

Heat Training & Sports Performance

熱適應訓練與運動表現



**HONG KONG
SPORTS INSTITUTE**
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Content

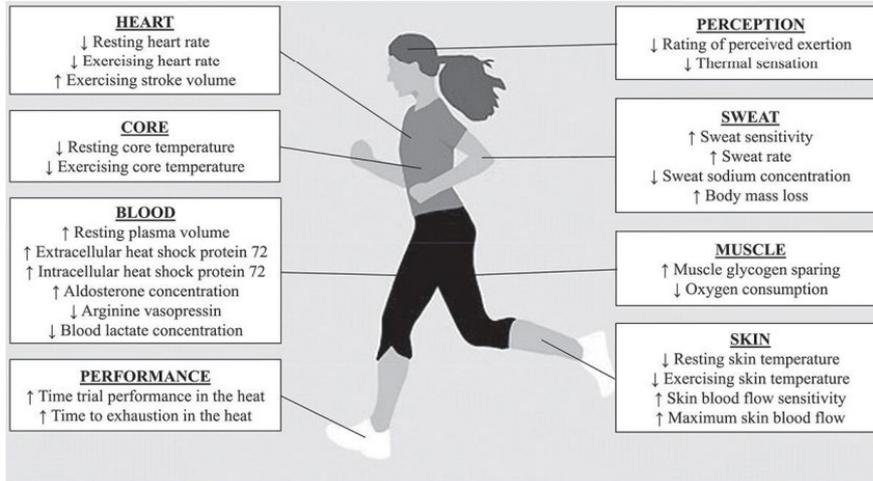
- **Physiology of Heat Adaptation**
- **Reasons of enhancing performance in hot condition & temperance condition**
- **Heat Training Protocols**
- **Monitoring during heat training**
- **Heat trainings & studies conducted in HKSI**
- **Q & A**

PHYSIOLOGY OF HEAT ADAPTATION

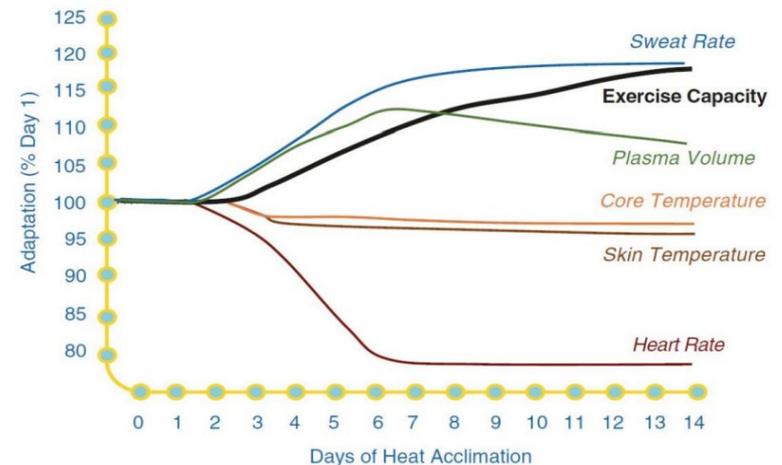
Heat Training

- **Definition:** The intentional, repeated exposure to heat during exercise, either in a controlled environment (like a chamber) or outdoors, to stimulate the body to adapt.
- **Environment:**
Acclimation = controlled/artificial
Acclimatization = natural/outdoor
- **Goal:** To trigger physiological adaptations that improve the ability to tolerate and dissipate heat.
- **Applications:** endurance sports, military, occupational performance and rehabilitation context.

Heat Adaptations examples and time course



Physiological and Perceptual Adaptations during Heat Acclimation (Pryor et al., 2018).



Time course of Adaptations to exercise-heat acclimation. (Periard & Racinais, 2019).

- Heat adaptation occur over ~10–14 days, with some appearing within 3–5 days.
- Adaptations appear quickly and stabilize with consistent exposure.

i) Cardiovascular Adjustments

- **↑ Plasma volume 血漿量 (5–25%)** → improves central blood volume and stroke volume.
 - Plasma volume expansion as early as 3 days post-exposure due to increased plasma proteins and water retention.
 - Improved cardiac filling 心臟充盈 and reduced cardiovascular drift 心跳率偏移 during endurance activity.
- **↓ Heart rate and ↑ cardiac efficiency** at same workload.
- Maintains blood pressure and heat dissipation capacity.
- **↓ Skin and core temperature gradient** = improved cooling.

Sawka et al., 2011; Périard et al., 2015

ii) Thermoregulatory Adaptations

- **Earlier onset of sweating**, ↑ sweat rate, wider distribution of glands.
 - Fine-tuning of sweat gland sensitivity and improved hypothalamic thermoregulation allows improved heat dissipation.
- **Reduced sweat electrolyte concentration** (Na^+ , Cl^- losses ↓).
 - Electrolyte conservation protects against hyponatremia 低血鈉症 during prolonged exercise.
- **↓ Resting and exercising core temperature.**
- **Enhanced skin blood flow** for efficient convective and evaporative cooling.

