

3. Extreme Conditions

Sometimes football is played in extreme environmental conditions (either cold or hot). It is well known that endurance performance is reduced in hot conditions, but short (sprint) disciplines may actually benefit from them. In football, a single sprint may not be affected, but fatigue will develop more rapidly, and the number of high intensity sprints will decrease. In this section we will discuss the effects of heat on endurance performance, the reasons why it is impaired and strategies to minimise the impact of heat on performance.

Human body temperature is regulated within narrow limits. A normal temperature is 37°C. During exercise, body temperature may rise to 39.5°C, but normally 40°C is hardly ever reached or exceeded. The lowest temperature is around 36°C, so the normal range is 36-39.5°C. To keep core temperature within such a narrow range, a complex thermoregulatory system makes sure that heat is dissipated to prevent overheating and that body heat is conserved to prevent undercooling. In the next section we will discuss mechanisms of heat gain and heat loss and its central regulation through the hypothalamus.

3.1.1 Thermoregulation

During exercise in hot environmental conditions, there are a number of ways in which a player gains heat and a player has a number of mechanisms to dissipate heat (Wendt, van Loon, & Lichtenbelt, 2007). Conversely, in cold conditions the body has mechanisms to minimise heat loss. This makes it possible to prevent core temperature from rising or dropping to dangerous levels. Heat can be gained from the environment and from muscle contraction. Environmental heat stress is determined by the ambient temperature, relative humidity, wind velocity, and solar radiation (both directly from the sun and reflected from the ground). During exercise, the working muscles produce heat at a high rate and this is a major cause of the rise in body temperature.

Let's do a quick calculation of the potential impact of this heat production. In the following example, we will do the calculations for a 75-kg football player with a VO_2max of 4.3 L/min and 15% body fat. Football is played with an average intensity of 70% VO_2max and, thus, this player would play with an average VO_2 of 3 L/min. Energy expenditure is roughly 5 kcal per litre of oxygen consumed per minute. Approximately 20% of this is used for muscle contraction; the remaining 80% is heat. So, heat production is 12 kcal/min or 720kcal/hour (or 837 Watt). The specific heat capacity for lean tissue is 0.83 kcal/kg/°C and for fat this is 0.41 kcal/kg/°C. So, for our player with 15% body fat, this means that the specific heat capacity of the body is $(0.85 \times 0.83) + (0.15 \times 0.41) = 0.77$ kcal/kg/°C. Heat storage would therefore be $75 \text{ kg} \times 0.77 \text{ kcal/kg/°C} = 57.5 \text{ kcal/min/°C}$.

This means that with 720 kcal of heat production would take 12.5 min to increase body temperature 1°C and it would take approximately 37 min to reach dangerous levels. During high intensity physical activity, heat production through supramaximal efforts will be many times higher and core temperature could reach critical levels within 10-12 min.

Mechanisms to dissipate heat are therefore crucial. If the skin is hotter than the surroundings, heat is lost through the skin by physical transfer (evaporation of sweat, convection, and conduction) to the environment. If the environment is hotter than the skin, heat is gained by convection (convection is the exchange of heat between a solid medium (e.g., the human body) and one that moves (e.g., air or water) and conduction (direct transmission of heat to environment, without movement). Conduction is usually only a small percentage of heat loss (3%). Radiation (the transfer of energy waves by emission from one object and absorption by another) also plays a role. All objects that are not absolutely zero temperature radiate heat. Our body radiates heat, the sun radiates heat. Radiation in thermoneutral conditions accounts for approximately 60% of total heat loss. When the environmental temperature is high and radiation heat from the sun is high, radiation from the body is insignificant and heat is gained. More radiation heat is gained when there is no cloud cover or shade.

