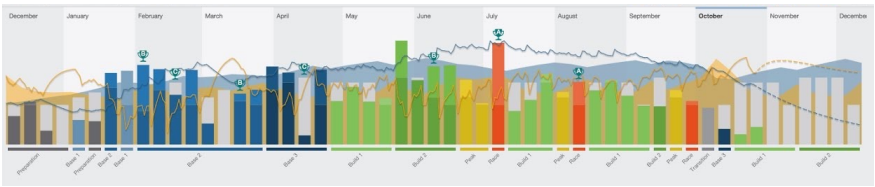
Heat acclimation – Elite athlete considerations



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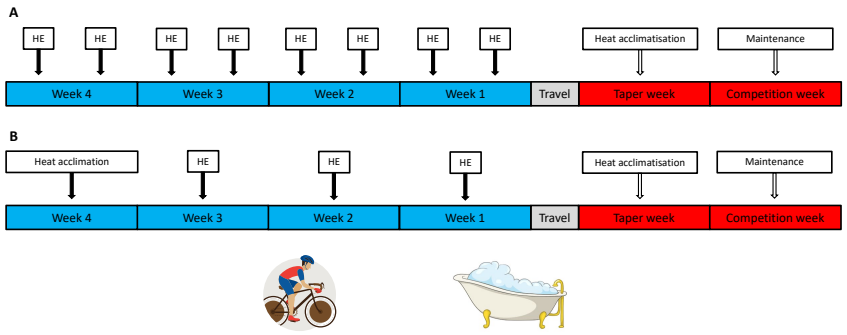
Heat acclimation – Considerations (early)



- **HE - heat exposure:** Unique exposures
- **Heat acclimatisation:** Training outdoors at competition venue in the heat
- **Maintenance:** Heat acclimation/acclimatisation adaptations maintained through training in outdoor heat
- **Heat acclimation:** Daily exposures for 5 to 10 days using different approaches

Saunders et al. (2019) *Int J Sport Nutr Exerc Metab*

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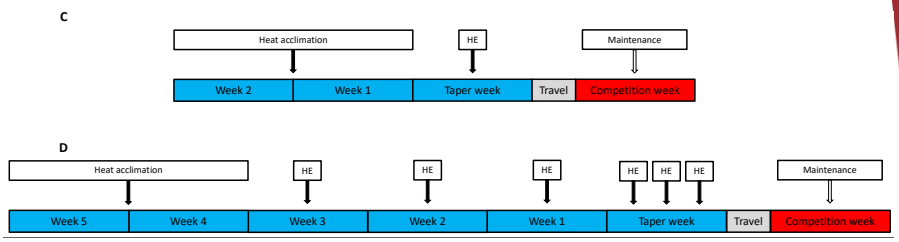
Heat acclimation – Considerations (late)



- **HE - heat exposure:** Unique exposures
- **Heat acclimatisation:** Training outdoors at competition venue in the heat
- **Maintenance:** Heat acclimation/acclimatisation adaptations maintained through training in outdoor heat
- **Heat acclimation:** Daily exposures for 7 to 14 days using different approaches

Saunders et al. (2019) *Int J Sport Nutr Exerc Metab*

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Cooling techniques – practical considerations

Cooling Technique	Examples	Precooling	Per-Cooling	Key Advantages	Potential Disadvantages
External Cooling					
Cooling garments	Cooling vest Ice vest Cooling packs Ice towel Neck collar	✓	✓	Most effective per-cooling strategy Available in different types and sizes Garments can be adjusted to sport type Phase change materials can be adjusted to melting-point specific cooling temperatures (i.e., 6°C, 15°C, 21°C) Easy to apply and implement	Additional weight may hamper use for per-cooling Large differences in cooling time and rate across garments Sport rules and regulations may prohibit use during competition
Cold water immersion	Whole body immersion Partial water immersion	✓		Most effective precooling strategy Covers a large part of the body	Difficult to implement in field-based settings Special equipment is needed (e.g., bath, ice) May lower muscle temperature below optimal physiological state
Fan use	(Cold) air fanning Water spray + fanning	✓		Easy to apply and implement	Only applicable to static conditions Less effective in humid environments Electricity or batteries required
Internal Cooling					
Cold/iced beverage ingestion	Cold water ingestion Ice slurry ingestion	✓	✓	Direct effect on core body temperature Contributes to maintain fluid balance Easy to apply and implement	Potential gastrointestinal discomfort

Périard et al. (2021) *Physiol Rev*

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Take home messages

- Human interaction with the environment
  - Thermal environment: 4 environmental and 2 personal parameters
  - Heat stress index: integrative index most strongly related to thermal and cardiovascular strain…use to expand on UCI extreme weather protocol
- Endurance performance in the heat
  - Heat stress increases thermal and cardiovascular strain → impairs performance
    - Progressive reduction in VO_{2peak} and increase in relative intensity for given work rate
  - Dehydration exacerbates thermal and cardiovascular strain → precipitates fatigue
  - Hydration strategy: individual (fitness, acclimation) and context (task, conditions) specific
- Heat mitigation
  - Heat acclimation for elite cyclists:
    - Adapt to training/competition schedule, availability of resources and predicted weather → using a variety of approaches
  - Cooling interventions for elite cyclists:
    - Identify what works in different setting → combine different approaches

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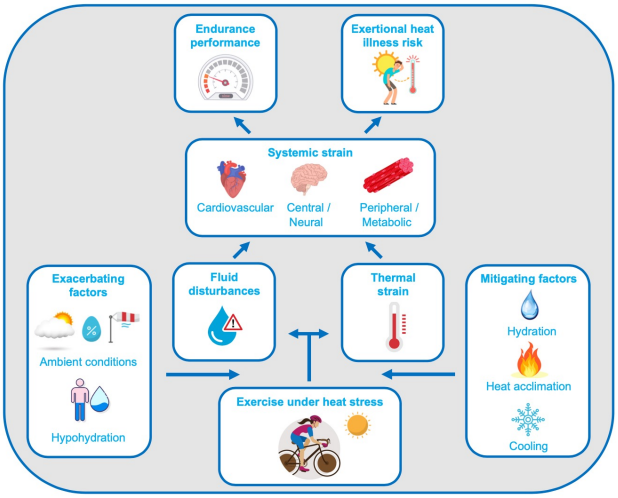
Graphical summary



Exercise under heat stress: thermoregulation, hydration, performance implications and mitigation strategies
Julien D. Périard, Thijs M.H. Eijsvogels, and Hein A.M. Daanen
https://t.co/kS1mfxkvlW?amp=1

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Thank you

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