- **Rising core and skin temperatures lead to ↑ Myocardial Strain**

Reasons:

- Elicit reflex and locally mediated vasodilation of the cutaneous vasculature to facilitate transfer of blood-borne heat to the skin where it can be dissipated to the environment
- Vascular resistance necessitates an elevation in cardiac output to maintain arterial pressures and systemic blood flow

Kenny, G.P et al.,2013; Crandall,C.G et al., 2015

iii) Hematological and Hormonal Adaptations

- **Aldosterone 醛固酮** and **Vasopressin/Antidiuretic Hormone (ADH) 抗利尿激素** promote sodium and water retention.
- **Increased Erythropoietin (EPO) 紅血球生成素** release may occur transiently due to plasma expansion and mild hypoxia.
- Maintains volumetric homeostasis and oxygen delivery.

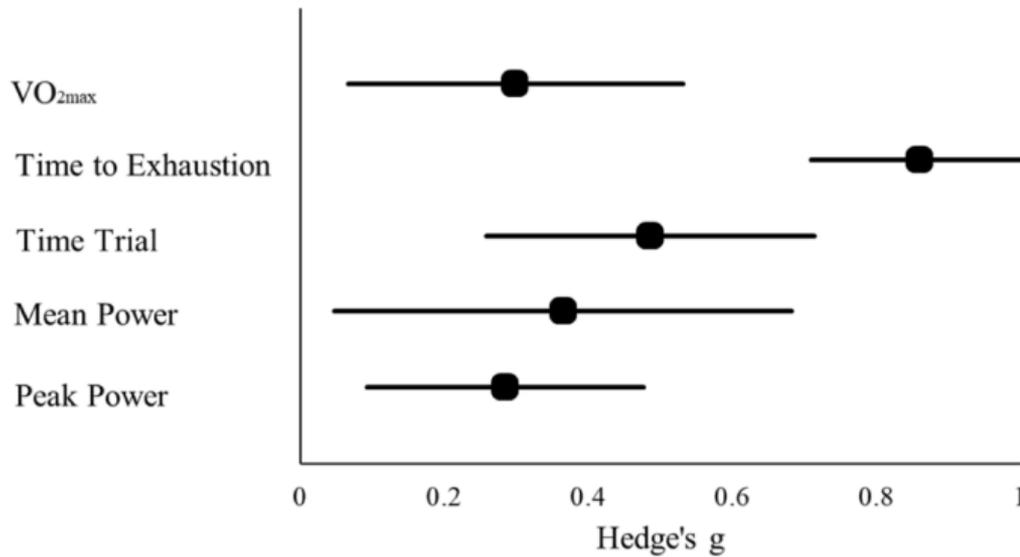
Hormonal mechanisms underpin the fluid retention and cardiovascular stability critical for endurance performance, indirectly supporting oxygen transport efficiency.

iv) Metabolic and performance-level adaptations

- **↑ Heat shock proteins 熱休克蛋白 (HSPs)** protect cellular integrity and enzyme function.
 - Stress proteins contribute to a “cellular memory” for future heat exposures.
- **↑ Mitochondrial efficiency 線粒體效率 and fat oxidation rates**, reducing glycogen 肝糖 depletion.
 - Metabolic shifts reduce oxygen and energy expenditure for a given workload.
- **Cross-adaptation:** partial tolerance to hypoxic stress.

Riabowol et al. 1988; Walsh et al. 2001; Marshall et al. 2006; Lovell et al. 2007; Zhizhong Geng et al., 2025; Patrick R. et al, 2025

Performance enhancements examples and magnitude



Greatest improvement:

- 1) Time to exhaustion
- 2) Time trials
- 3) Mean power
- 4) VO₂ max
- 5) Peak power

Improvements in Performance following heat acclimation

REASONS OF ENHANCING PERFORMANCE IN HOT & TEMPERANCE CONDITION

Performance Enhancement in Hot Conditions

- Lower core & skin temperatures during exercise in heat.
- Reduced cardiovascular strain (\downarrow HR, \uparrow stroke volume).
- Better sweat efficiency delays dehydration onset.
- Improved endurance time and power maintenance.

These benefits directly reduce thermal discomfort and prevent overheating, enabling sustained performance in hot races or training environments.

Electrolyte and Fluid Optimization

- Improved sodium retention conserves plasma volume.
 - The repeated activation of aldosterone–vasopressin pathways helps athletes handle fluid loss more efficiently, maintaining muscle perfusion and thermoregulation.
- Hyponatremia risk decreases with repeated exposure.
- Rehydration response is optimized via renal hormonal feedback.

Sustained Aerobic Capacity in Heat

- Trained athletes show smaller decline in $VO_2\text{max}$ under heat stress.
- Enhanced blood flow distribution prioritizes working muscles.
- Less cardiovascular drift and fatigue.

10 days of heat acclimation increased temperate exercise $VO_2\text{max}$ by 5% and time trial performance by 8% in heat.

Cross-Environmental Performance Gains

- ↑ Plasma volume strengthens cardiovascular function in all temperatures.
- Larger thermal reserve → longer time before fatigue onset.
- Gains extend 2–3 weeks post-acclimation.

“Cross-acclimation” effect: improvements produced by heat exposure carry over into temperate or mild conditions due to enhanced circulatory and metabolic efficiency.