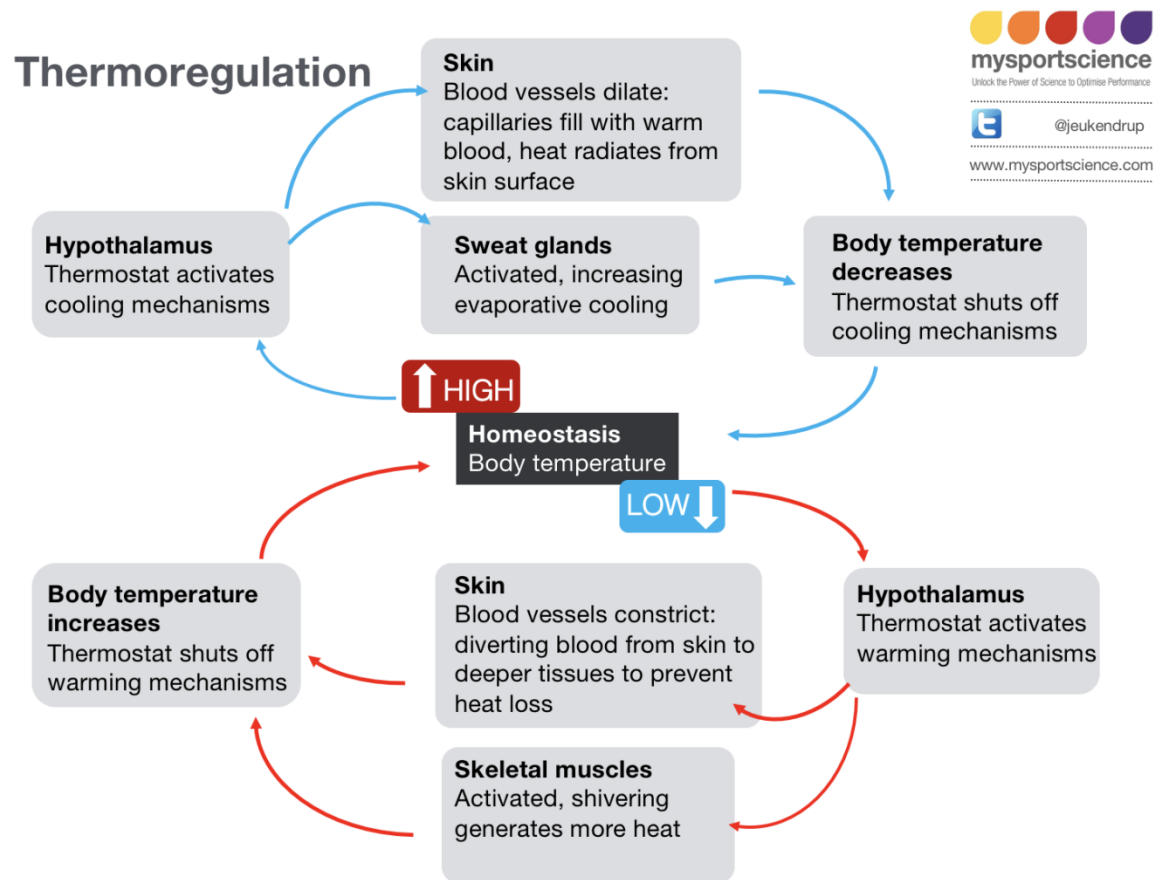
Evaporative heat loss is the final methods to dissipate heat. A small fraction of this occurs through ventilation and diffusion for which we do not have control mechanisms. Far more significant is evaporative cooling through sweating. In dry air, significant amounts of sweat can evaporate. Evaporation of 1 L of water from the skin will remove 573 kcal of heat from the body. However, if the environment is saturated with water vapour (i.e., relative humidity = 100%), evaporation of sweat does not occur, and the body does not lose heat. Relative humidity is therefore an important factor, because high humidity severely compromises the evaporative loss of sweat and sweat must evaporate from the body surface to exert a cooling effect. (Jeukendrup and Gleeson, 2018. <https://bit.ly/2LC9XB7>) When sweat rolls off the skin, it has virtually no cooling effect.

