COACHES' GUIDE

TO TRAINING AND COMPETING IN THE HEAT

EP2 FINLAND

ENVIRONMENTAL EXERCISE PHYSIOLOGY PROGRAM

About this guide

This guide is designed to provide athletes, coaches, and practitioners with a comprehensive, evidence-informed understanding of training and competing in hot environments. It brings together scientific principles and practical strategies that help readers optimize performance while minimizing health risks associated with heat stress.

Originally developed by members of EP2 FINLAND, with contributions from national and international partners, this guide builds on years of research in the field of environmental exercise physiology.

The content is organized into five key parts, each addressing a critical aspect of heat and performance:

- Heat Physiology – explains how the body produces, exchanges, and regulates heat
- Athletic Performance in the Heat – explores how different sports are uniquely affected
- Heat Acclimatization – outlines how the body adapts to heat exposure
- Heat Stress Mitigation Strategies – provides practical tools such as cooling, hydration, and training adjustments
- Heat-Related Hazards – highlights risks, prevention, and first-aid responses

Throughout the guide, emphasis is placed on bridging theory and practice. Scientific concepts are presented in a way that supports decision-making in training and competition settings, enabling users to adapt strategies to their specific sport, environment, and individual needs.

Whether preparing for competition in hot climates or managing everyday training in the heat, this guide serves as a practical resource to support safe, effective, and high-performing outcomes.

Additional resources are available online at hula.fi/ep2.

This guide is for informational purposes only and does not replace professional medical or other expert advice. Users assume all risk for their training and competition decisions.

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ENVIRONMENTAL EXERCISE PHYSIOLOGY PROGRAM

PART 1

Heat Physiology

Heat Physiology

1. The Science of Heat Exchange and Heat Balance
2. Thermoregulation and Heat Storage
3. Physiological Responses to Heat

Understanding how the human body responds to heat is the foundation for safe and effective training and competition in hot environments. In this section, we explore the physical and physiological principles that govern heat exchange and thermoregulation, as well as the body's acute responses to heat stress. Whether preparing for a competition in the heat or international events in hot climates, a solid grasp of heat physiology helps coaches and athletes make smarter decisions. These chapters translate complex science into practical knowledge, providing the groundwork for the strategies that follow.

Learning Objectives:

- Understand the different mechanisms of heat exchange between the human body and the environment.
- Learn how environmental conditions and internal heat production interact to affect body temperature regulation.
- Recognize the role of thermoregulation in heat balance.
- Identify how physiological responses to heat can limit performance.
- Gain insights into why training and competing in hot conditions demands special strategies to maintain safety and performance.

The Science of Heat Exchange

When we talk about "hot weather" in the context of sport, air temperature alone doesn't tell the whole story. Exposed individuals need to understand that the true thermal stress placed on the human body is a combination of several environmental and physiological factors. These interact to determine the end result for heat balance: whether the body is gaining or losing heat.

The human body continuously exchanges heat with its environment. This happens through four primary mechanisms: radiation, conduction, convection, and evaporation. Each of these plays a crucial role in how athletes experience and respond to heat during training and competition.[1]

RADIATION

Radiation is the transfer of heat via electromagnetic waves, most noticeably from the sun. On a clear summer day, solar radiation can greatly increase the heat load from the environment.

CONVECTION

Convection involves the movement of heat away from or towards the body via a surrounding fluid, usually air or water. The direction of heat transfer depends on the temperature gradient between the skin and the environment: when the environment is hotter than skin surface, convection increases heat gain. High velocity sports (e.g., cycling) are bound to be affected by convective heat transfer even during less windy conditions.

CONDUCTION

Conduction is heat transfer through direct contact. It's typically a minor factor in sport, but it can matter in specific contexts like sitting on hot ground, holding warm equipment, or cooling with cold, wet towels.

EVAPORATION

In extreme heat, evaporation of sweat may be the only cooling method for the human body. As sweat evaporates from the skin, it dissipates heat and helps lower skin and body temperature. However, this process is heavily influenced by humidity as high humidity decreases evaporation. If sweat is not evaporated but drips off or is wiped away, heat is not dissipated. This makes hot and humid environments a major challenge for participating athletes.

Finding the Balance

While environmental factors like sunlight, humidity, and air movement shape the thermal stress an athlete faces, one critical heat source comes from the athlete itself: the body's own metabolic heat production. During exercise, the body's muscles convert chemical energy into mechanical energy, but this process is inefficient. Most of the energy used during intense physical activity is released as heat, not movement, and heat production can increase 15 to 20-fold during intense exercise.[7] This internal heat must be continuously transferred to the environment to prevent dangerous rises in core temperature. Clothing also affects heat balance by influencing factors of heat exchange. Taking into account environmental conditions, clothing, and the athlete's own heat production gives a more complete picture of thermal strain and can help athletes maintain heat balance.[1]

Thermoregulation and Heat Storage

When training or competing in the heat, understanding how the body regulates its internal temperature is critical. Thermoregulation is the body's ability to maintain a stable core temperature, typically around 37°C, despite fluctuations in environmental conditions or metabolic heat production. During exercise, the thermoregulatory system plays a central role in maintaining heat balance and performance, especially in hot environments where external heat load compounds the body's own metabolic heat production.

The primary control center for thermoregulation is located in the hypothalamus, a region of the brain that acts like a thermostat for the body. It receives input from thermal sensors in the skin, muscles, and organs, then coordinates appropriate responses to maintain thermal balance. These responses can be both behavioural (seeking shade, reducing activity) and physiological (increased skin blood flow, sweating).[1]

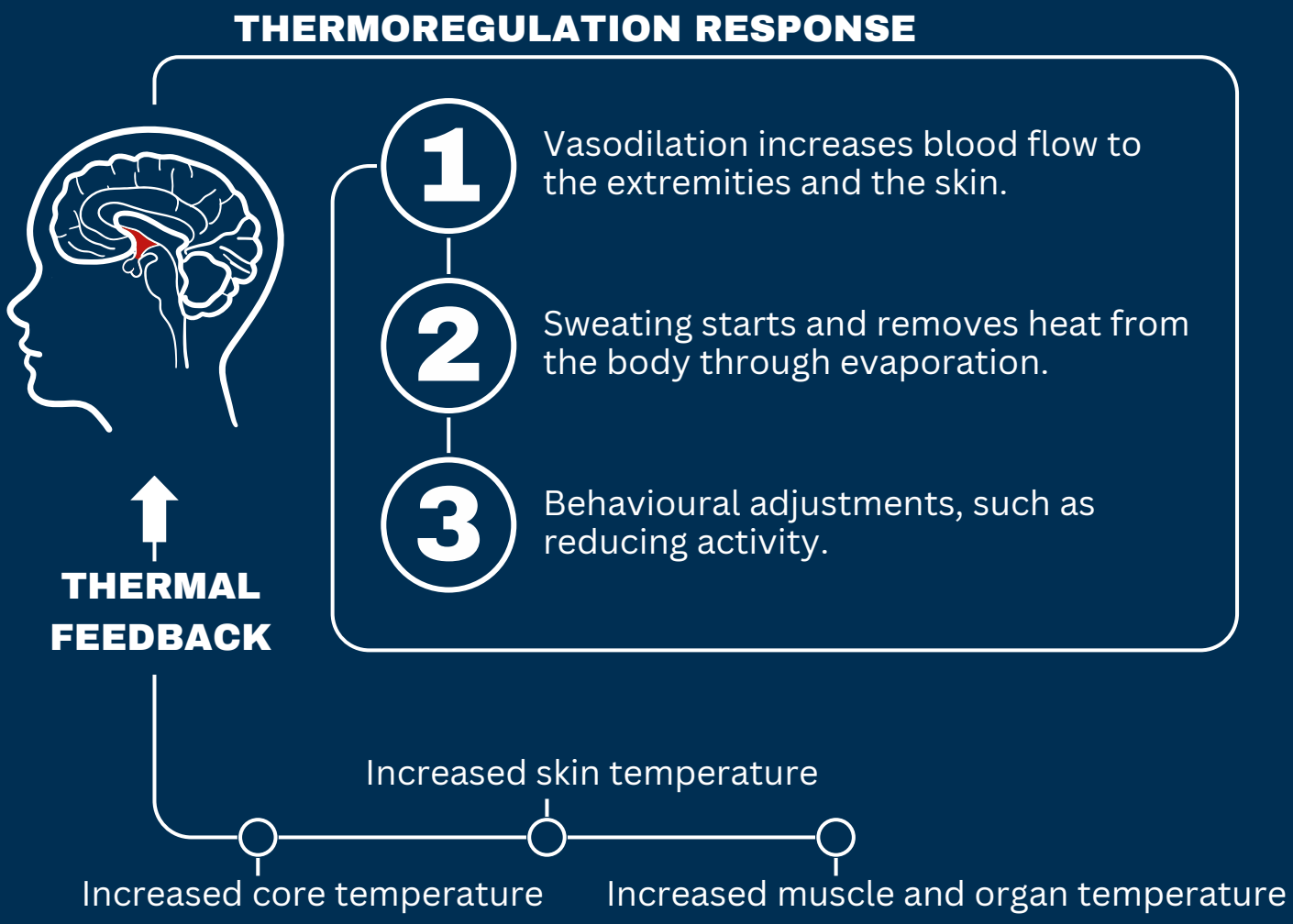

FIG 1.1. The pathway from thermal feedback from the body to thermoregulation responses governed by the hypothalamus.

While mechanisms of thermoregulation try to maintain heat balance at all times, this balance is often disrupted during exercise in the heat. When the thermoregulation response is insufficient to manage the heat stress, the body begins to store heat, causing core temperature to rise. The rate of heat storage depends on factors such as exercise intensity (heat production), environmental conditions, clothing, and individual characteristics, such as anthropometrics.

Individuals with greater body mass and lean muscle mass have a higher capacity to store heat, which can help moderate the rise in core temperature during passive exposure. This means that larger individuals may experience slower and smaller increases in body temperature compared to those with lower mass during brief exposures. However, when heat exposure is prolonged or it is accompanied with heat production from exercise, the emphasis shifts from storage to the body's ability to effectively dissipate heat.[2] Under these conditions, a high body surface area-to-mass ratio (BSA:mass; m^2/kg), typical of a small and lean build, is more favourable.[9] Mild to moderate heat storage and an increase in core temperature is a normal and well-tolerated part of exercise. However, as core temperature approaches 39–40 °C, performance detriments and an increased occurrence of heat-related illnesses can be expected.[1,3]

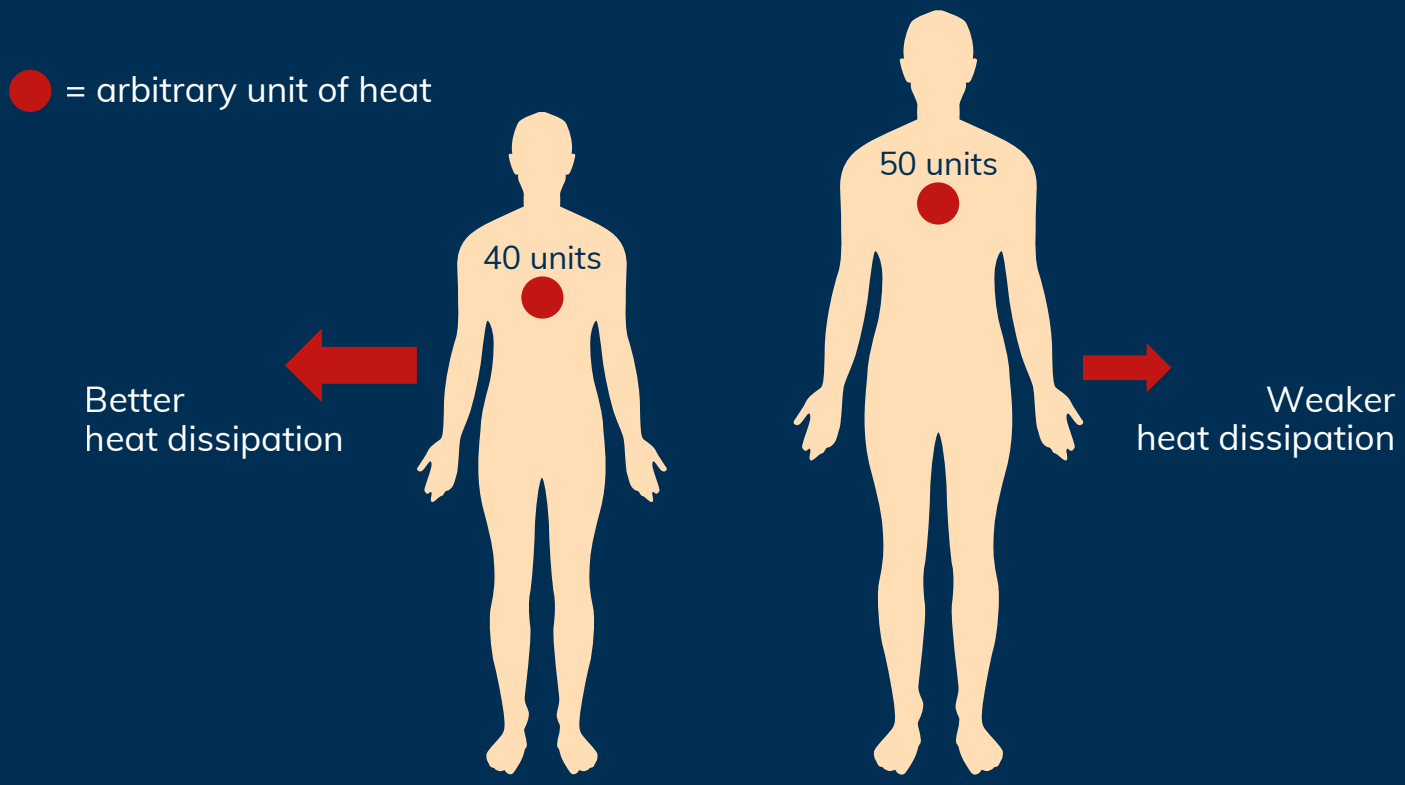

FIG 1.2. Larger individuals can store a larger amount of "heat units" which results in slower and smaller changes in core temperature under similar conditions. However, smaller-framed, thinner individuals are capable of proportionately more effective heat dissipation during prolonged exposure.