Hemodynamic and VO_2max Efficiency

- More oxygen delivered per heartbeat.
- ↓ Heart rate for given load, ↑ stroke volume (“cardiac training effect”).
- Supports recovery and pacing stability.

The cardiovascular economy gained from heat exposure underpins improvement in cool conditions, often equivalent to low-altitude hematological training.

Thermal Reserve and Fatigue Resistance

- Lower core temperature at onset → greater thermal reserve.
- Delays central fatigue and mental exertion costs.
- Improved blood flow and oxygen utilization efficiency.

Heat-acclimated athletes start cooler, accumulate heat more slowly, and sustain higher intensities before perception of heat distress limits performance.

Hematological Carryover

- Repeated plasma volume expansion may stimulate erythropoiesis.
- Improves blood oxygen-carrying capacity similar to mild altitude exposure.
- Short-term hematological gains may persist up to 1–2 weeks.

HEAT TRAINING PROTOCOL

Different heat acclimation Protocols

- Protocol various by design:
 - 35-40°C
 - 10-90% relative humidity
 - Up to 90 mins exercise duration
 - 8-22 consecutive days

PERIARD ET AL.

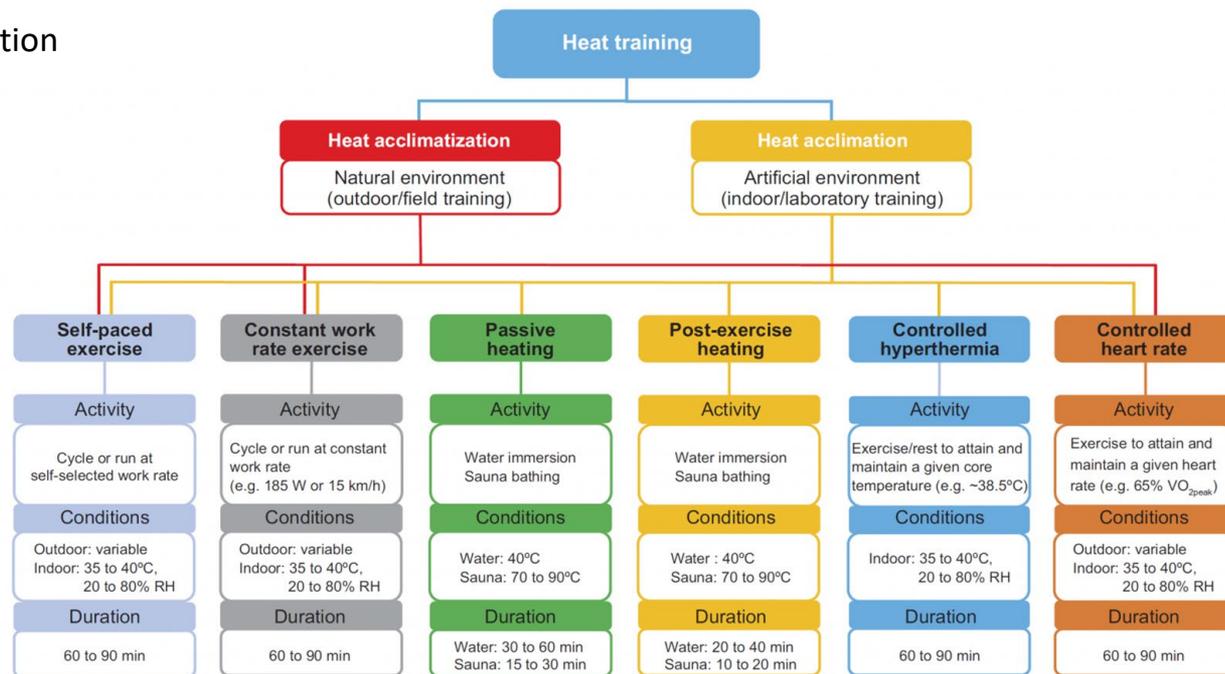


FIGURE 22. Schematic overview of the methods used for heat acclimation and heat acclimatization, with examples for activity selection, environmental conditions and duration. Manipulation of temperature and humidity is recommended in accordance with the anticipated environmental conditions to be encountered during upcoming competitions. RH, relative humidity. Adapted with permission from Daanen et al. (814).

Different heat adaptation protocols

Table 2. Various heat acclimation induction methods with advantages and disadvantages.