The rate of heat transferred away from the body core is the product of the skin blood flow and the temperature difference between the core and the skin. A first response is, therefore, an increase in cutaneous vasodilation. Adjustments in the cutaneous vascular tone will modulate skin blood flow. Blood flow is not only regulated by thermoregulatory responses, but also by non-thermoregulatory responses. For example, muscle contraction will increase the demand for blood flow and might result in vasoconstriction. When exercising in hot conditions, the cutaneous circulation is subject to conflicting demands: vasoconstriction to allow more blood flow to the muscle and vasodilation for cooling purposes (Kellogg, Johnson, & Kosiba, 1991).

High skin blood flow alone may not be sufficient to remove heat from the body core during exercise in hot, humid conditions when the skin temperature rises because of the inability to evaporate sweat. The effectiveness of this route of heat loss also depends largely on the amount of body surface available for heat exchange and the temperature gradient between the body surface and the surrounding atmosphere. Inappropriate clothing makes it more difficult to dissipate heat. When ambient temperature is close to body temperature, heat loss via increased skin blood flow is minimal. The body then depends almost entirely on evaporative cooling (sweating) (Jeukendrup and Gleeson, 2018. <https://bit.ly/2LC9XB7>).

The hypothalamus is the central thermostat that acts like a normal thermostat making sure the temperature in the body stays within relative narrow limits (Figure 1). The hypothalamus has many heat- and cold-sensitive neurons in its pre-optic and anterior nuclei. In addition to sensing the core temperature, the hypothalamus also receives afferent information from thermoreceptors throughout the body, including the spinal cord, abdominal viscera, greater veins and the skin. When body temperature increases, this is sensed by the hypothalamus itself as well as by these peripheral thermoreceptors and, thus, the hypothalamus will activate cooling mechanisms. These include vasodilation of capillaries in the skin. The skin will fill with warm blood from the core and heat can radiate to the environment. Simultaneously, sweat glands are activated for evaporative cooling (Figure 1). The result is that body temperature will decrease, and this means the thermostat can shut off again.

Figure 1: Regulation of body temperature and the role of the hypothalamus



Source: Jeukendrup. www.mysportscience.com

When temperatures are low, this is sensed as well, and the hypothalamus will activate warming mechanisms: blood vessels in the skin constrict so less heat is lost and skeletal muscles are activated. Muscle contractions, especially shivering, increase heat production. When the body heats up, the hypothalamus shuts off the warming mechanisms.

3.1.2 Effect of heat stress on performance

It is difficult to measure football performance in competition and compare different environmental conditions, but there are a lot of data from endurance sports. For example, when marathon times were studied in different WBG temperatures for a given marathon time, the findings were that there is a performance decrement with increasing heat stress. Faster runners are affected less by the heat than the slower runners, but in all cases, performance is affected by temperature. The fastest marathon times are usually seen around temperatures of 10-11°C. The optimal temperature for football is not known because endurance may be impaired in the heat, but sprint performance may be improved. It is likely that it will be at a higher temperature than marathon running, but not too hot, as endurance may be compromised too much. Grantham et al. (2010) suggested that players who

play at an air temperature below 22 °C are not at risk of heat stress and its negative consequences, while the risk is low between 22 and 28 °C and high above 28 °C. Football matches played at 43 °C demonstrated a decline in total game distance by 7% and in high intensity running (>14 km/h) by 26% in hot conditions when compared to control conditions (Mohr, Nybo, Grantham, & Racinais, 2012). However, peak sprint speed was 4% higher in hot conditions, while there were no differences in the quantity or length of sprints (>24 km/h). Passes and crosses success rates were 8 and 9% higher in hot conditions compared to control conditions (Mohr et al., 2012). Playing in hot conditions resulted in a dramatic increases of peak core (T_c : $39.5 \pm 0.1^\circ\text{C}$) and muscle (T_{mu} : $40.3 \pm 0.1^\circ\text{C}$) temperatures (Mohr et al., 2012).

One study suggested that, in football, high intensity running may not be affected by heat actually, but rather, the pacing may change, and recovery times may increase (Coker, Wells, & Gepner, 2018).