Physiological Responses to Heat

As outlined in the previous chapter, the human body has evolved highly effective thermoregulatory mechanisms to maintain internal temperature within a narrow safe range. This includes increasing skin blood flow and sweating to promote heat loss. However, during prolonged or intense exercise in hot conditions, the physiological cost of these thermoregulatory responses, as well as heat gain itself, becomes increasingly apparent. These changes have direct implications on performance through cardiovascular, neuromuscular, and perceptual pathways.[1]

Cardiovascular Response

One of the most immediate and important systemic responses to exercise in the heat is the redistribution of blood flow. As more blood is directed to the skin for heat dissipation, less is available for venous return and cardiac output. This occurs because the skin's large, compliant venous bed dilates during heat stress, causing blood to pool in the periphery and reducing central blood volume. To maintain cardiac output, heart rate increases. However, since maximal heart rate cannot rise beyond its physiological limit, this compensation eventually plateaus with increasing exercise intensity. As a result, maximal cardiac output is reduced, leading to the decline in oxygen delivery to the working muscles and maximal oxygen consumption (VO_2max) thus ultimately limiting aerobic performance in the heat.[1]

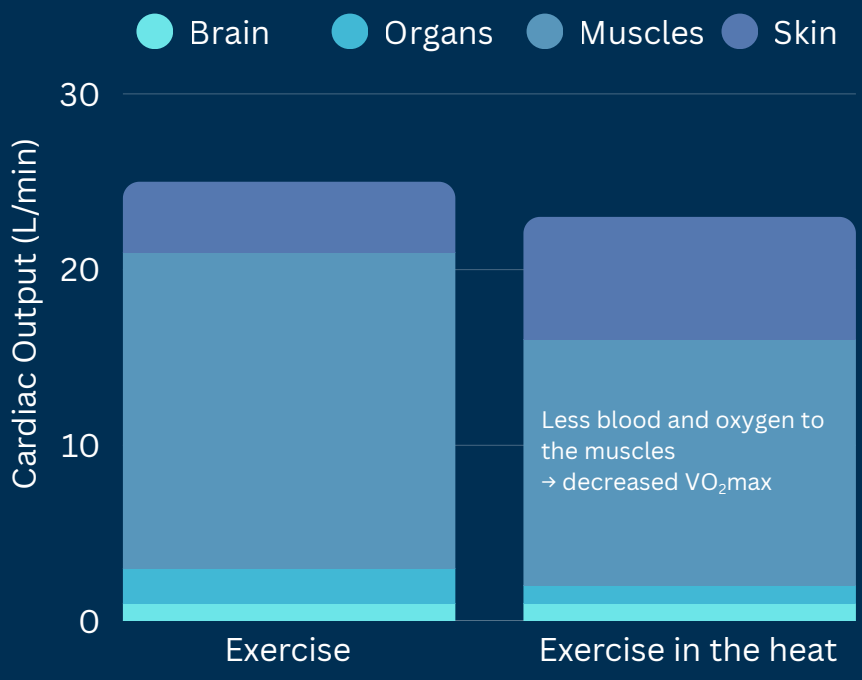

FIG 1.3. Blood flow distribution during exercise in cool and hot environment for an individual with a maximal cardiac output of ~25 L / min. Blood flow to the muscles and total cardiac output are decreased and blood flow to the skin is increased during exercise in the heat.

Sweat Response

As body temperature rises, either from high external temperature or exercise, the brain activates sweat glands to start sweat secretion. The threshold for sweat onset is individual but is affected by training and hydration status: low training status and hypohydration delay the onset of sweating. Typically, athletes sweat around 0.5–2 L/h during exercise, but for some heavily sweating athletes the rate can exceed 3 L/h. As most of the fluid for sweat is pulled from the blood, high sweat rates can eventually lead to a decrease blood and plasma volume, further decreasing venous return, cardiac output, and maximal oxygen consumption.[1]

Cardiovascular Drift – Why Heart Rate Rises Over Time in the Heat?

Cardiovascular drift refers to the gradual increase in heart rate that occurs during prolonged exercise. Characterized by the increase in oxygen consumption during prolonged constant rate submaximal exercise, this effect is further emphasized in the heat by the thermoregulatory responses. As the body works to cool itself, more blood is redirected to the skin to facilitate heat loss. At the same time, plasma volume decreases due to fluid loss (sweating) and redistribution, further reducing the amount of blood returning to the heart. To maintain cardiac output, the heart compensates by increasing heart rate over time during exercise.[1]

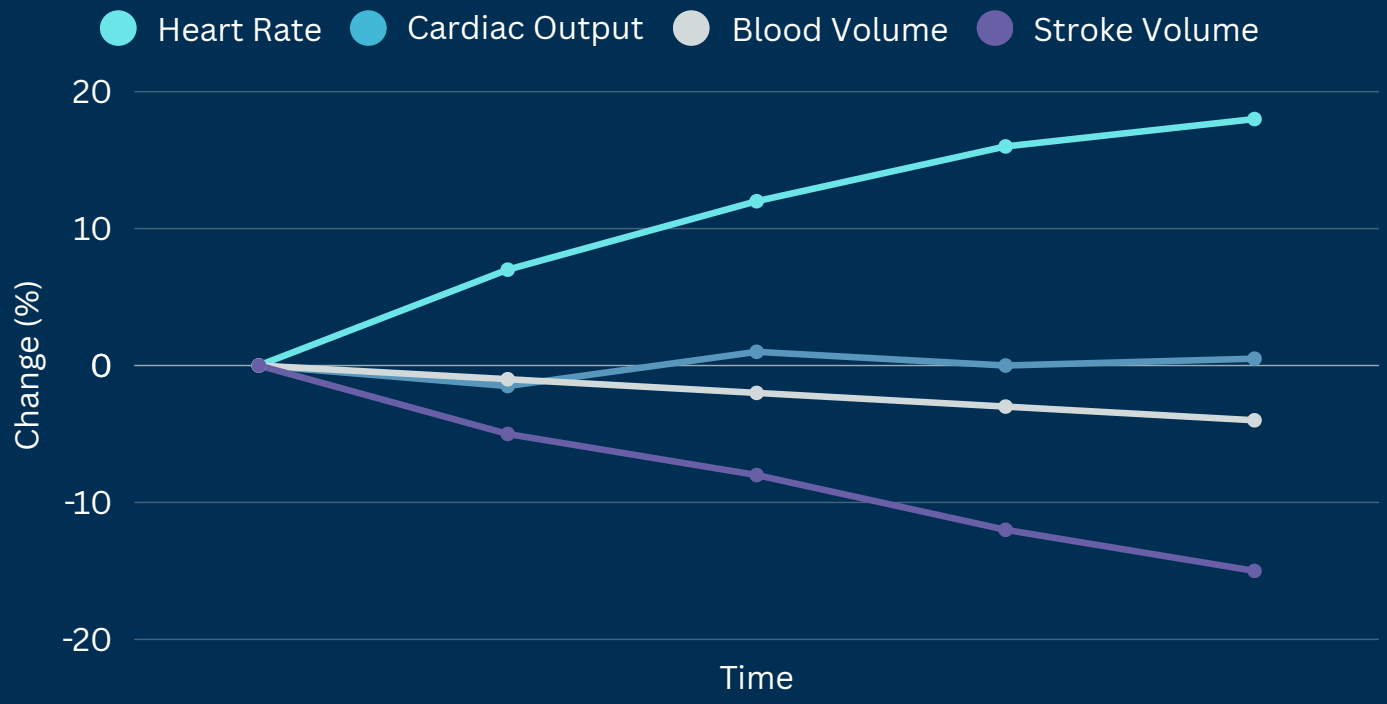

FIG 1.4. Oxygen consumption and heart rate drift upwards during prolonged steady state submaximal exercise. This drift is greater in hot environments, where skin blood flow and plasma loss through sweating decrease venous return and stroke volume, requiring heart rate to increase to support cardiac output.

Neuromuscular Effects

A moderate rise in environmental temperature and muscle temperature can be beneficial for neuromuscular performance. Increased muscle temperature can enhance muscle contractile properties and metabolic function increasing force output and power production – particularly during high contraction velocities (e.g., sprints, jumps, throws).[6] However, as muscle temperature continues to climb, these benefits can begin to reverse.[1,4,5] Furthermore, prolonged exercise in the heat can increase muscle glycogen utilization, anaerobic metabolism, and lactate production, causing greater accumulation of acidity (H+) and inorganic phosphate (Pi) both of which also have the potential to decrease muscle force production.[1]

In addition to these local muscular effects, heat can also affect the central nervous system which can play a key role in limiting performance. Rising core and brain temperatures can reduce our central drive, essentially limiting the recruitment of muscle fibers and willingness to continue exercising. Even if exercise intensity is maintained, athletes typically report higher Ratings of Perceived Exertion (RPE) in hot conditions even before critical body temperature thresholds are reached. While short bursts of maximal force can still be achieved, maintaining that force over time becomes more difficult as internal temperature rises. This central fatigue can be triggered by both active exercise in the heat and passive heat exposure, highlighting the importance of managing thermal strain even before competition begins.[1,6]

Cognitive Effects

Heat doesn't affect all mental tasks the same way. Simple tasks like basic reaction time (e.g., reaction to a starting pistol) are usually well maintained, even in quite hot conditions. However, more complex thinking, such as planning, decision-making, accuracy, and maintaining focus over time, declines with heat stress. The increased discomfort associated with heat exposure may lead to a decrease in available cognitive resources, ultimately decreasing cognitive performance in these more "resource-heavy" tasks. In addition to the environmental conditions and the task performed, the length of the exposure and its effects on core temperature affect cognition. As core temperature climbs around 1–1.5 °C above baseline, athletes become more error-prone, less accurate, more impulsive, and often feel more confident than their abilities justify. Longer duration tasks, decision-making, and precision work show the clearest performance drop in the heat.[8]

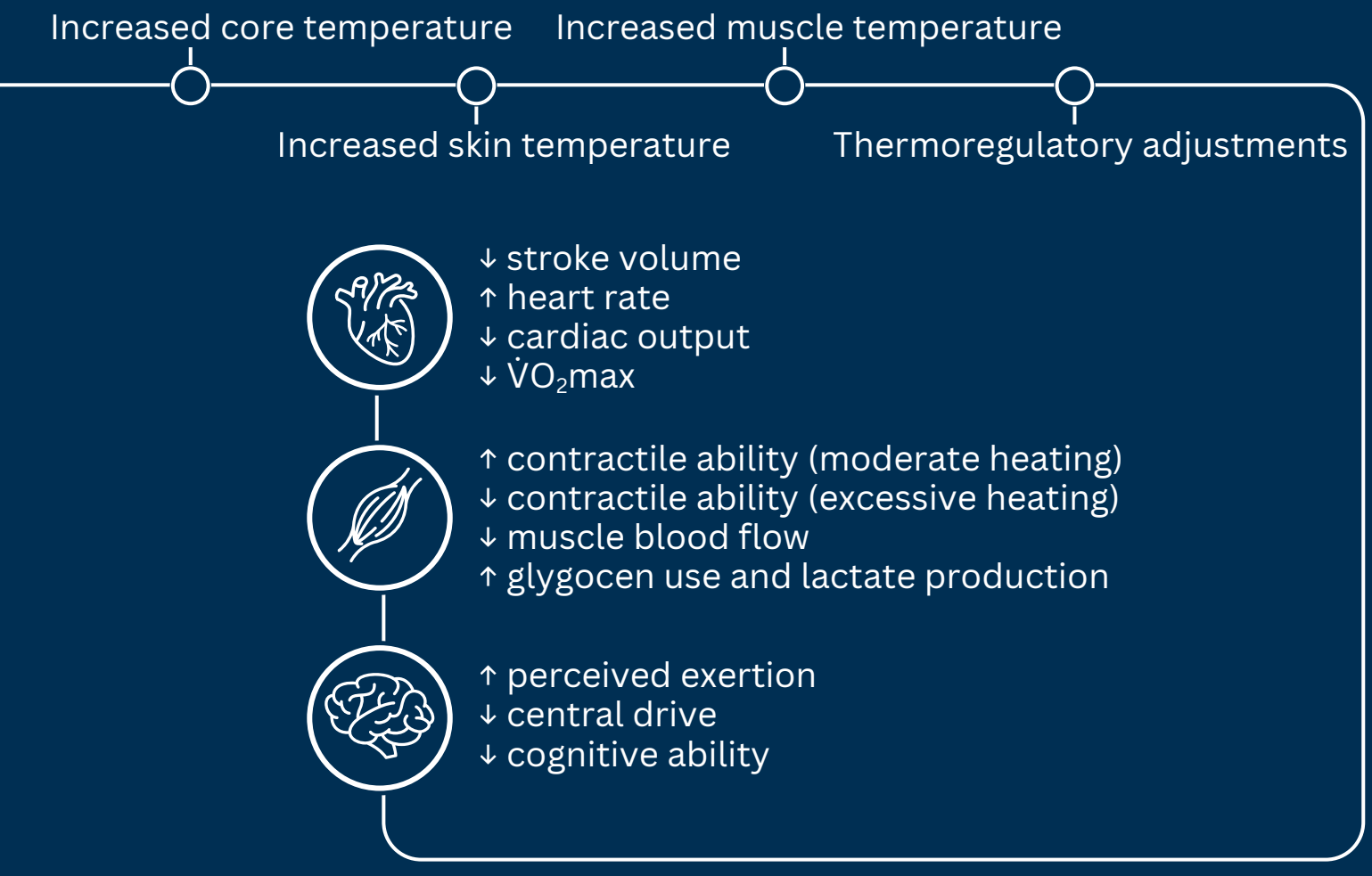

FIG 1.5. Increased skin, muscle, and core temperature and the physiological adjustments from the thermoregulatory response affect cardiovascular, muscular, and neural function, with clear implications for physical and cognitive performance.

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PART 2

Athletic Performance in the Heat

Athletic Performance in the Heat

1. Endurance Sports
2. Team and Intermittent Sports
3. Strength and Power Sports

The effects of heat are not one-size-fits-all: they depend on not only the individual but the demands of the sport as well. In this section, we explore how various disciplines are uniquely challenged by hot conditions, from the prolonged thermoregulatory strain of endurance events to the repeated bursts of effort in team sports and the high force output required in strength and power sports. By understanding the specific ways in which heat influences performance in different athletic contexts, coaches and athletes can make sport-adapted decisions to support performance, safety, and gain a competitive edge in the heat.

Learning Objectives

- Learn how heat impairs endurance by reducing time to exhaustion, increasing cardiovascular strain, and limiting oxygen delivery.
- Recognize the concept of a critical core temperature and how it influences fatigue and pacing decisions.
- Identify how athletes in team and intermittent sports adjust work rate and pacing in response to heat stress.
- Understand how muscle temperature and core temperature influence maximal strength, strength endurance, and power output

Endurance Sports

Endurance athletes are particularly vulnerable to the performance-limiting effects of heat. Sustained efforts over long durations place a significant demand on both thermoregulatory and cardiovascular systems. As the body works to dissipate accumulated heat, blood flow is increasingly directed toward the skin for cooling reducing central blood volume and impairing oxygen delivery to the working muscles. This competition for blood flow creates a physiological bottleneck that compromises aerobic performance.[1] In addition to this cardiovascular strain, rising core temperature itself can become a direct limiting factor, if critical core temperature thresholds are reached.[7]

Time to Exhaustion

One of the clearest impacts of heat on endurance performance is the reduction in time to exhaustion. Simply put, athletes are unable to sustain exercise at a standard pace or power output for as long in hot conditions compared to cooler environments. As exercise continues, the progressive strain on the cardiovascular system – with decreasing stroke volume and rising heart rate – means that sustaining a given workload requires a higher relative intensity (% of VO_2max) and thus becomes more taxing. Athletes often find themselves reaching exhaustion or volitional fatigue earlier because the combined cardiovascular and thermal load becomes too great to continue. Importantly, even moderate levels of dehydration, common during prolonged exercise in the heat, can exacerbate this effect by further reducing plasma volume, cardiac output, and $\dot{V}O_2$max, and increasing thermal strain.[6]

Critical Core Temperature

A major factor behind the earlier onset of fatigue and decreased time to exhaustion in the heat is the concept of a "critical core temperature." Research suggests that most athletes tend to fatigue when their core temperature approaches approximately 39–40 °C, regardless of how long they have been exercising.[7] This temperature threshold may act as a physiological safety limit: as core temperature nears dangerous levels, the body triggers protective mechanisms that reduce central drive and limit exercise intensity to prevent further overheating. Reaching this critical temperature often coincides with a high level of perceived exertion, signalling the body to slow down dramatically or stop altogether.