Protocol	Duration	Intensity	Length	Advantages	Disadvantages
Variable workload					
Controlled hyperthermia	60–90 min	Initially high to achieve $T_c = 38.5^\circ\text{C}$ within ~30 min, then lower intensity to sustain T_c thereafter	5–14 days	Sustained thermal adaptive impulse Potential optimization of adaptations [18]* Plasma volume, HR, and the emergence of thermoregulatory and metabolic adaptations improve thermal tolerance and performance after only 5 d in trained athletes [75]	Requires valid T_c measurement [60,61] Ideal (usually high) exercise intensity to achieve $T_c \geq 38.5^\circ\text{C}$ within 30 min unknown and changes as adaptations occur; may be challenging for novice athletes Overall mean relative work rate and HR ↓ over protocol [75]
Self-paced	60–90 min or duration of practice	Varies	7–14 days	Very practical for team-based sports Induce HA while training sports skills during practices or pre-season activities [91–93] Trained athletes can sustain intensities within narrow range [94]	Less control of exercise variables and adaptive stimuli, day-to-day improvements not easily measured Requires motivated athletes May not induce all HA adaptations
Controlled heart rate	60–90 min	~70% heart rate reserve or heart rate at lactate threshold	5–14 days	Sustained relative exercise intensity and cardiovascular strain [32,78] May use sport-relevant intensities	Thermal adaptive impulse difficult to quantify Cardiac drift may lower absolute exercise intensity
Constant workload					
Average fitness athletes	100 min	40–50% $\dot{V}O_{2\text{max}}$	10–14 days	Easy to implement Day-to-day improvements easily measured	Thermal strain/adaptation stimuli ↓ as HA progresses May ↓ magnitude of adaptation*
High fitness athletes	30–45 min	75% $\dot{V}O_{2\text{max}}$	5–9 days	Easy to implement Day-to-day improvements easily measured May supplement with passive-heat exposures	Thermal strain/adaptation stimuli ↓ as HA progresses May ↓ magnitude of adaptation
Passive-heat exposure Sauna bathing	20–30 min	50–100°C, 10–20% RH	5–21 days	↓ exercise-heat training volume May use every other day	Requires sauna room Time constraint due to exercise immediately before or after
Hot water immersion	30–60 min	40–44°C	14–21 days	↓ exercise-heat training volume May use every other day	Time constraint due to exercise immediately before or after

T_c = core temperature. $\dot{V}O_{2\text{max}}$ = maximal oxygen consumption. Table modified from [95]. * One studied showed controlled hyperthermia and constant workload protocols exhibited similar physiological and cellular adaptations [76].

Induction method of heat acclimation

5 general induction method:

- Controlled hyperthermia/isothermal
- Controlled work-rate
- Self-regulated
- Controlled heart rate/relative intensity
- Passive heating (i.e sauna, hot water)

May be beneficial to use multiple methods to obtain the greatest HA adaptations
(Pryor et al., 2019a)

- Little consensus exists on which induction method is most optimal
- Limitation: Maximal potential thermal load of all induction methods may not be achieved

Recommendation for effective heat acclimation

- Core temperature: elevation to **38.5oC** (minimal requirement)
- Duration: Not less than **60 mins**
 - Although heat adaptation may be induced with shorter duration/higher intensity protocols in highly trained athletes, prudent recommendations are that athletes should aim for **60–90 min** of exercise-heat exposure
 - Aim up to **2 hours** to enhance heat acclimation effectiveness and delay adaptation decay
- Ideal timing prior to competition: **1-3 weeks prior** to competition to allow sufficient recovery and enable a training taper

Other consideration:

Heat acclimation decay and maintenance

- **Much variation** in current studies regarding the rate at which the physiological adaptations from heat acclimation are lost or decay
- In general, adaptation **fades within ~2 weeks** but **re-acclimates faster** than initial phase.
- Many studies show that heat acclimation is **better retained using dry-heat acclimation** rather than **humid-heat acclimation**
- **Longer period** of heat acclimation, the longer adaptation will remain
- The rate of heat adaptation may depend on factors:
 - Fitness level, environmental conditions, and intensity/duration of training, no. of heat exposures per week, the degree at which core body temperature is increased, and individual's pre-existing natural heat
- Periodic “**maintenance**” sessions (once/week) help retain benefits.

Pandolf, 1998; Lorenzo et al., 2010; Garrett et al., 2011; Pandolf et al., 1977; Armstrong & Maresh, 1991; Racinais et al., 2015

Other consideration: Short- vs. Long-Term Acclimation

- **Short-term (3–7 days):** HR ↓, sweat onset earlier, small plasma expansion.
- **Long-term (10–14 days):** full thermoregulation, higher sweat rates, greater plasma stability.
- **Decay rate:** half-life \approx 5 days without heat exposure.

Other consideration:

Post-Exercise Passive Heat Exposure

- Hot-water immersion (39 °C, 30–40 min) **immediately post exercise**.
- Raises core temperature to > **38.5 °C** threshold → adaptation signal.
- **Feasible in athletes unable to perform high-intensity training in heat.**

Zurawlew et al. (2016) showed repeated passive HWI produces similar physiological outcomes to traditional hot-room cycling protocols.

MONITORING DURING HEAT TRAINING

Stress and Hydration Monitoring

- Physiological: HR, core temperature
- Subjective: RPE
- Aim for < 2% body mass loss during sessions.
- Pre/post weigh-ins,
- Replace ~150% of fluid lost with water + Na-containing fluids.