Managing Intensity to Reach the Finish Line

In real-world competitions, athletes typically do not exercise to the point of complete exhaustion. Instead, they subconsciously or consciously regulate their exercise intensity to ensure they can sustain performance until the finish line. In hot conditions, this self-regulation becomes even more pronounced. As the body senses rising thermal and cardiovascular strain, athletes naturally reduce their pace or power output earlier than they would in cooler environments.[7] This adjustment helps avoid critical overheating but inevitably leads to slower overall race times. Understanding this helps athletes and coaches plan better pacing strategies for competitions held in hot environments, accepting that slower finish times are a normal and expected consequence of racing under heat stress.

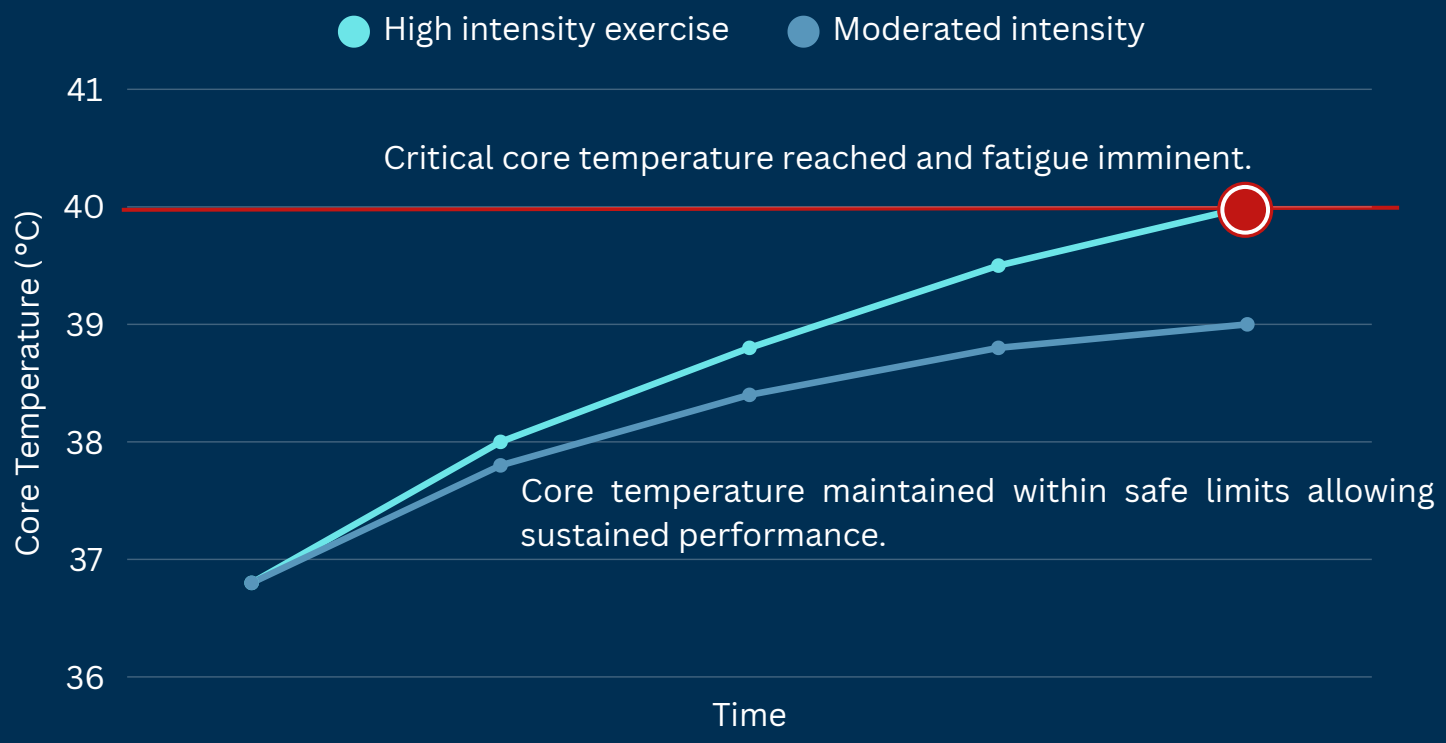

FIG 2.1. Reaching a critical core temperature accelerates fatigue and leads to exhaustion. Reducing exercise intensity lowers metabolic heat production, slowing the rise in core temperature and allowing performance to be sustained over a longer duration – essentially providing a chance to cross the finish line.

Team and Intermittent Sport

Team and intermittent sports such as football, rugby, or tennis are characterized by repeated high-intensity efforts interspersed with periods of low-intensity activity or rest. These bursts of maximal and sub-maximal action – sprints, jumps, tackles, changes of direction – place unique demands on the body that differ from steady-state endurance exercise. When performed in hot environments, the stop-and-go nature of these sports presents distinct challenges for the recovery between efforts and overall performance.

Heat and Intermittent Performance

In hot environments, athletes in team sports often adopt a lower overall work rate compared to thermoneutral conditions. This typically results in a decrease in the total distance covered and to a reduction in the volume of high-intensity running. The physiological strain imposed by the heat, such as increased cardiovascular load and thermal discomfort, leads players to subconsciously or consciously pace themselves to avoid early fatigue or overheating, ultimately reducing their overall output during play.[4]

Despite this reduction in total workload, certain performance elements may remain stable or even improve in the heat.Specifically, peak sprint speed and high force and power production in general can be preserved or even enhanced early in the event, due to the performance benefits of elevated muscle temperature. However, maintaining repeated high-intensity performance becomes more difficult as heat stress accumulates and core temperature rises resulting in a decrease in performance even in these short bursts of high-intensity efforts.[2,3,8]

In racket sports like tennis, where matches typically involve repeated bouts of effort lasting 5–10 seconds interspersed with rest periods of 15–25 seconds, players often adapt their match behavior under hot conditions. Playing in the heat tends to extend recovery times between points. As thermal strain builds, athletes may unconsciously or strategically slow down routines such as serve preparation, increasing total match duration and shifting the work-to-rest ratio. These changes appear to be closely tied to the athlete's perception of heat stress, highlighting how performance can be modulated by thermal discomfort and not just physiological fatigue.[5]

Not Just Heat – The Effects of Work-to-Rest Ratio

Assessing performance outcomes in intermittent sports under heat stress is challenging, as both the duration of active exercise and rest intervals significantly influence cumulative heat load. The metabolic heat produced during high-intensity efforts must be offset during recovery periods, making the work-to-rest ratio a key determinant of whether thermal strain accumulates or is managed effectively. When rest intervals are sufficiently long relative to the exercise bouts (i.e., when the work-to-rest ratio decreases) a sufficient time for heat dissipation is provided, core temperature rises more slowly, and the athlete is better able to maintain performance, even in high environmental temperatures. Consequently, identical external conditions can produce markedly different internal strain depending on the structure of activity, making it difficult to generalize or predict performance impacts without accounting for sport-specific demands.[2,3]

This has direct implications for interval training and sports with distinct periods of light and high-intensity work in hot conditions: sessions with shorter rest periods may lead to faster heat accumulation, increasing fatigue and limiting quality in later repetitions. Adjusting the rest duration can help manage thermal strain and ensure that intensity and quality targets are met, especially when the goal is to maintain sprint speed or power across intervals. Using the same work-to-rest ratio in different environmental temperatures may provide a significantly different physiological stimulus.

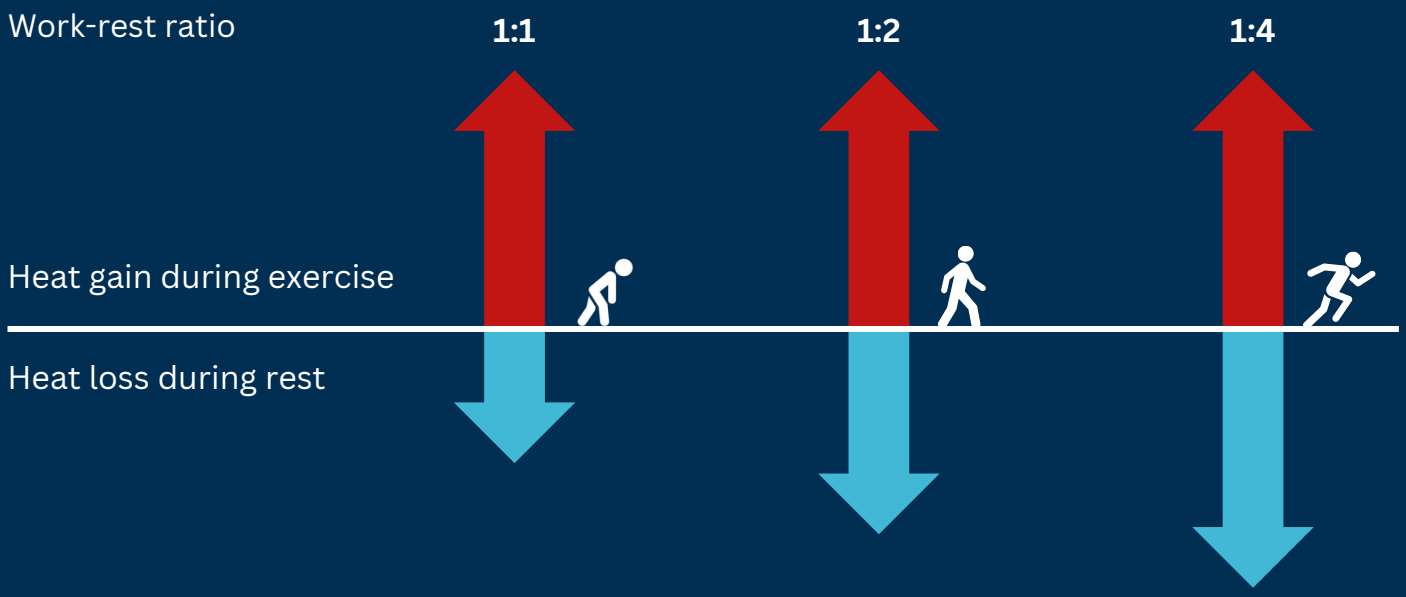

FIG 2.2. Illustration of heat production, dissipation, and performance sustainability at different work-to-rest ratios (1:1, 1:2, and 1:4). In intermittent sports, metabolic heat is produced during high-intensity efforts and must be dissipated during rest. With longer rest intervals, there is more opportunity for heat loss, helping to maintain thermal balance and preserve high-intensity performance when environmental temperature is rises.

Strength and Power Sports

Strength and power sports, such as weightlifting, sprinting, throwing, and jumping events, demand maximal or near-maximal efforts over brief time intervals. While these efforts may be short in duration, high environmental temperatures can still influence performance.[1,8] Unlike endurance sports, where performance is typically optimized in cool environments, strength and power athletes may benefit from moderate heating, that has the potential to enhance force production. However, as temperatures rise too high, the tipping point between beneficial and detrimental effects may be reached.

Effects of Muscle and Core Temperature on Performance

Moderate increases in muscle temperature (e.g., from 34°C to ~38°C) can enhance rate of force development and power output in explosive tasks such as sprinting, jumping, or throwing,[9] underlining the reason why warm-ups are essential for strength and power athletes for optimizing muscle function and readiness for high-intensity efforts. Hence, power production can remain stable or improve even in fairly high environmental temperatures, provided that excessive rise in core temperature is prevented, as the increase in core temperature can more easily reduce power and strength performance. As systemic thermal load increases, maximal strength begins to deteriorate, particularly as core temperature approaches or exceeds ~39°C. At this point, impairments in motor coordination, reaction time, and voluntary muscle activation contribute to the reduced force output.[9] Notably, repeated efforts or sustained muscle contractions, like high-repetition sets or extended training bouts, are especially vulnerable to rising core temperatures and excessive muscle temperatures.

To take advantage of the benefits while avoiding performance decline, athletes should aim to maintain warm muscles while preventing large increases in core temperature. This balance helps preserve or even enhance performance capabilities while minimizing the risk of overheating and its detrimental effects on neuromuscular performance.

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PART 3

Heat Acclimatization

Heat Acclimatization

1. Physiological Adaptations to Heat Exposure
2. Performance Benefits of Heat Acclimatization
3. Heat Acclimatization Strategies

Adapting to heat through continuous or repeated exposure is one of the most powerful tools an athlete has to enhance performance and reduce risks during training and competition in hot environments. This section focuses on the process of heat acclimatization: what physiological changes take place and how these adaptations translate into improved performance. We also explore evidence-based strategies to plan and implement effective acclimatization protocols. Understanding these principles allows athletes and coaches to approach heat not as a threat, but as a manageable and trainable environmental factor.

Learning Objectives

- Understand the physiological mechanisms through which the human body adapts to repeated heat exposure.
- Learn the key benefits of heat acclimation across endurance, strength and power, and intermittent sports.
- Recognize the differences between active and passive heat acclimation strategies, and how to apply them effectively.
- Understand the time span of heat acclimation, and how to maintain or regain adaptations through maintenance and reacclimation protocols.
- Learn how to structure a heat acclimation plan before competition to balance adaptation, tapering, and practicality.

Physiological Adaptations to Heat Exposure

Although heat can significantly impair physical performance, the human body possesses a remarkable ability to adapt to thermal stress through a process known as heat acclimation (or acclimatization). Heat acclimation occurs when the body is repeatedly or continuously exposed to elevated temperatures, particularly in combination with exercise. In response, a range of time-dependent physiological adaptations are developed. Together, these changes reduce both cardiovascular and thermal strain, enhance exercise capacity in the heat, and lower the risk of heat-related illnesses.[1]

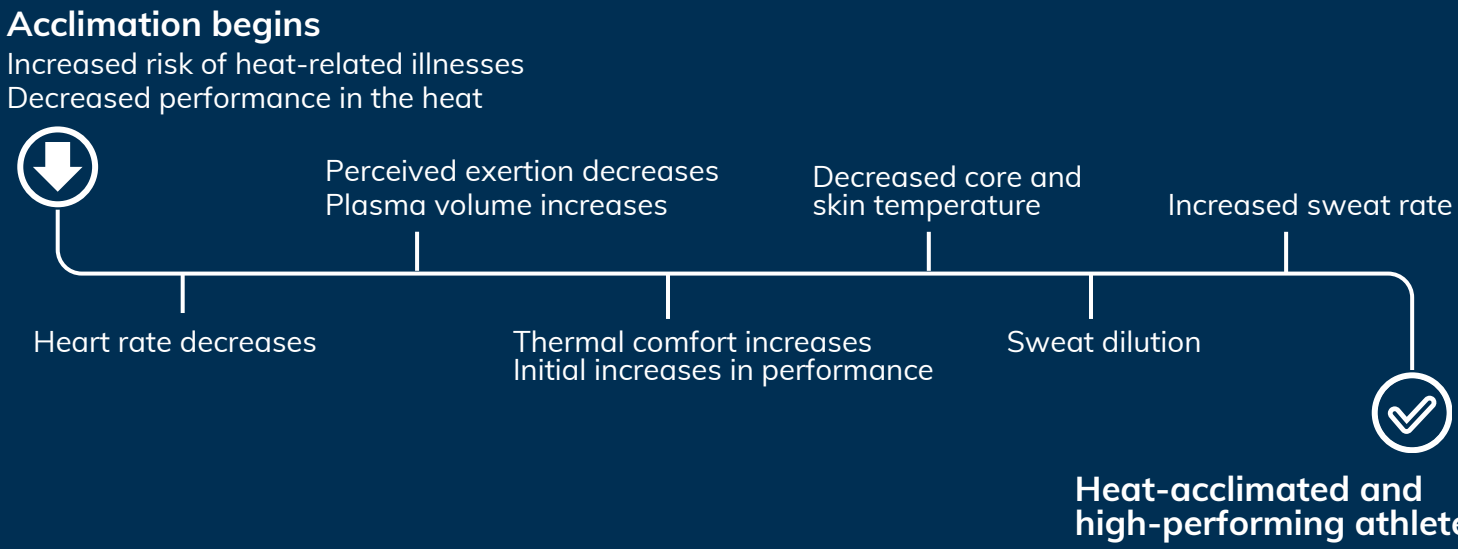
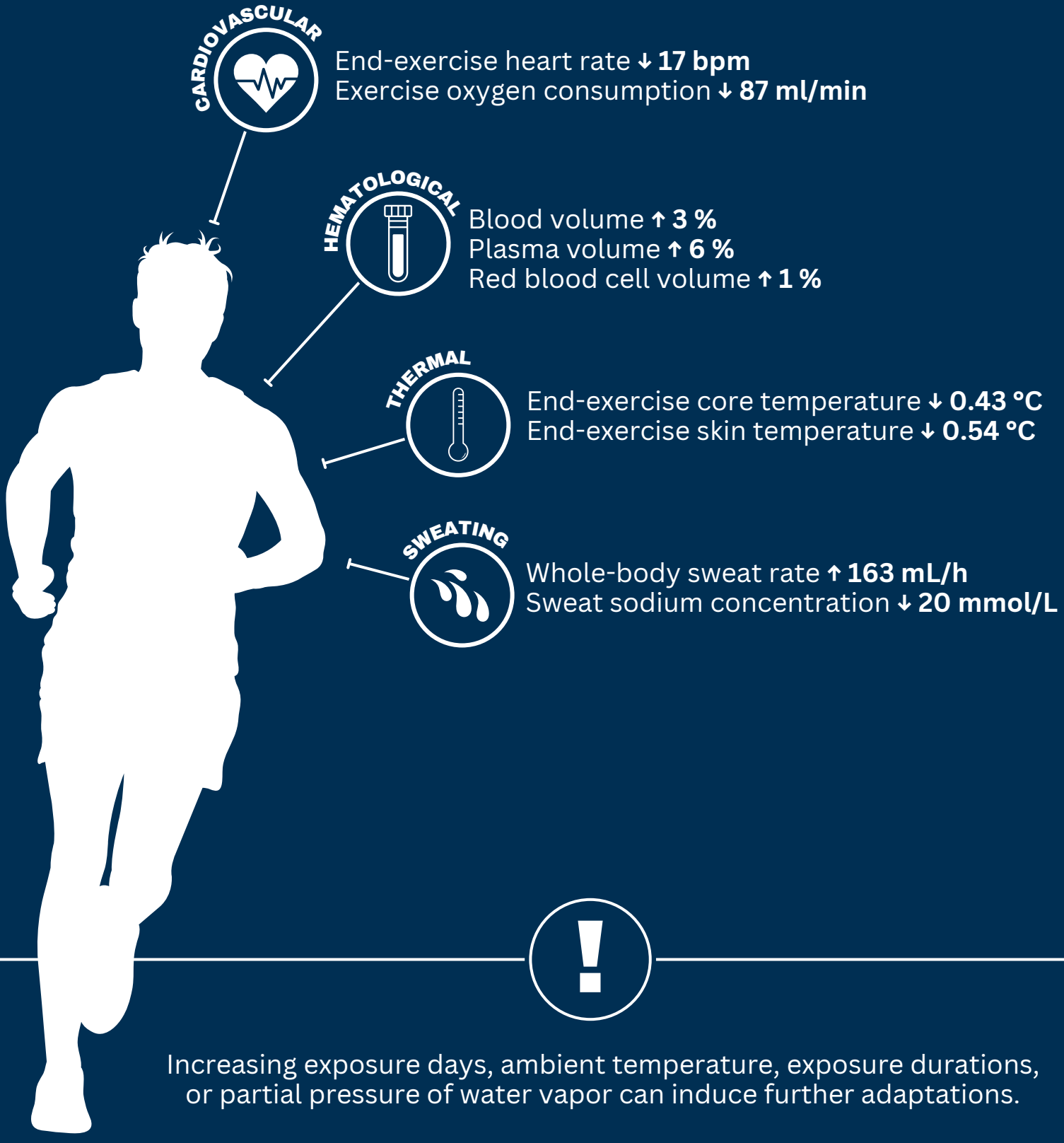


FIG 3.1. Timeline of physiological adaptations to heat acclimation.

These adaptations begin to emerge rapidly within the first few days of heat exposure refining over the following days and weeks. While no athlete becomes entirely immune to heat stress, those who undergo structured heat acclimation can expect to outperform their unacclimated counterparts under identical hot conditions. The magnitude and speed of adaptation vary between individuals, but nearly all athletes from elite competitors to dedicated recreational participants can benefit from a structured acclimation protocol. A carefully planned approach is especially critical when travelling to compete from a cool climate into a warmer one.

FIG 3.2. Average expected physiological adaptations associated with exercise heat acclimation (~8 days, 90 minutes of exposure per day, 39.1°C air temperature, and 2.78 kPa partial pressure of water vapor in air). Data from McDonald et al. 2025.



Performance Benefits of Heat Acclimation

The benefits of heat acclimation extend beyond increased thermal comfort and reduced risk of heat-related illnesses as acclimated athletes are able to train and compete more effectively in hot environments. While endurance performance sees the most pronounced improvements, strength, power, and skill-based activities can also be influenced through improved thermal comfort, and reduced thermal strain and fatigue. Here we explore how heat acclimation supports performance across three key domains: endurance, strength and power, and skill.

Endurance performance

One of the most well-documented benefits of heat acclimation is the extension of time to exhaustion (TTE). With repeated exposure to heat, athletes often demonstrate the ability to sustain a given workload for longer durations in hot conditions. A key mechanism behind this improvement may be the slower rise in core temperature and improved thermal comfort during exercise. Since exhaustion in the heat is often associated with reaching a critical core temperature, heat acclimation effectively prolongs the time it takes to reach this threshold, delaying fatigue. Heat acclimation can lead to a 40 % or greater increase in time to exhaustion (TTE) in hot conditions. However, the magnitude of improvement is highly dependent on the specific environmental conditions and the exercise protocol.[2]

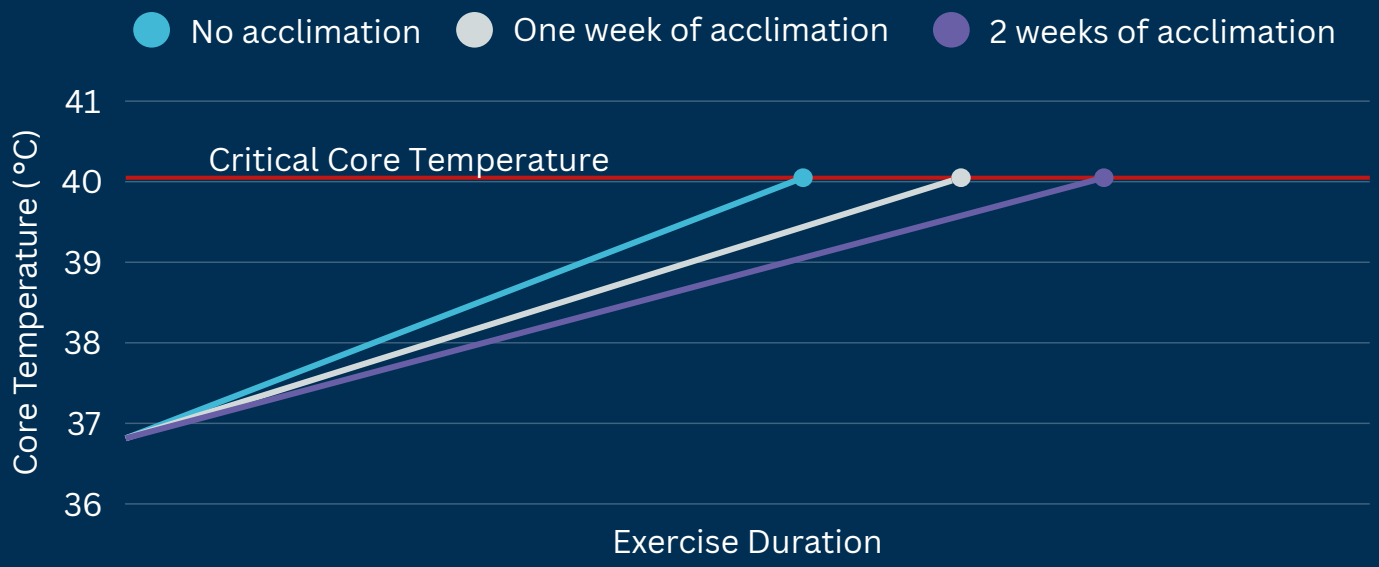


FIG 3.3. Acclimation to heat reduces the rise of core temperature during exercise prolonging the time until critical core temperature and exhaustion are reached.

Improvements are also observed in time trial performance, where athletes must complete a fixed distance as fast as possible, closely reflecting real life competition scenarios. In such events, performance is not only limited by physiological capacity but also by pacing strategies influenced by perceived effort and thermal comfort. Heat-acclimated athletes typically show lower ratings of perceived exertion (RPE) at a given pace, allowing them to sustain higher intensities and adopt more aggressive pacing strategies without excessive thermal strain.[3] Acclimated athletes also tend to increase their pace or power at lactate threshold as well as their $\dot{V}O_2$max, improving their physiological ability to maintain higher intensities in warm environments, and further supporting improved endurance capacity in the heat.[4] Overall, for sports such as running, cycling, and triathlon, the performance gains from heat acclimation can translate into decisive advantages in hot and humid race environments.

Heat Acclimation for Endurance Athletes

- ↑ time to exhaustion
- ↑ time trial performance
- ↑ $\dot{V}O_2$max
- ↑ lactate threshold

Strength and Power Sports

Unlike for endurance sports, heat acclimation likely does not directly enhance maximal strength, power output, or strength endurance under heat stress.[5] In fact, performance in strength and power sports is often supported by a moderate increase in ambient temperature. However, this doesn't mean heat acclimation cannot have a role in these disciplines. When even minor differences in performance can determine outcomes, the indirect benefits of heat acclimation may still offer meaningful advantages.

One potential advantage of heat acclimation could be the improved thermal comfort and better cognitive functioning under heat stress. Although research on whether heat acclimation directly enhances cognitive performance under heat stress is equivocal[6], it is reasonable to suggest that athletes who feel more comfortable in the heat may be better able to maintain focus, technical precision, and decision-making capacity during high-pressure moments. Such ability is particularly valuable in high-intensity, skill-dependent sports, such as weightlifting, throwing events, and short-duration track and field disciplines, where the smallest errors can decide podium placements.

Heat Acclimation for Strength and Power Athletes

- ↔ strength / power
- ↑ thermal comfort
- ↑ cognitive function / focus

Team and Intermittent Sports

In team and intermittent sports such as football, basketball, rugby, and tennis, athletes perform repeated bursts of high-intensity effort interspersed with low-intensity movement or rest. While these athletes can benefit from the improved endurance capacity under heat stress gained through heat acclimation, there is also evidence to support that acclimation can enhance repeated-sprint ability in the heat[7] and possibly the total distance covered during the game.[13] However, very little research has examined whether heat acclimation can preserve or improve sport-specific skills such as passing, ball control, or technical decision-making despite clear evidence that these skills can deteriorate under heat stress.[8,9]

Heat Acclimation for Team and Intermittent Sports Athletes

- ↑ endurance performance
- ↑ repeated sprint performance
- ↑ total distance during a match
- ↑ cognitive function

Heat Acclimation Strategies

To gain the performance and safety benefits of heat acclimation, athletes should follow a structured and intentional exposure plan. The goal of a heat acclimation protocol is to produce a sufficient thermal impulse that drives the body's adaptive responses without overly compromising training quality during the acclimation period. These strategies can vary in intensity, timing, and duration, but they all aim to progressively improve thermoregulation, cardiovascular stability, and physical performance in the heat. Understanding how to design and apply different acclimation approaches, whether active or passive, short- or long-term, is key to effective preparation for training and competing in the heat.

How Long to Acclimate?

Heat acclimation begins rapidly upon exposure and significant benefits are acquired during the first week of the acclimation period, including a lower heart rate during submaximal exercise, lowered core temperature, and increased physical performance. Individuals wanting to maximize the available benefits should still aim for approximately 10 to 14 days of daily exposure as some physiological adaptations, such as improved sweat rate, require a longer time to develop to their full potential[1]. If necessary, the acclimation period can be interrupted by days of no-exposure, but this slows down the acclimation process if more than 1-3 heat exposures are missed.[10]

Active and Passive Strategies

Heat acclimation strategies can be divided into active and passive methods – essentially, whether heat exposure is performed with or without exercise. For athletes, active methods may be a more effective approach for improving performance-related outcomes as the combination of metabolic heat from physical activity and the thermal load from the environment give a strong stimulus to drive adaptations.[11] Exercise-based acclimation is typically performed in environments of 30–40 °C, but it is advisable to start from the lower end of this range with low to moderate-intensity exercise when the body is still unadapted. At this early stage, both the risk of heat illness and the performance limitations are at their highest, so a gradual progression in thermal load is advisable.[10] As adaptation develops, increasing the environmental temperature and/or exercise intensity helps to maintain an adequate stimulus: what was effective in the beginning may no longer be sufficient to drive further physiological gains.[11]

While active strategies are preferred for producing sport-specific adaptations, passive exposure can still play a valuable role.[1] Passive methods – such as using saunas post-exercise or in separate heat sessions – are especially useful when training quality needs to be maintained and heat cannot be used during training, for example during tapering phases or key workouts. As the name suggests, passive methods involve no exercise but instead rely solely on elevating body temperature through environmental exposure. For most athletes, sauna bathing can often be a very convenient and accessible method of passive heat acclimation. Spending 30 minutes in a dry sauna at 70–80 °C has been shown to promote adaptation[1], though other options – such as hot water immersion or wearing extra layers of clothing – can also be effective.