Casa et al., 2015

HK RUGBY men's Team Heat Training monitoring: HR, RPE, Pre/post weight

Date	Group	Duration (min)	Station	Rest (min)	Max HR (Station)	Avg HR (Station)	Overall RPE	Max HR (Personal)	Avg HR %	BW Before (kg)	BW After (kg)	Weight Differer	
4/11/2025		1	4	Wattbike	1	136	127	4	199	63.82%	81.4	81.0	-0.4
4/11/2025		1	4	Ski Erg	1	155	140	5	199	70.35%			
4/11/2025		1	4	Wattbike	1	155	148	5	199	74.37%			
4/11/2025		1	4	Ski Erg	1	156	149	4	199	74.87%			
4/11/2025		1	4	Wattbike	1	163	153	5	199	76.88%			
4/11/2025		1	4	Ski Erg	1	163	157	6	199	78.89%			
4/11/2025		1	4	Wattbike	1	138	128	4	187	68.45%	75.3	75.3	0.0
4/11/2025		1	4	Rowing	1	151	141	5	187	75.40%			
4/11/2025		1	4	Ski Erg	1	150	144	5	187	77.01%			
4/11/2025		1	4	Wattbike	1	153	146	5	187	78.07%			
4/11/2025		1	4	Rowing	1	159	152	5	187	81.28%			
4/11/2025		1	4	Ski Erg	1	159	156	6	187	83.42%			
4/11/2025		1	4	Wattbike	1	141	131	4	193	67.88%	94.2	93.4	-0.8
4/11/2025		1	4	Ski Erg	1	152	144	6	193	74.61%			
4/11/2025		1	4	Wattbike	1	158	151	5	193	78.24%			
4/11/2025		1	4	Ski Erg	1	160	152	7	193	78.76%			
4/11/2025		1	4	Wattbike	1	163	153	6	193	79.27%			
4/11/2025		1	4	Ski Erg	1	171	151	9	193	78.24%			
4/11/2025		1	4	Rowing	1	158	138	5	198	69.70%	87.7	87.9	0.2
4/11/2025		1	4	Ski Erg	1	153	147	5	198	74.24%			
4/11/2025		1	4	Wattbike	1	163	153	6	198	77.27%			
4/11/2025		1	4	Rowing	1	174	159	6	198	80.30%			
4/11/2025		1	4	Ski Erg	1	170	163	5	198	82.32%			
4/11/2025		1	4	Wattbike	1	172	163	6	198	82.32%			

Core temperature measurement

- Temperatures which are too high or too low can change metabolic rates, perturb organ function and cause tissue damage.
- Typically differs from their skin temperature by 23 °C and varies between 36.5 and 37.5 °C (Quast and Kimberger, 2015)

→ Body temperature and the temperature of the body's surroundings are of vital importance for life and health.

1. Ingestible Sensor

- Silicone-coated sensor.
- Contains a micro battery, communication coil, circuit board, and other components.
- Remains in the body for approximately 24 to 36 hours.
- Accuracy may be affected by the movement of the pill from the stomach to different locations.
- Relatively expensive.

2. Rectal or Esophageal Temperature Measurement

- Wired device.
- May be uncomfortable during exercise.
- Known for accuracy and reliability.

3. Non-Invasive Core Temperature Sensor

- AI-powered algorithm that uses data for core temperature calculations with medical-grade accuracy.

Note: Oral and auditory canal temperature measurements do not accurately reflect core temperature.

HEAT TRAININGS & STUDIES CONDUCTED IN HKSI

Case 1

HK Rugby men's Team: Heat training

For preparing Asian Series : HangZhou & Sri Lanka in September & October 2025

Training information:

10 session of heat training in environmental chamber , 1 session/wk

38oC, 70% humidity

4 mins on/1 min off x 6 sets

Intensity 80% of mHR

Pre & post step test comparison (i.e. heart rate and lactate)

- Some players showed lower heart rate and right shift of the lactate curve

Case 2

HK Triathlon Team: Heat training

For preparing 2022 U23 World Championships (Abu Dhabi, United Arab Emirates) or
2022 Aisa Triathlon Cup (Ipoh, Malaysia)

Training information:

Started 3 weeks before competition

5 active (Running/Cycling) + 3 passive (Post-exercise hot water immersion) = total 8 sessions

4 session in week 1, 4 sessions in week 2

Remarks:

HA sessions were integrated into the existing training programme, such that planned external training load remained unaltered

Outdoor high-intensity training sessions were followed by 30–50 min HWI (water temperature ~ 39 °C), whilst low intensity running/cycling sessions were relocated to a thermostatically controlled environmental chamber (running; 35 °C, 50% relative humidity [R.H.], cycling; 39 °C, 50% R.H.)