ACTIVE METHODS

Self-Paced Exercise

Self-paced exercise is easily done indoors or outdoors. Work rate will vary but aim for 60 to 90 minutes of moderate exercise at 30—40 °C.

Controlled Heart Rate

Exercise at a target heart rate (e.g., 65 % of maximum heart rate) for 60 to 90 minutes at 30—40 °C.

Controlled Hyperthermia

Exercise until target core temperature is reached (e.g., 38.5°C). Adjust exercise intensity to maintain core temperature for 60 to 90 minutes at an ambient temperature of 30-40 °C.

Passive Heating

Use hot water bath or sauna to increase skin and core temperature. A water temperature of 40 °C or air temperature of 70 to 80°C are sufficient with an exposure time of 30 to 40 minutes.

Post-Exercise Heating

Similarly to passive heating, use hot water baths or sauna to increase skin and core temperature following exercise. A water temperature of 40°C or air temperature of 70 to 80°C are sufficient with an exposure time of 20 to 40 minutes.

PASSIVE METHODS

FIG 3.4. Active and Passive Heat Acclimation Methods. Different protocols can be used to induce heat adaptations. Active methods involve exercising in the heat, with options such as self-paced sessions, heart rate-controlled exercise, or maintaining a target core temperature. These are typically performed for 60 to 90 minutes at 30–40 °C. Passive methods rely on raising body temperature without exercise, such as using saunas or hot water baths either independently or post-exercise. These approaches especially useful when training in the heat is not feasible. **If hot environments are not available, extra layers of clothing can be used to support acclimation during both active and passive methods.**

Adaptation Maintenance and Re-acclimation

Practical arrangements, structure of training, and personal preference should be considered when choosing the optimal protocol and timeline for heat acclimation. If the preparations during the final weeks before the event do not allow for intensive acclimation, athletes may choose to complete their primary heat acclimation protocol earlier and implement strategies to maintain adaptations until the event. With intermittent heat exposure, acclimation decay can be attenuated by performing 1-2 heat exposures per week[11] making it possible to put more emphasis on training quality. However, even then a partial loss of adaptation can be seen, and a short re-acclimation is encouraged following a prolonged period of intermittent exposure.[12]

Fortunately, re-acclimation occurs more rapidly than the initial adaptation phase. A few consecutive heat exposures in the days before the event can help reestablish previously gained benefits and ensure the athlete is physiologically and perceptually prepared for competition in the heat.[11] While it's commonly agreed that a reacclimation is effective during the weeks following the initial acclimation[12], some evidence suggest a more prolonged "heat memory" where some heat tolerance can be maintained for up to 6 months after very long heat acclimation periods.[13] This may have important implications for athletes who include heat training periods throughout the year to maintain a basic level of acclimation.

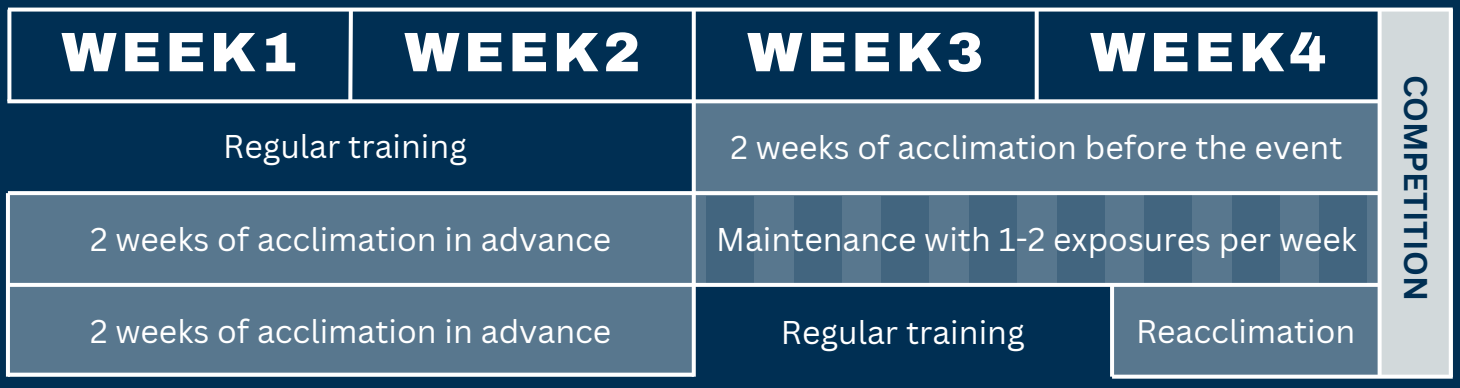


FIG 3.5. Example structures for timing heat acclimation before a competition in the heat after week 4. Finding the balance between performance tapering, practicality, and individual athlete needs will provide the best results.

Adaptation Decay

Much like training-induced adaptations, those developed through heat acclimation will decline if exposure stops entirely. The rate of decay varies between individuals, but studies suggest that within two weeks of ending exposure, approximately 35% of heart rate, 30% of sweat rate, and 6% of core temperature adaptations may be lost.[11] These changes highlight the importance of strategically planning both the initial acclimation phase and any necessary maintenance or re-acclimation protocols to align with competition schedules.

Acclimation or Acclimatization?

Though often used interchangeably, acclimatization refers to physiological adaptations that occur in response to natural environmental conditions, for example at the competition location, while acclimation involves using a more controlled artificial setting such as saunas, heat chambers, or even insulating clothing. Regardless of the method, the key principles and the available benefits are comparable.[1] It's important to note though, that environmental conditions at the competition site can be unpredictable: highly affected by time of day and weather fluctuations. As such, athletes should avoid depending solely on natural acclimatization upon arrival, as conditions during the preceding days may not reflect those during the event. Preparing to use acclimation strategies to simulate the worst likely scenarios, ensures more robust and reliable adaptations. This prepares athletes not only for typical race conditions but also for the unexpected. Other environmental conditions (e.g., time zone, hypoxia) should be considered as well, when planning your acclimation / acclimatization protocol.

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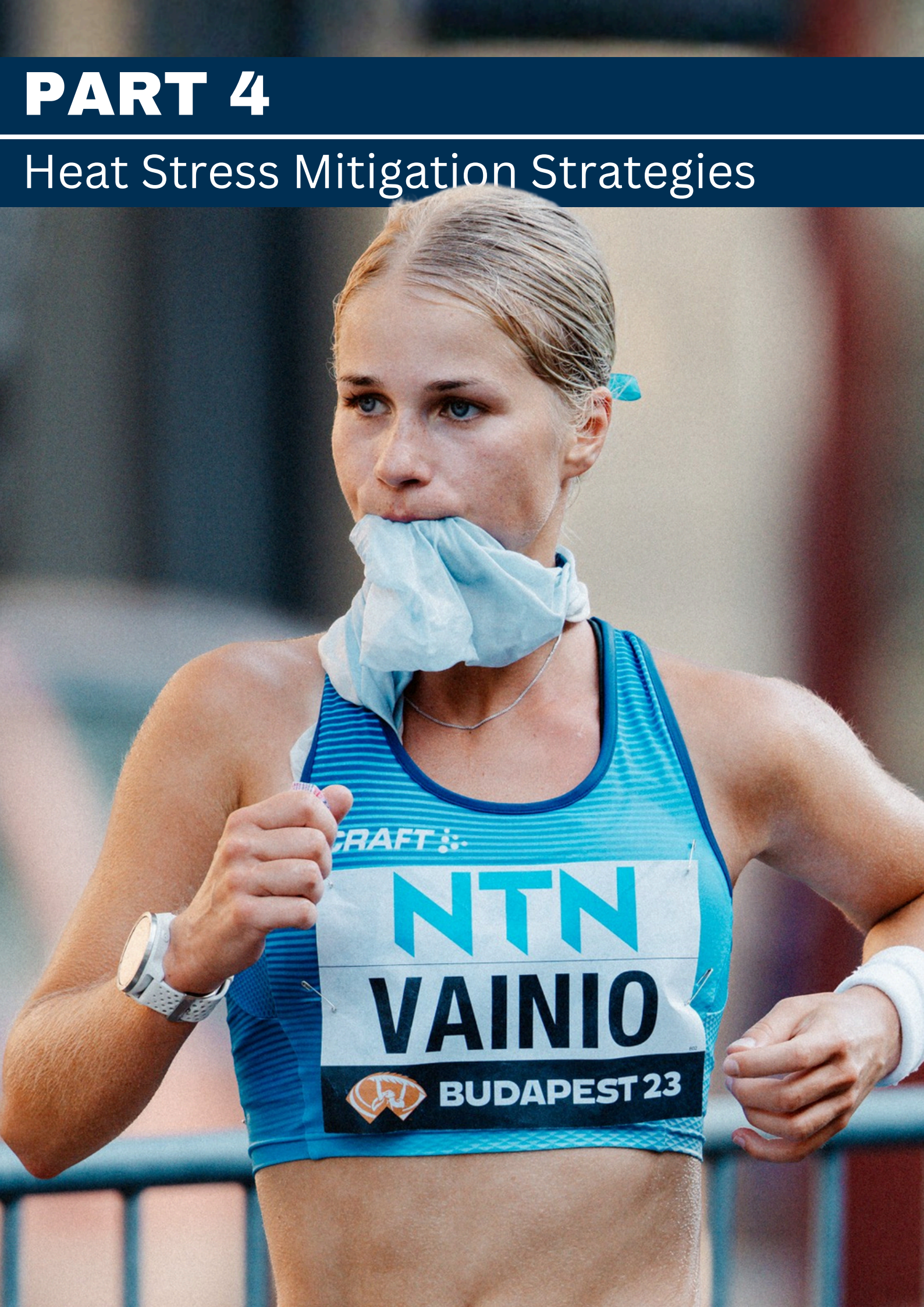
PART 4

Heat Stress Mitigation Strategies



PART 4

Heat Stress Mitigation Strategies

1. Pre- and Per-Cooling
2. Hydration and Fluid Balance
3. Training Adjustments and Monitoring

Even with optimal preparation and acclimatization, heat can still present a significant challenge during training and competition. Fortunately, there are effective strategies to manage heat stress in real time. This section focuses on three key areas that help athletes maintain performance and reduce the risk of heat-related issues: cooling techniques, hydration and fluid balance, and using monitoring tools to make smarter training adjustments. These strategies offer practical ways to support thermal balance, enhance performance, and make informed decisions in the heat.

Learning Objectives

- Understand the physiological rationale behind pre-cooling and per-cooling and know how and when to apply cooling methods.
- Recognize the effects of dehydration on physical performance in the heat
- Know how to effectively manage hydration and fluid balance
- Know how to implement training adjustments under heat stress
- Know the difference between internal and external load monitoring and their implications in different environmental conditions

Pre- and Per-Cooling

Pre-cooling (before exercise) and per-cooling (during exercise) are practical tools that can help athletes start cooler, stay cooler, and ultimately perform better. These methods aim to reduce core and skin temperature, delaying the effects of heat-related fatigue, and improving thermal comfort and physical performance in hot environments. When applied effectively, cooling strategies do not only support athletic efforts but also reduce the likelihood of heat-related illnesses.[1,2] Their effectiveness, however, depends on several factors, including the demands of the sport, timing, duration of use, environmental conditions, and method and intensity of application making it essential for coaches and athletes to understand how and when to use them.

Pre-cooling

Pre-cooling involves lowering skin and core temperatures before exercise to create a thermal buffer that delays the onset of heat-related fatigue and performance detriment in hot environments. By starting with a reduced body temperature, athletes are able to perform longer or at a higher intensity before reaching critical temperature thresholds that impair performance or lead to exhaustion. This strategy is especially effective for prolonged endurance exercise in the heat, but meaningful improvements have been observed in intermittent performance as well (such as those often seen in team sports or interval training), where heat stress is cumulated during subsequent work phases.[3] Pre-cooling techniques have been shown to enhance performance by approximately 5.7% on average, specifically in these endurance and intermittent events.[5] It is, however, vital to recognize that the demands of the activity – such as duration of the event or work and rest intervals as well as the work intensity – as they play a key role in determining whether pre-cooling will be effective.

In high-intensity and short-duration efforts that rely on maximal power production and high velocity – such as single isolated sprints, jumps, or other explosive movements – pre-cooling may unnecessarily lower muscle temperature, potentially impairing muscle function and reducing power output. In addition, cooling the body's core too much can decrease voluntary muscle activation and thus physical performance in these events even if muscle temperature is maintained.[4] Athletes taking part in short duration, high power output sports may still gain benefits from pre-cooling, if athletes are exposed to excessive heat before their event, i.e., during long waiting times, provided that the

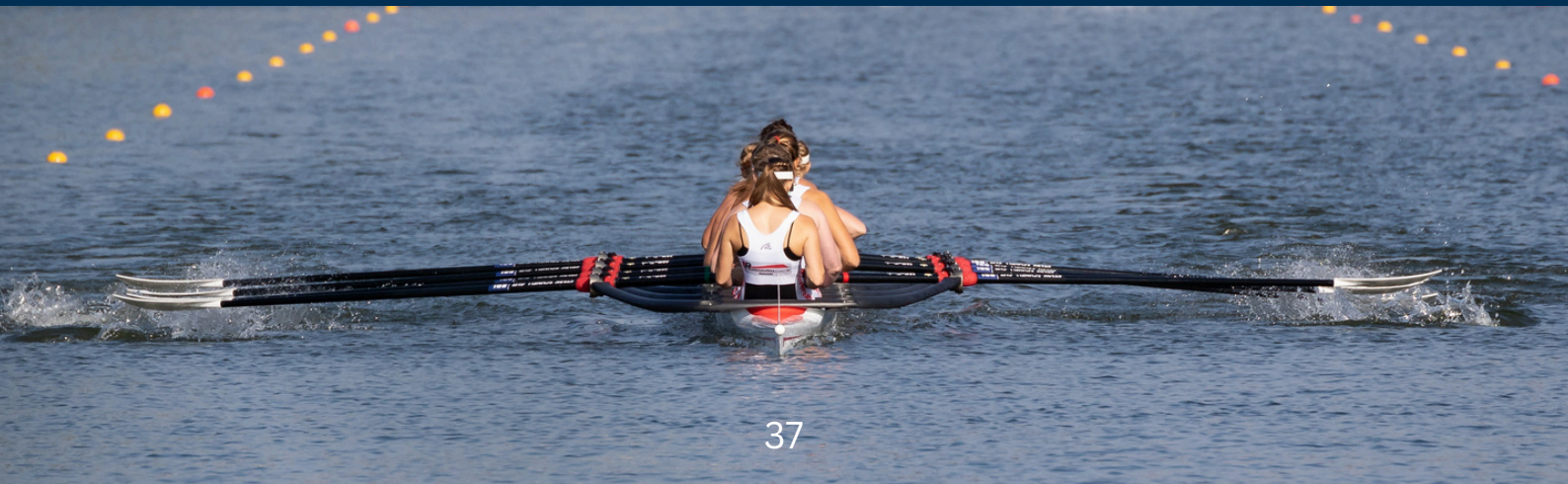
cooling method used does not directly reduce the temperature of the working muscles and adequate sport-specific warm-up is completed before the event.

Per-cooling

Per-cooling refers to cooling interventions applied during exercise to help limit the increase in core and skin temperature and thermal discomfort, and it has the potential to attenuate the heat-related detriments to physical performance.[1,2,3] These strategies can be especially valuable and practical in sports or events that allow for natural breaks or pauses, like between sets, quarters, and points, or during interval training. In continuous endurance events, brief opportunities to apply cooling may help sustain performance as the event progresses. On average a 9.3% performance improvement has been observed across different per-cooling strategies.[5] As with pre-cooling, the importance of per-cooling is emphasized with increasing environmental temperature, but the intensity and duration of the effort, and the cooling strategy used are just as relevant factors as benefits may be very limited or non-existent during short-duration events. Nonetheless, for athletes competing or training in the heat for longer periods of time per-cooling represents a potential strategy to reduce heat strain and preserve performance.

Effectiveness of Different Cooling Methods

The cooling method of choice impacts the outcomes. When using external cooling methods such as vests, collars or ice packs, the covered surface area contributes to the overall effect. Cooling smaller areas, such as the head, face, and neck, has been shown to improve thermal sensation and comfort in the heat, but their effect on self-paced physical performance have been negligible.[6] For athletes preparing to compete in the heat, the most effective approach is to use methods that cool a large surface area and, when possible, to combine external and internal cooling strategies for maximum benefit.[7]



Although large average improvements of 5.7% and 9.3% have been reported for different pre- and per-cooling methods[5], It is important to remember, however, that these figures are based on highly controlled research measurements, where both the environmental conditions and the exercise protocols have usually been carefully designed and may not always reflect real competition situations in the sporting world. Logistical constraints, competition rules, or limited access to cooling equipment can make achieving the same level of benefit challenging. Athletes and coaches should therefore treat these improvements as indicative of potential rather than guaranteed gains and prioritize selecting and practicing methods that prove to be practical and effective within their specific environment. Practicing cooling strategies in training, while monitoring their effect on factors such as heart rate, perceived exertion, and performance, helps ensure that the chosen approach can be applied smoothly and effectively in competition.

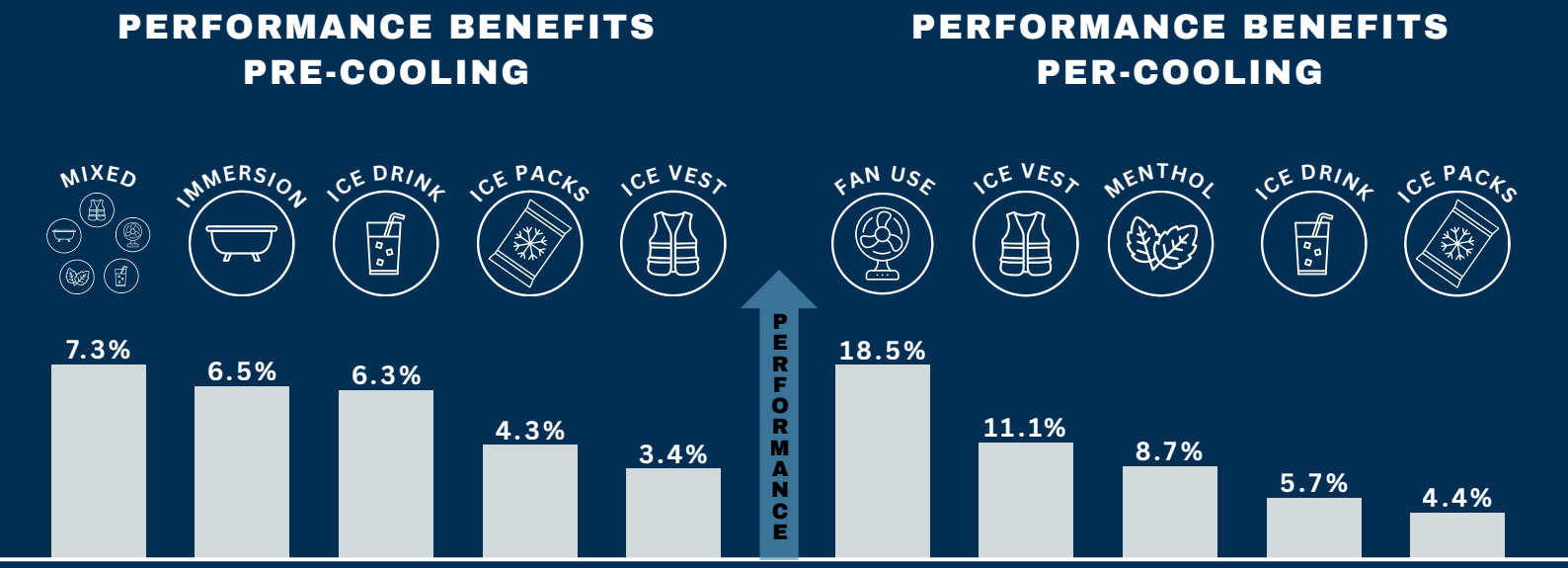


FIG 4.1. Summary of mean performance improvements associated with various pre-cooling and per-cooling strategies based on published research. These values illustrate trends observed in controlled studies and should be interpreted as indicative rather than exact estimates for applied sport contexts. For example, fan cooling may appear highly effective in no-wind laboratory settings, yet its real-world benefit is likely smaller due to natural airflow during most sports. Data from Bongers et al. 2017.

Cooling Techniques for Athletic Performance

Cold water immersion is a common and effective cooling strategy which involves immersing the body in water at 20–25 °C for 45–60 minutes. Very cold water (below 15 °C) is usually unnecessary for precooling but can shorten the required immersion time. Submerge up to the chest or neck to maximize heat loss. After immersion, allow enough time for a sport-specific warm-up before starting the event as the temperature of the working muscles is effectively cooled as well and may not be optimal for physical performance. Always rehearse this method in training to get used to the immersion and transition to performance before applying it in a competition setting. Evidence suggests that CWI may be the most effective pre-cooling method for athletic performance.[5]

Cooling garments, such as cooling or ice vests help lower core body temperature while preserving a higher temperature in the working muscles of the limbs. Their key advantage is that they can often be worn during sport-specific warm-ups and short breaks in the event. If the rules of the sports allow its use, cooling vest may be the most effective per-cooling method for athletic performance[5]. Changing the cooling elements during prolonged use maintains cooling efficiency. Practice using the vest in training to fine-tune comfort, fit, and timing before relying on it in competition.

Fan cooling enhances heat loss through both increased convection and the evaporation of sweat. In dry heat, they can provide significant cooling but in very humid conditions, the effect is smaller as the evaporation of sweat is significantly decreased. Fan use can be combined with water spraying for greater evaporative heat loss and cooling effect in dry heat.

I**ce slurries** are drinks with numerous small ice particles suspended in liquid, offering greater cooling potential than cold fluids alone. As the ice melts, the phase change (i.e., melting) absorbs roughly three times more heat energy than simply warming cold water, making slurries a more powerful internal heat sink for the body. A common precooling dose is around 7 g/kg body mass, taken in smaller portions before activity. Small servings of ice slurries can also be used during exercise for per-cooling. Practice during training to find your tolerance and pacing to avoid stomach discomfort or an untimely brain freeze. Adding menthol to ingested fluids has been observed to produce a possible mild synergistic effect on physical performance, likely through an enhanced cooling sensation.[8]

Mixed methods refer to the use of two or more cooling strategies to lower core and skin temperature. For example, sipping an ice slurry while wearing a cooling vest may give the benefits of both internal and external cooling. Do note that mixed strategies may require more planning and preparation. Practice the timing, sequence, and transitions in training to ensure the method works smoothly on competition day.

FIG 4.2. Overview of different cooling methods used in sport. It is strongly recommended to rehearse any new cooling strategy in training before applying it in competition settings.

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Hydration and Fluid Balance

Fluid balance is a key determinant of both performance and safety in all environments, but it becomes especially critical in the heat. If exercise begins in an already dehydrated state (i.e., hypohydrated) both endurance[2] and strength[3] performance can be compromised. Endurance athletes in particular are greatly affected by a negative fluid balance in the heat since sweating, a fundamental mechanism of heat loss during exercise, is heavily dependent on hydration status. Unfortunately sweating comes at the cost of fluid and electrolyte loss, and if these losses are not covered through adequate repletion, dehydration develops, and with it, progressive impairments to physical performance.

Effects of Dehydration on Endurance Performance in the Heat

A large part of our endurance performance is explained by our body's capability to transfer and use oxygen. With dehydration the blood volume in our body is decreased and oxygen transfer is compromised: the heart has to work harder to maintain the same level of cardiac output to provide enough oxygenated blood to the working muscles while also maintaining sufficient circulation of the skin for effective cooling. If these requirements are not met, and oxygen transfer and cooling efficiency decrease, endurance performance will eventually suffer. Both the reduction in oxygen transfer and the increase in body temperature have their own significant implications for limiting endurance performance.[1]

It is thus commonly recommended that dehydration be prevented or at least limited to about 2 % reduction in body mass during endurance exercise to sustain performance.[4] However, observations both from real-world competitions as well as laboratory research suggest that athletes who begin exercise in an euhydrated state (i.e., in fluid balance) can sometimes tolerate even greater fluid losses, up to 3–4 % of body mass, without clear performance decrements.[7,9,13] In fact, larger body mass losses are often associated with faster finishing times in marathons and triathlon, indicating that moderate dehydration can coexist with high performance.[5,6] These findings do not mean dehydration is beneficial or irrelevant, but rather that its impact is influenced by many interacting factors such as fitness level, environmental conditions, and individual tolerance. Overall, it seems clear that dehydration can decrease endurance performance and increase health risks, especially in the heat, but mild to moderate exercise-induced dehydration can be tolerated even during longer endurance events.

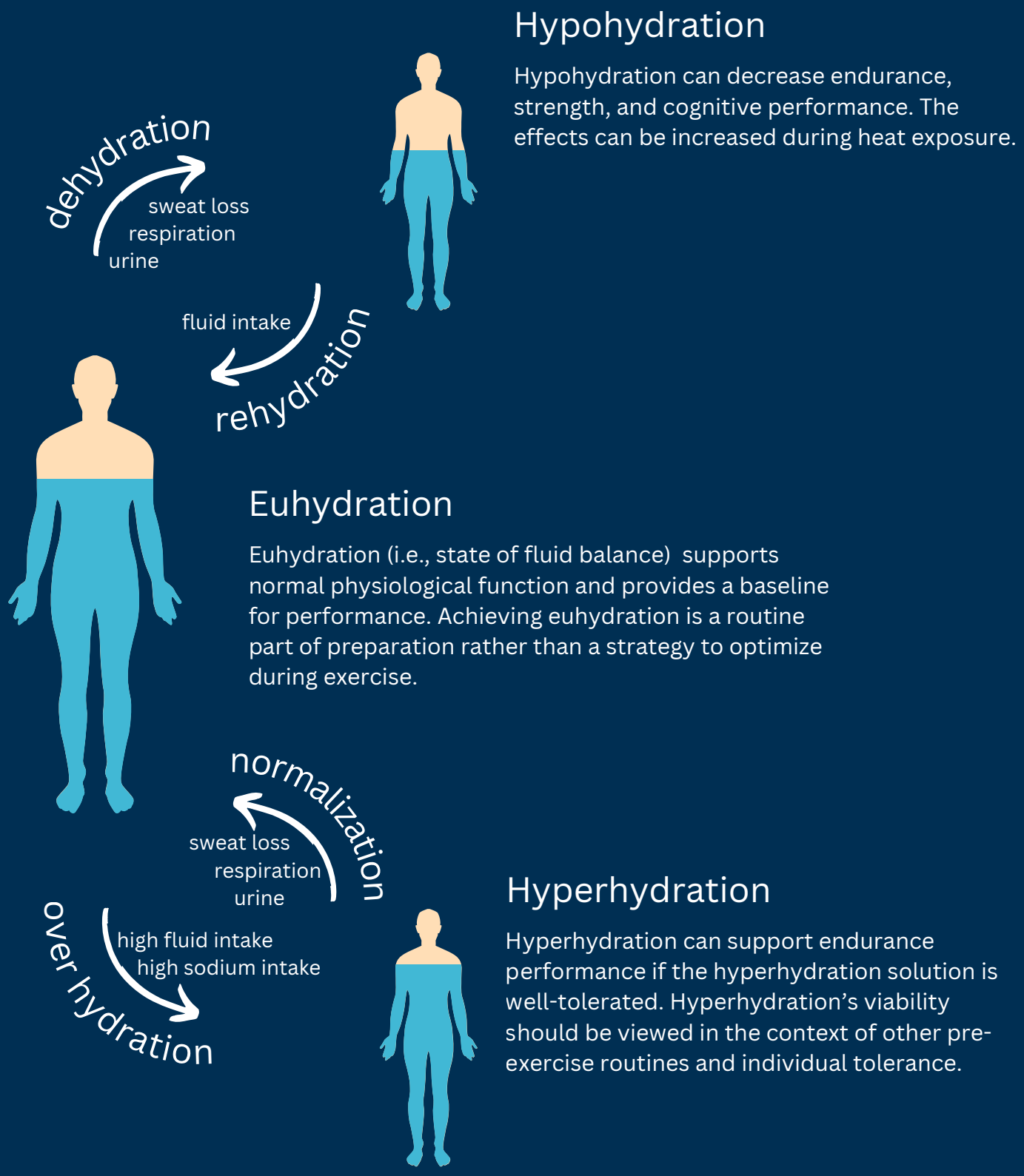

FIG 4.2. Euhydration, hypohydration, and hyperhydration have clear implications to physical performance. Fluid balance is altered by fluid loss through sweating, respiration, and urine, as well as food and fluid intake.

Strength and Power Performance

In strength and power sports marked dehydration rarely occurs during the active work intervals of the competition but more likely during the preceding hours or the idle time between attempts if hydration is not properly managed. It seems that hypohydration does significantly decrease upper and lower body strength and strength endurance as well as anaerobic power making hydration essential for strength and power athletes. Interestingly, exercise-induced dehydration (i.e., sweating from exercise) seems to be more detrimental to strength performance than passive dehydration through heat exposure, which may bring relevance in weight-cut scenarios.[11] Less is known about how acute heat exposure and dehydration interact to affect strength performance, but intuitively their combined effects may be cumulative, making adequate hydration critical for physical performance in strength and power sports during heat exposure.

Pre-Exercise Fluid Balance Assessment

Starting exercise in an euhydrated state is vital in ensuring exercise performance. Measuring first-morning body weight after voiding, combined with an assessment of urine concentration, provides good sensitivity to detect changes in fluid balance while minimizing false negatives. Some urine biomarkers such as urine specific gravity (USG) are quantifiable, with values of ≤ 1.020 indicating euhydration. In contrast, urine colour and urine volume are less reliable, as they can be subjective and can be influenced by other factors[4], though their ease of use makes them understandably widely used in practice.