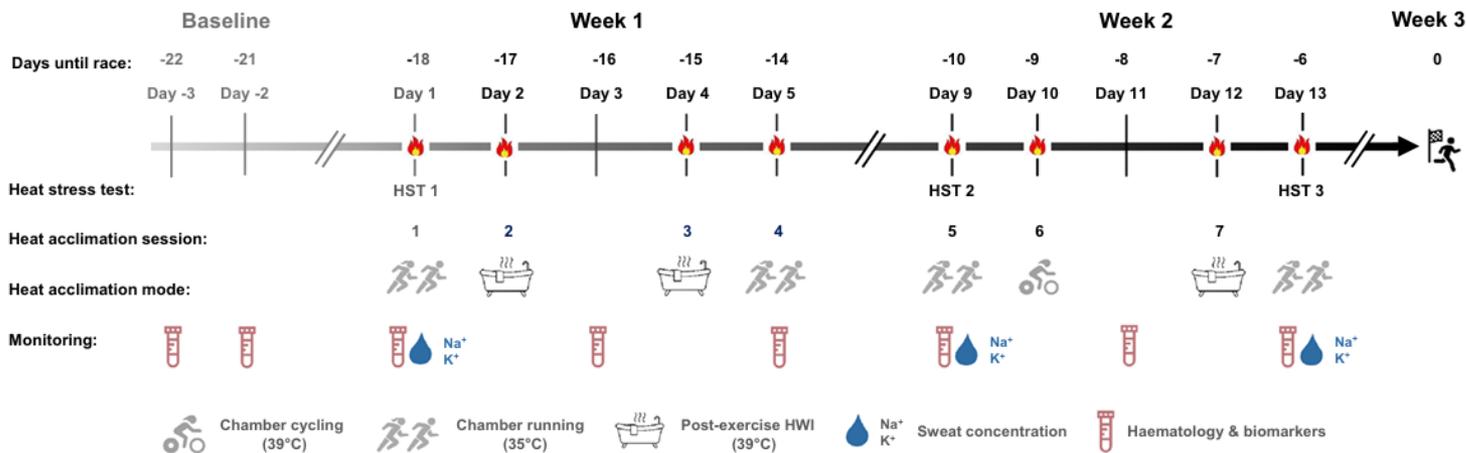
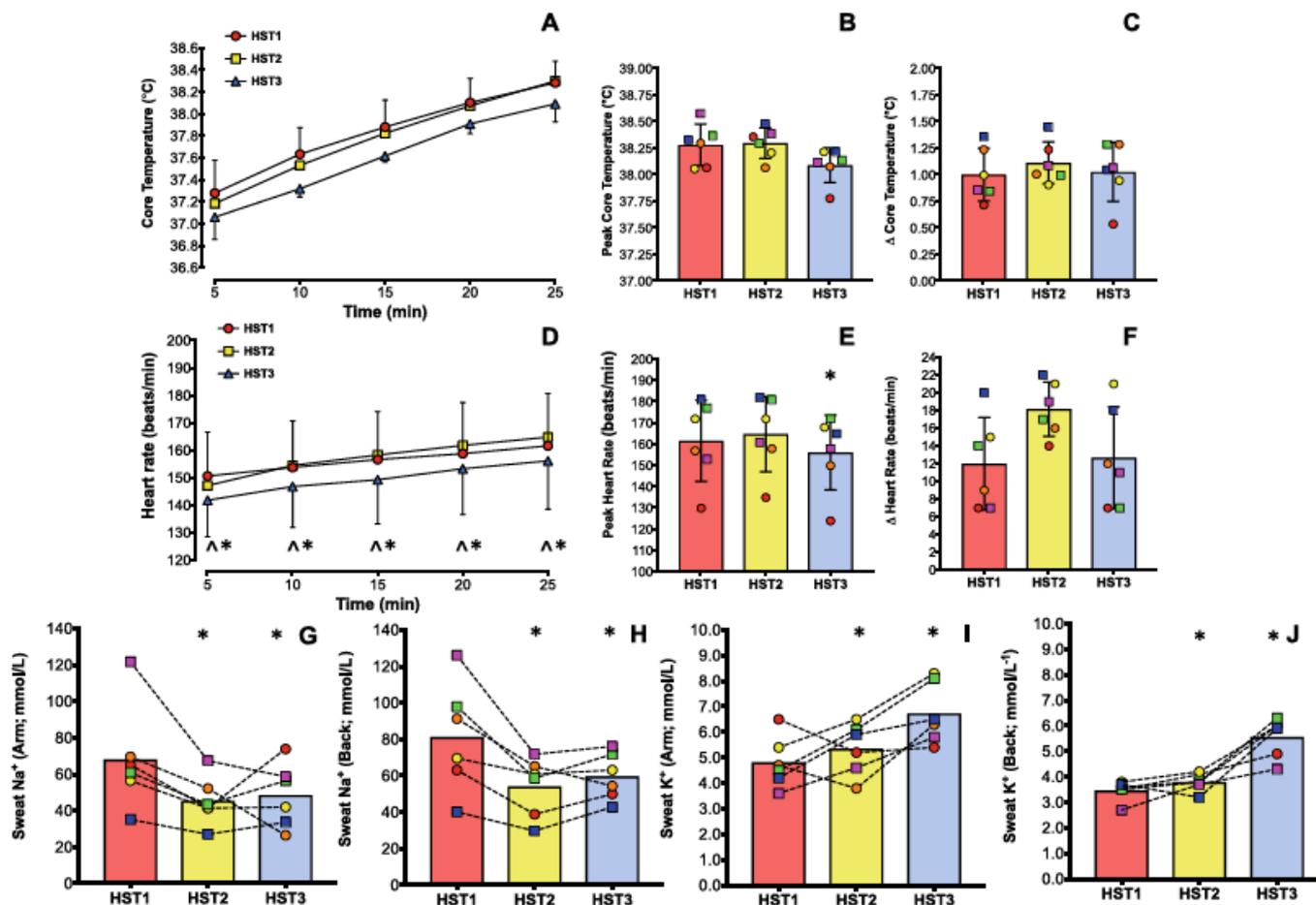
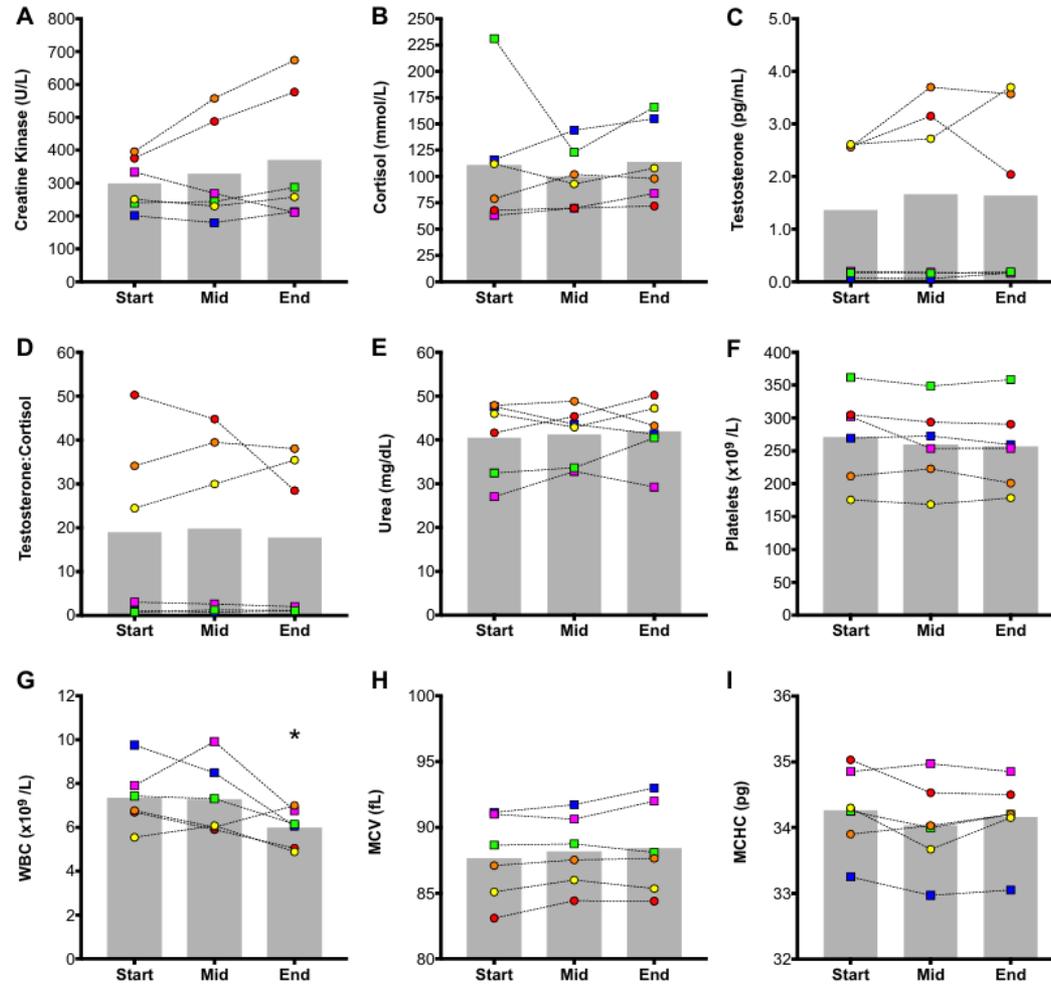