Pre-Exercise Hyperhydration

Some athletes may opt for hyperhydration (deliberately increasing body water before exercise) before training or competition to support endurance performance. While hyperhydration can enhance performance during endurance events, the performance effects are usually modest. In practice, if an athlete finds it challenging to manage multiple pre-exercise routines (nutrition, warm-up, mental preparation, pre-cooling) hyperhydration may not be the most critical priority. However, if an athlete can incorporate it without disrupting other key elements of their preparation, it may be worthwhile to trial during training and, if well-tolerated and effective, consider hyperhydration for competition. Hyperhydration (usually fluid gain less than 1 L) is commonly achieved by drinking hydration solutions with high sodium or glycerol content to enhance fluid retention.[16]

Hydration During Exercise

It is important that athletes begin competition confident in their overall race strategy, hydration included. The demands of the competition as well as individual differences in dehydration tolerance may influence whether an athlete relies more on thirst-driven drinking or a structured plan based on individual sweat rate and expected fluid and electrolyte loss. Still, some preparation is always advisable: identifying opportunities to drink, ensuring access to fluids, and having a back-up plan for hotter conditions and higher-than-expected sweat losses.

Amount

Drinking according to thirst is often sufficient even during high-intensity exercise performed in hot conditions. In some cases, like during very demanding exercise in a harsh environment, making a hydration plan where individual sweat rate and electrolyte losses are considered, may be appropriate. After exercise, normal eating and drinking will restore fluid balance. For rapid rehydration, drink 150% of the weight lost during exercise.

Carbohydrates

Carbohydrates can increase fluid absorption and provide energy / increase performance during exercise. A solution with 4-8 % of glucose and fructose can increase absorption but can delay gastric emptying.

Temperature

Cool beverages (~10 C°) can increase spontaneous fluid intake and limit dehydration. Cold drinks and ice slushies can additionally provide cooling during exercise.

Electrolytes

Electrolytes can increase fluid absorption and provide replenishment for the electrolytes lost during exercise. 25–50 mmol/L of sodium (1,5–3 g/L of table salt) can be optimal for fluid absorption and retention but exceeds most available commercial sport drinks' concentrations.

Flavour

Flavouring can increase the palatability of fluids but its effects on fluid consumption are not consistent.

Try new drink solutions during practice before competition use!

FIG 4.3. Maintenance of fluid balance during prolonged (> 1 hour) exercise can benefit from optimizing the hydration solution. For optimal hydration the carbohydrate and electrolyte concentration must be considered alongside with temperature and flavouring for increased palatability.

Water is often sufficient for hydration during exercise, with exercise durations of 1 hour or less. During prolonged exercise and with significant sweating, including electrolytes is beneficial for both hydration and electrolyte balance. 25—50 mmol / L of sodium (translating to around 1.5—3 g / L of table salt) helps to retain fluids and to replace the sodium lost via sweating. Fluid absorption can be further enhanced by including carbohydrates (e.g., 3 % glucose, 3 % fructose) with the additional benefit of providing energy for exercise.[14] Thirst-driven drinking can be further supported by providing cool, palatable drinks for athletes. Research shows that drinking cool drinks (10—22°C) can increase fluid intake by 50 % during exercise compared to warmer drinks and this can attenuate dehydration during exercise by 1.3 % of body mass – a very meaningful effect.[12] Noteworthily, drink flavouring does not seem to consistently carry the same effect[15] though flavouring might prove to be useful with fluids of high sodium concentration.

Rehydration After Exercise

Acute changes in body weight can be used to assess water loss during exercise to determine the need of hydration during the recovery period but in most cases normal water and food intake sufficiently restores fluid and electrolyte balance. A more strategic approach can be warranted when a second bout of exercise is expected, and a limited time is allowed for rehydration. To maximize rehydration consuming 150 % of the body mass loss in fluids is recommended.[14] The fluid used should contain electrolytes (e.g., sodium) to increase fluid retention and often the highest retention rate is acquired with concentrations exceeding those regularly found in sports drinks. Concentrations of sodium around 50 mmol / L (about 2.9 g of NaCl per litre of water) are useful when rapid rehydration is pursued, and the benefits may be higher when the concentration is further increased. Adding carbohydrates (e.g., 3 % glucose and 3 % fructose) can increase fluid retention further but high concentrations may delay gastric emptying.[14] Using hydration and rehydration solutions should be first done during training to ensure palatability and stomach comfort before using them in competition. Individual tolerance may steer the athlete toward milder sodium and carbohydrate concentrations for best overall effect. Those prone to gastrointestinal discomfort from high fluid intake, or high concentrations of carbohydrates or electrolytes, can opt for “gut training” (i.e., frequent high intake of fluid, carbohydrates and electrolytes during training) to improve their tolerance to more aggressive hydration strategies for both hydration during and after exercise.[17]

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Training Adjustments and Monitoring in the Heat

Training in the heat amplifies physiological strain, meaning that maintaining the same pace or power output imposes a substantially greater internal load. Elevated heart rate, lactate, and perceived exertion all signal that the same external workload now produces a different physiological response, with distinct implications for both training adaptations and fatigue cumulation. Without appropriate monitoring and training adjustments, athletes may unintentionally train at a much higher physiological or internal intensity than intended, turning an easy run or ride into more demanding training. This excessive physiological stress can disrupt recovery, blunt adaptation, and compromise long-term progress[1]. Adjustments to training allow the desired physiological adaptations to occur while minimizing the negative effects of heat-related overload.

Internal and External Load Monitoring

To fully appreciate the value of training monitoring, training load should be understood. Training load can be viewed from two perspectives:

- External load refers to the measurable work performed such as pace, power output, distance, or number of repetitions.
- Internal load describes the physiological and perceptual response to that work such as heart rate, blood lactate, or ratings of perceived exertion (RPE).

The internal load elicited by the same external load varies between individuals and conditions. Individual characteristics and genes, training status, psychological status, health, nutrition, and environmental conditions all affect the final internal load accumulated from the external work done.[2] For instance, a steady pace or power that would normally elicit 75% of maximal heart rate may push heart rate closer to 85–90% in the heat, even though the external output remains the same. Monitoring both internal and external load provides a more accurate picture of training stress, but the goal of the training bout dictates whether internal or external load should be the primary guide when environmental conditions change. While relying solely on external metrics risks overexertion in harsh conditions or undertraining when conditions are more favourable, training guided on measures of external load is sometimes warranted (e.g., training for race pace or speed).

Training Thresholds and Zones in the Heat

Training zones (e.g., zones 1—5) and thresholds (e.g., aerobic and anaerobic threshold, lactate thresholds, or ventilatory thresholds) are often defined based on laboratory or field testing conducted under specific environmental conditions. However, when the environmental conditions, such as temperature, change, the body's physiological response to the pace or power at these thresholds or zones changes[3,4]. This means that threshold paces or power are not fixed, but that they shift with environmental stress.

For example, at the maximal lactate steady state (MLSS) intensity, the corresponding power or pace (external load) is typically lower in the heat compared with cooler conditions, even though the underlying physiological effort assessed by heart rate (internal load) remains similar.[3] If training intensities are based on tests performed in cool weather or indoor facilities, maintaining those same external intensities in the summer heat can unintentionally turn steady low-intensity aerobic training into a more demanding threshold session. Therefore, heart rate and perceived exertion, not pace or power, should be used to guide threshold or zone-based constant effort training to maintain the intended physiological stimulus in hot environments.

Importantly, even lactate-based thresholds can be altered in the heat. Although lactate production often increases in the heat[4], the lactate concentration corresponding to a given threshold may be lower[3] making training adjustments based on lactate concentrations difficult if the training conditions differ from the original testing conditions. If lactate-guided training, such as high-intensity interval training, is done in the heat, coaches and athletes should be aware of these implications. Minimizing heat exposure before a session to prevent excess heat gain or using cooling methods between work intervals, can help athletes and coaches to maintain exercise quality and make it more viable to use previously determined lactate concentrations to guide training. Also making use of cooler times of day, such as early mornings or late evenings, may help decrease some of the potential heat stress.

Measures of Strength and Power

Unlike in endurance training, where internal monitoring is common, internal measures of strength and power are often limited to subjective estimations of effort (i.e., RPE). Although RPE can be fairly accurate in common normothermic conditions[5], strength and power athletes frequently opt for external measures that autoregulate training based on preparedness and physical performance in the current conditions. For example, velocity-based training can be used as a guide to prevent athletes from under- or overshooting during strength training[6]: aiming for a target barbell velocity (e.g., 0.30 m/s) will provide a standardized intensity whereas aiming for a specific weight and repetitions will produce varying levels on intensity based on individual and environmental conditions. This autoregulation may help athletes when temperatures exceed those normally encountered during training. If excess heat affects our strength performance, we can still train at the intended intensity that we think will produce the best overall outcome.

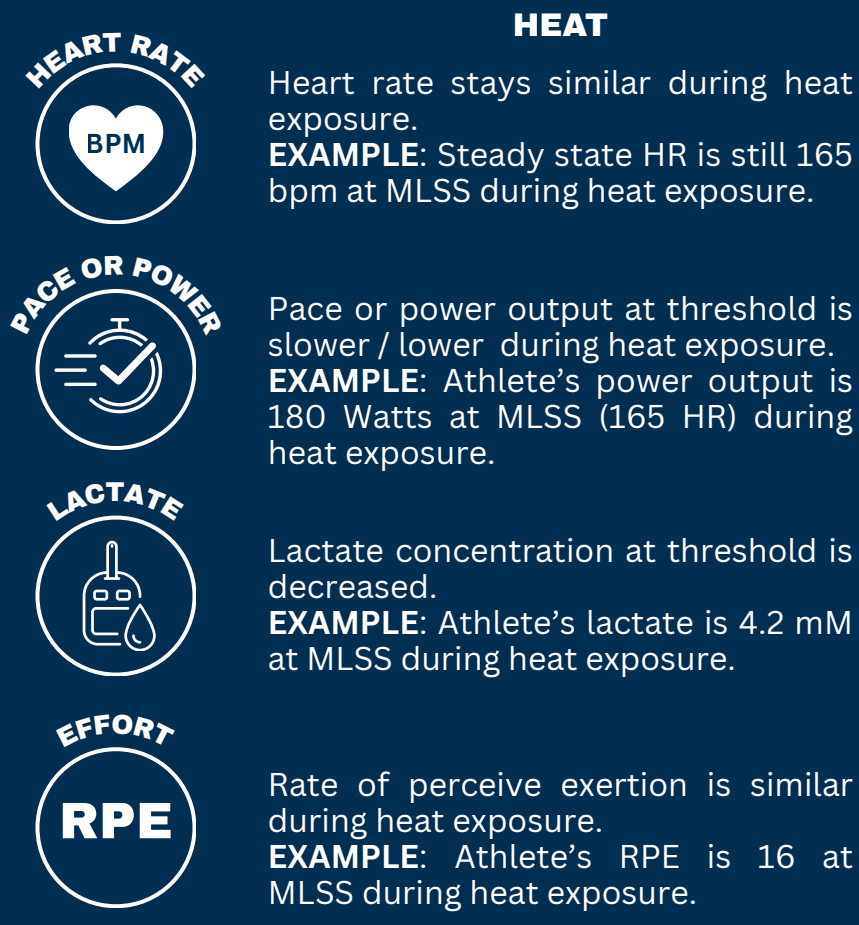

FIG 4.4. Common measures of exercise intensity and their behaviour during heat exposure. Example measures are provided for both temperate and hot environments for a hypothetical athlete.

Tracking Progress

When tracking progress across a prolonged period of time, it's important to interpret performance data within its environmental context. A decrease in pace or power output during the tracking period does not necessarily indicate a loss of fitness or detraining. It may simply reflect the body's physiological response to heat stress. Conversely, improved performance in cooler weather may reflect more favourable conditions rather than enhanced physiological capacity. To make meaningful comparisons, athletes should track both internal and external markers and interpret them within their environmental context.

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PART 5

Heat-Related Hazards

Heat-Related Hazards

1. Heat-Related Illnesses and Risk Assessment

Training and competing in hot environments carries not only performance challenges but also serious health risks. Here we address the most critical safety concerns linked to exercising in the heat, focusing on heat-related illnesses and the tools available for risk assessment. Understanding the mechanisms, signs, and progression of heat-related conditions, from mild heat cramps to life-threatening exertional heat stroke, is essential for timely recognition and effective intervention. Alongside this, assessing environmental and individual risk factors enables coaches and athletes to make informed decisions and adapt training safely. This part of the guide serves as a vital resource for protecting athlete health while continuing to train and perform in hot conditions.

Learning Objectives

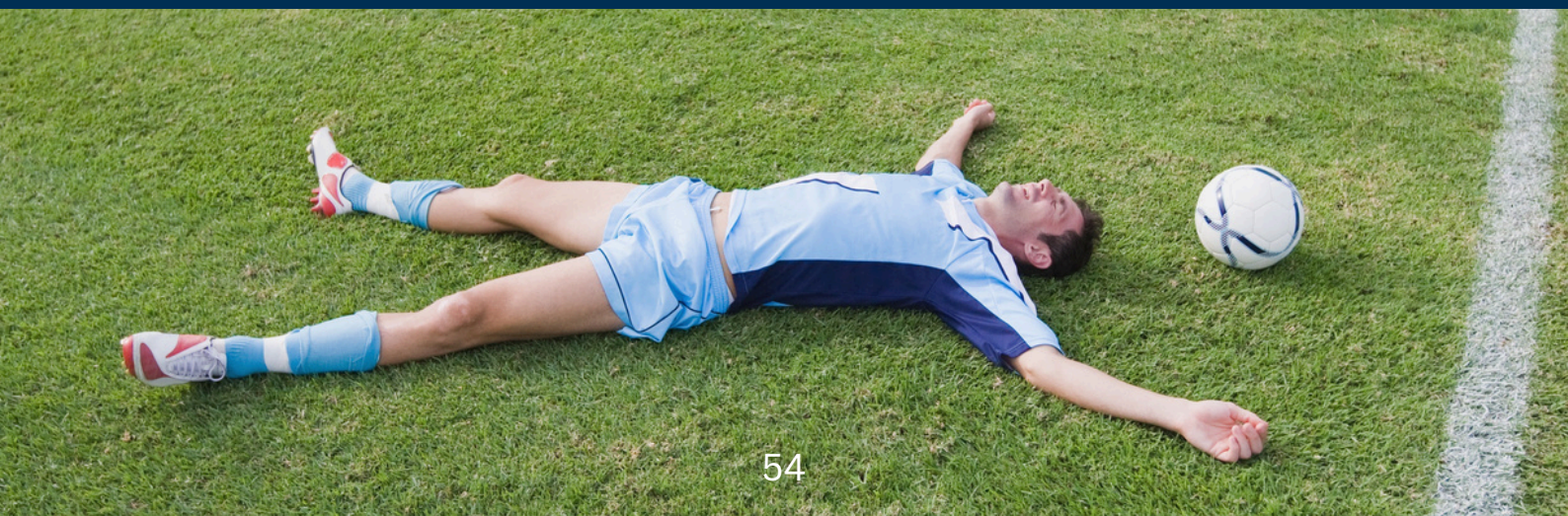
- Identify and differentiate heat-related illnesses
- Can implement an appropriate first-aid response to heat-related illnesses
- Understand how to assess environmental heat risks
- Can describe preparatory actions and prevention strategies to reduce the risk of heat-related illnesses

Heat-Related Illnesses and Risk Assessment

Heat-related illnesses exist on a spectrum, ranging from mild muscle cramps to life-threatening heat stroke. Most of them occur when the body's ability to dissipate heat cannot keep up with the heat gain from exercise or heat exposure. By recognizing early signs and symptoms, and by planning training, hydration, and cooling appropriately, most heat-related issues can be prevented entirely. It's important to recognize that heat acclimation is one of the key preparations that can be done to decrease the risk of heat-related illnesses, alongside cooling methods applied before and during heat exposure.