Fig. 1 Overview of HA training intervention. *HST* heat stress test, *HWI* hot water immersion

- Reduced exercising HR during Heat Stress Test 3 (HST3)
- Lower sweat Na⁺ concentrations from Heat Stress Test 2 (HST2)
- Core temperature was lower in four out of six athletes in Heat Stress Test 3 (HST3)



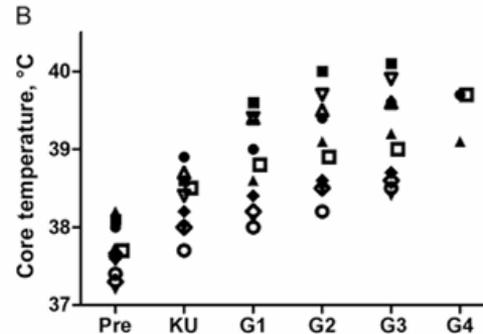
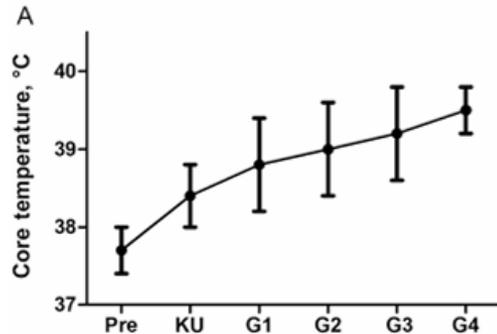
- Concurrently, no adverse effects on haematological immune and health markers were observed