Heat syncope is a relatively common and harmless heat-related illness that occurs with peripheral vasodilation and its effects on central blood pressure. As circulation is guided towards the skin and the extremities for effective cooling, the blood volume available for the brain is decreased causing dizziness and fainting especially after stopping exercise. Heat syncope often occurs with normal core temperature, and during the first days of unaccustomed heat stress. Recovery is usually quick when laid down with feet elevated.[1,3] While heat syncope itself is not life threatening, the sudden loss of consciousness has the potential to cause secondary injury.

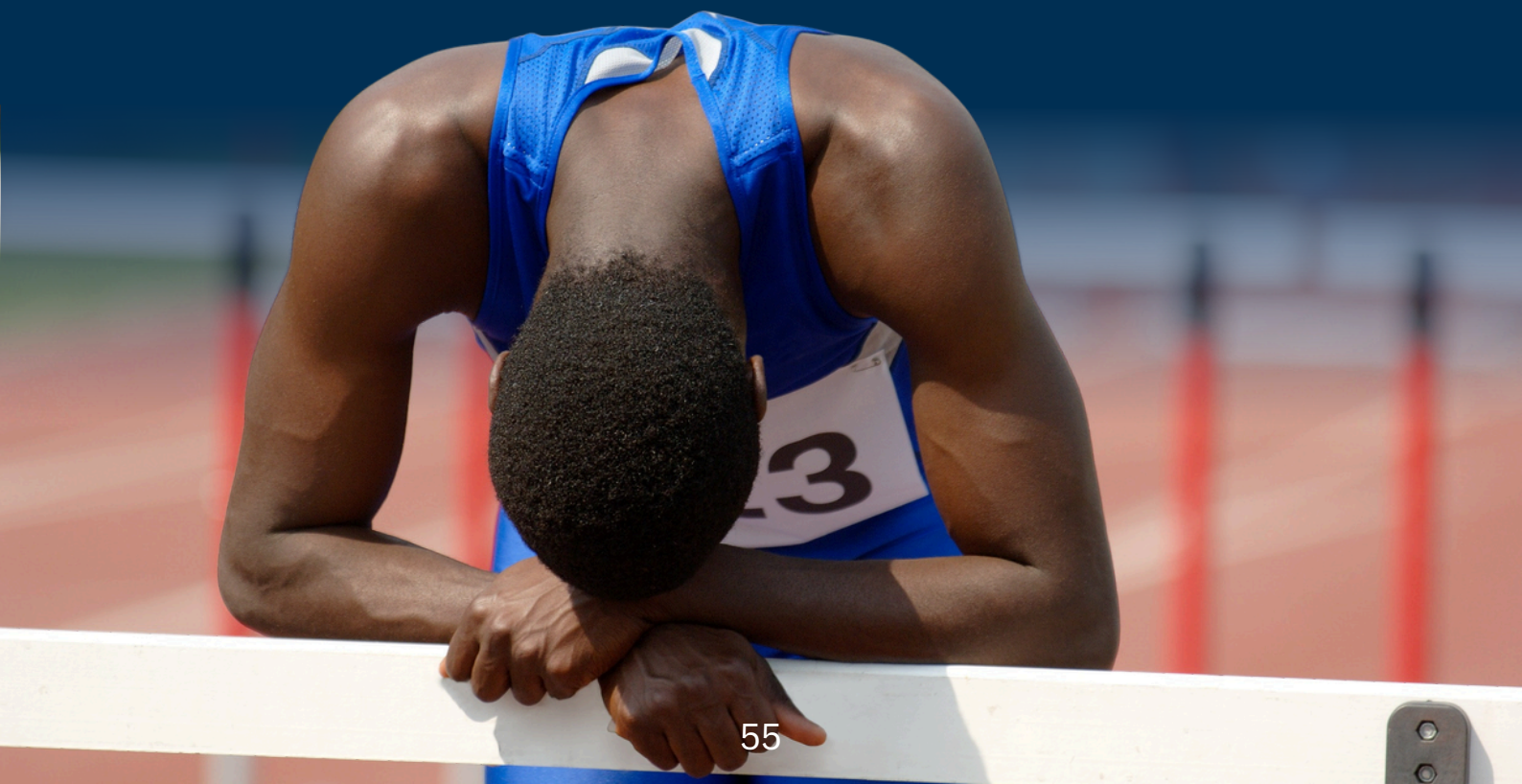
Exercise-associated cramps (EAMC) are sometimes referred to as heat cramps as they are often observed in the heat. However, EAMCs are also frequently observed in thermoneutral and cold conditions and are not specifically related to heat. Therefore, calling EAMC "heat-related" can be questioned. Often attributed to electrolyte imbalance, but evidence does not support an association with electrolyte concentrations and EAMC prevalence. Recently it has been suggested that EAMCs are the result of altered neuromuscular control particularly present in the fatigued state of the muscle.[2]



Heat exhaustion represents a more advanced stage of heat strain with more severe symptoms. Sweating is usually profuse, skin may feel cool or moist, and core temperature is typically elevated but below the critical threshold associated with heat stroke (<40°C). Common symptoms include intense fatigue and inability to effectively exercise, headache, nausea, and dizziness. Importantly, central nervous system function remains intact (the athlete can think and respond normally), which helps distinguish heat exhaustion from the more serious heat stroke.[1,3]

Heat stroke is a medical emergency and the most severe form of heat-related illness. It is defined by a markedly elevated core temperature (>40°C) and central nervous system dysfunction (confusion, disorientation, collapse, seizures, or loss of consciousness). Sweating may be present or absent. Heat stroke can lead to multiple organ failure and death if not treated promptly. Mortality rate is increased by the duration spent above critical temperature thresholds.[1,3] Heat stroke risk is increased by lack of heat acclimation, low fitness, high BMI, sleep deprivation, and previous history of heat stroke.[4]

Athletes' hyponatremia, while not strictly heat-related, is most commonly observed during heat exposure where sweating and excessive water consumption (without sodium) can disturb the body's normal electrolyte balance. Exercise-associated hyponatremia is defined as a plasma sodium concentration less than 135 mmol/L, and it can cause symptoms similar to heat stroke without the severe rise in core temperature.[5]



First Aid for Heat-Related Illnesses

Early recognition and prompt action are critical. When early symptoms occur during training or competition, the first step is to stop activity and move the athlete to a cooler environment such as shade or an air-conditioned room. Remove excess clothing and equipment to facilitate heat loss. For heat exhaustion, encourage cool fluid intake as tolerated and apply cooling strategies such as cold wet towels, ice packs or cold-water immersion. If the athlete's condition does not improve rapidly, core temperature continues to rise, or central nervous system symptoms are observed, suspect heat stroke and focus on aggressive cooling.

Heat Stroke Response

The most effective treatment for heat stroke is rapid cooling through cold-water immersion. Immersing the athlete up to the neck in cold or ice water allows for a rapid decrease in core temperature. The most effective cooling is produced by circulating ice water which can decrease core temperature by approximately 0.51°C per minute though uncirculated ice water immersion (0.35°C / min) and cool water immersion (0.19°C / min) are practical alternatives. Even temperate (~26°C) water can be used effectively to decrease core temperature if cold or cool water is not available. If immersion is not possible, use methods such as continuous cold-water showering (with fanning if available) or rotating cold towels / ice packs. The guiding principle is to cool first and transport second. Active cooling should begin immediately and continue until medical professionals take over or a core temperature under 38°C is reached.[1]

First Aid for Hyponatremia

If hyponatremia is suspected, do not encourage further water intake. If the athlete displays confusion, altered consciousness, seizures, or difficulty breathing, this indicates a more severe form and requires urgent medical attention. In these cases, infusion with hypertonic saline and water restriction may be necessary, and emergency services should be contacted immediately. Less severe cases may be treated with oral hypertonic saline intake. Often athletes present hyponatremia that is caused by excessive water consumption.[5]

Environmental Risk Assessment

Before planning training or competition in hot conditions, the first step is to understand the environmental risk: how the surrounding conditions will influence the athlete's heat balance, performance, and health. Assessing historical weather data in advance helps athletes and coaches to make initial preparations weeks and months before competition while more detailed assessment can be made closer to the event from the current weather data[4]. As heat stress is not determined by air temperature alone, the combined effect of temperature, humidity, solar radiation, wind, and the specific demands of the sport should be considered. A good environmental risk assessment helps coaches and athletes decide if, how, and under what precautions training or competition should proceed.

Prevention Strategies

While effective first aid can be lifesaving in severe heat-related illnesses, the safest and most reliable approach is to prevent these conditions from developing in the first place. Implementing proactive strategies such as structured heat acclimation, appropriate hydration practices, and screening is essential. Preparticipation medical screening can identify athletes who are particularly susceptible to heat-related illness, allowing for closer observation during high-heat conditions. Training schedules, work-to-rest ratios, and practice timing can be adjusted according to environmental stress, with extra caution during early-season sessions or when athletes are unaccustomed to the environmental conditions. Education of athletes, coaches, and support staff, combined with established emergency action plans and immediate access to cooling equipment, such as cold-water immersion tubs, ensures that any heat-related issues are recognized and can be addressed promptly.[6]

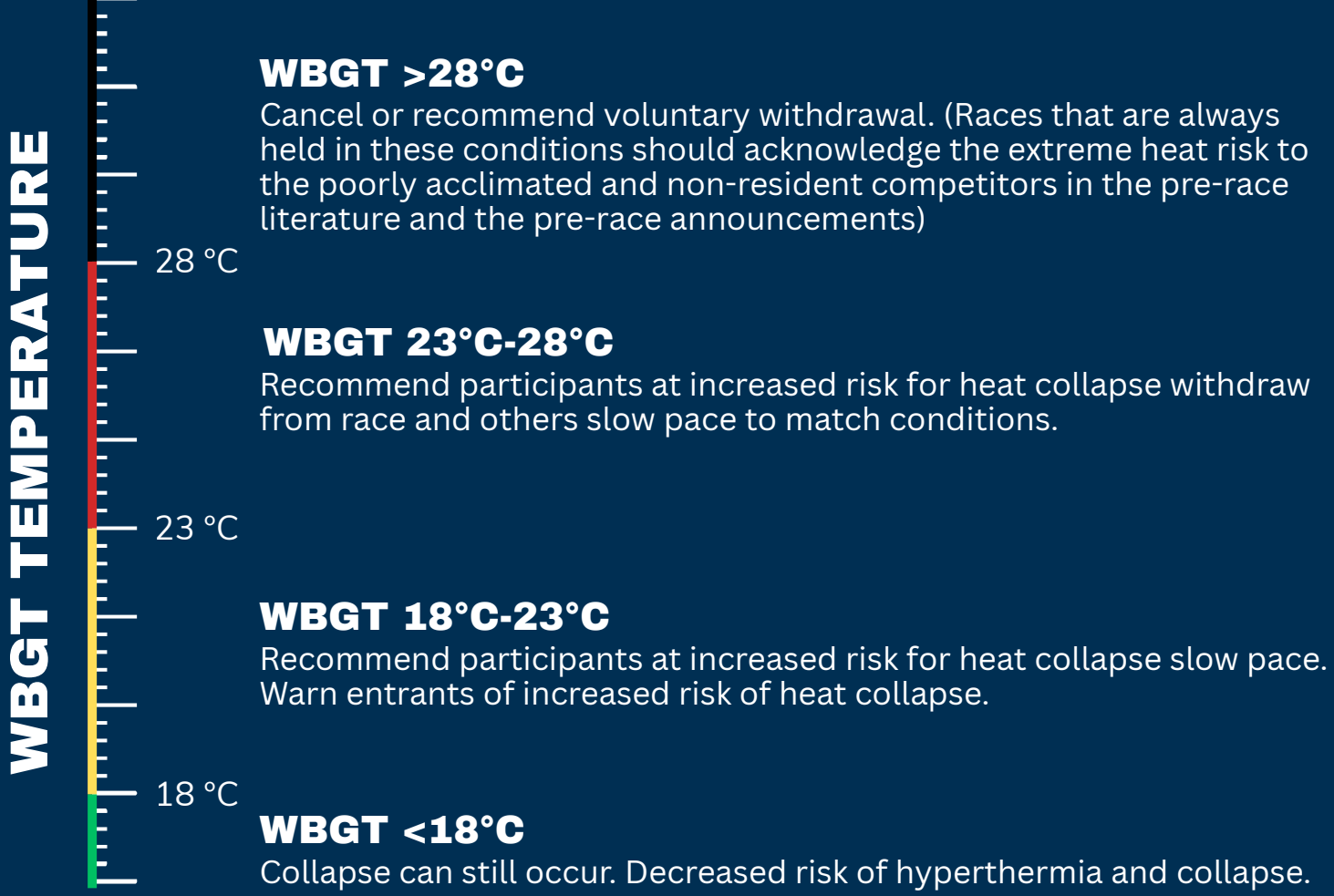


FIG 5.1. Example guidelines for heat risk assessment for athletes derived from the ACSM guidelines for road races. The guidelines are based on wet-bulb globe temperature.

Key Environmental Factors

A comprehensive assessment considers not only the surrounding temperature but all other aspects of heat transfer as well. Wet-bulb globe temperature (WBGT) may be one of the most useful indicators for heat stress in sports as it takes into account air humidity, radiant heat from the sun and surrounding surfaces, and the cooling effect of the wind, making it far more representative of real-world exercise environments. WBGT is widely used by sports federations to set heat thresholds after which competition is altered or cancelled[4] but its wide use among individual coaches or athletes may be limited as the necessary equipment may be unattainable. In these cases, using current available weather data to calculate an estimation of WBGT can be a viable option, though this will essentially leave out important information on the specific conditions on the field. For example, the colour and material of the track, turf, or other surfaces, can greatly affect heat gain from the environment.[5] Those seeking a more practical and simpler, and arguably cruder, approach, may use, for example, the National Weather Service's heat index[9] that combines humidity and temperature to provide an estimation for human heat stress.

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EP2 FINLAND

ENVIRONMENTAL EXERCISE PHYSIOLOGY PROGRAM

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