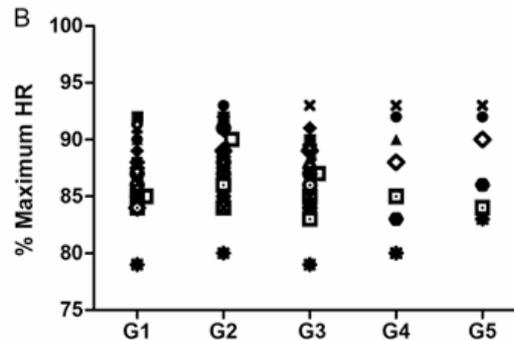
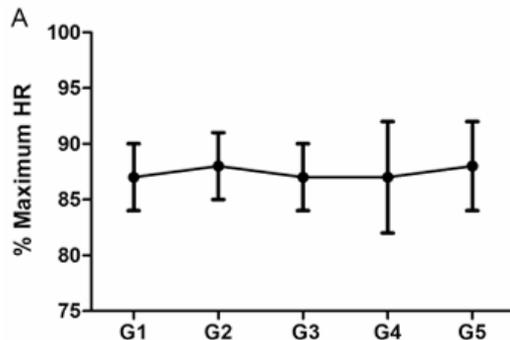
Panel of measured biomarkers during the HA training intervention

Case 3

HK Squash Team: Study on player's heat strain during tournament match play in order to evaluate the need and effectiveness of tailored mitigation strategies for preparing Los Angeles 2028



Mean (panel A) and individual (panel B) changes in core temperature prior to warm-up (Pre) and following KU and G1 to G4 during squash tournament match play. Data include 10 observations from 4 athletes. G1–G4 indicates games 1 to 4; KU, knock up.



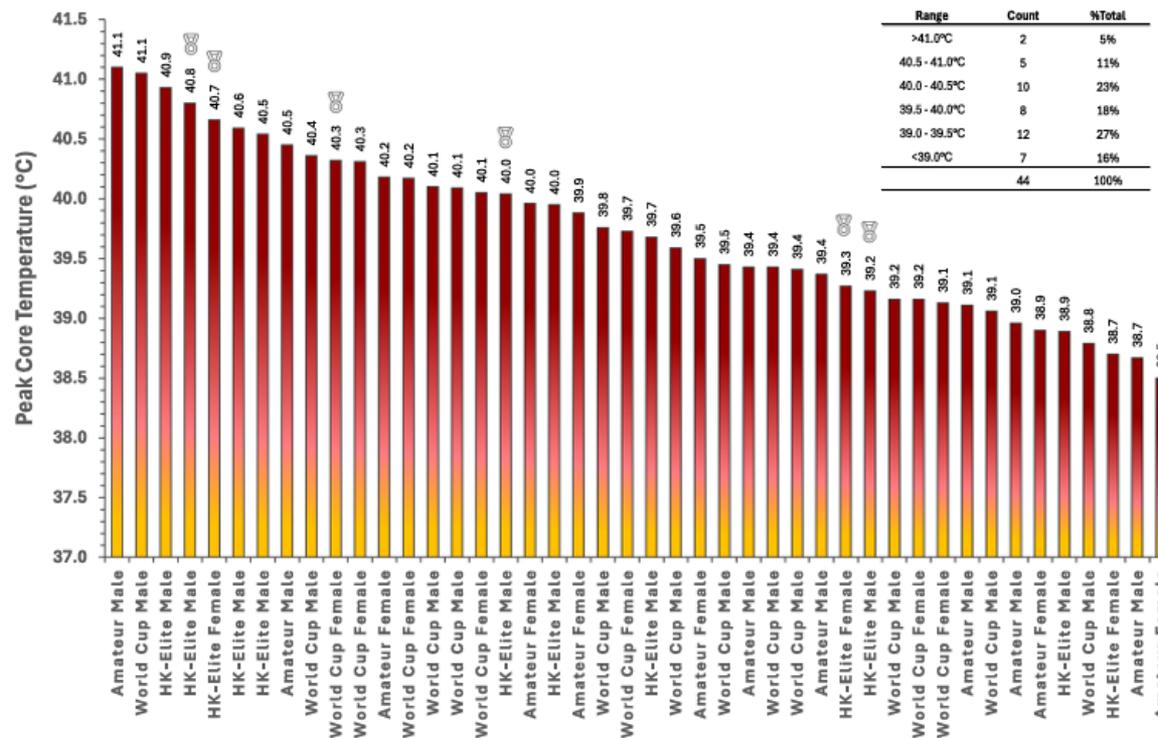
Mean (panel A) and individual (panel B) changes in HR during G1 to G5 during squash tournament match play. Data include 22 observations from 6 athletes. G1 to G5 indicates games 1 to 5; HR, heart rate.

Case 4

HK Triathlon Team: Study on triathlon athletes' heat strain during a sprint triathlon, questioning whether this remains a suitable exertional heat illnesses (EHI) safety mitigation strategy for Olympic-distance triathlons held under Red/Back flag condition (>30oC WBGT)

Core temperature monitoring and analysis during Hong Kong Triathlon World Cup 2024

- Core temperature may rise > 41 °C during a sprint triathlon held under Green/Blue flag conditions, (~26 oC WBGT)



Conclusion

- Heat training produces multi-system adaptation improving endurance performance.
- Transferable benefits extend beyond hot-weather competition.
- Requires control, safety, and tailored programming.
- 10–14 days of controlled heat exposure = optimal window.
- Benefits persist ~1–3 weeks.
- Individual monitoring essential for safety.
- Scientifically validated tool for performance optimization.

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Thank You



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