However, an analysis of the World Cup in Brazil in 2014 in mixed conditions, some extremely hot, suggests that top-level players seem to modulate their activity pattern during matches in a hot and humid environment (i.e., less high-intensity but more low-intensity running and successful passes) to preserve the global match characteristics (i.e., similar total distance covered, similar actual playing time, peak running speed and goals scored). (Racinais, S., Alonso, J. M., Coutts, A. J., Flouris, A. D., Girard, O., Gonzalez-Alonso, J., Hausswirth, C., Jay, O., Lee, J. K., Mitchell, N., Nassis, G. P., Nybo, L., Pluim, B. M., Roelands, B., Sawka, M. N., Wingo, J. E., Periard, J. D. 2015. <https://bit.ly/2ETri87>)

For a long time, there was a theory that there was a critical temper: once this temperature was reached, fatigue would occur in an attempt to prevent damage as a result of a continued rise in core temperature. This theory was derived from a number of studies in which fatigue coincided with core temperatures around 40 °C. It is striking that, with heat acclimation, subjects have a different starting core temperature, but exhaustion occurs always at the same temperature. An acclimation study conducted during 10 days of heat acclimation demonstrated that, even though every day exercise to exhaustion increased, the temperature at which exhaustion occurred stayed the same. This means that the rate of heat accumulation was lower every day.

Other studies have shown that pre-cooling the body can delay exhaustion, while pre-heating it will accelerate it. If the exercise is initiated with a lower starting temperature, it will take longer before exhaustion occurs and if initiated with higher temperature, it will take shorter. But the core temperature at the end was always the same (around 40°C). Therefore, it is not surprising that it was concluded that there was a critical core temperature.

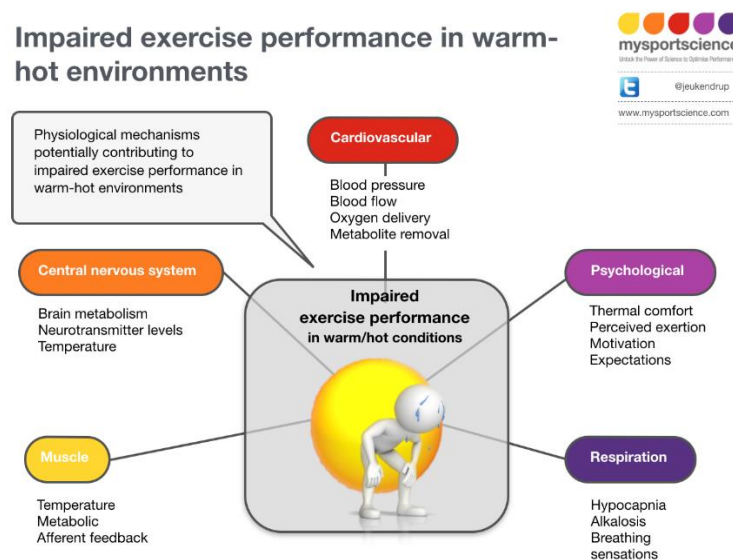
A single cause of fatigue in the heat may be a little too simplistic though; it is likely to be multifactorial (Nybo, Rasmussen, & Sawka, 2014). For instance, concomitant development of dehydration, which aggravates physiologic strain, seems to lower the tolerable core temperature at the end of exhaustive

exercise in the heat. Enhancing the synaptic dopamine levels (using dopamine reuptake inhibitors) increases subjects' exercise capacity in the heat and results in higher core temperatures at the end of exercise without reported side effects. Finally, trained subjects seem to tolerate higher core temperatures better than untrained individuals and, thus, the concept of one critical core temperature as a sole explanation seems too simplistic.

Field and laboratory studies have clearly demonstrated that aerobic exercise is impaired in the heat and it is very likely that the causes of this are multifactorial.

Physiological mechanisms potentially contributing to impaired exercise performance in warm-hot environments are depicted in figure 2. Hypo-hydration may exacerbate these effects. If hypo-hydration is sufficiently severe, all physiological functions are likely to be compromised, though the effects are more selective at the levels of hypo-hydration normally encountered.

Figure 2: Physiological mechanisms potentially contributing to fatigue during exercise in warm/hot environments

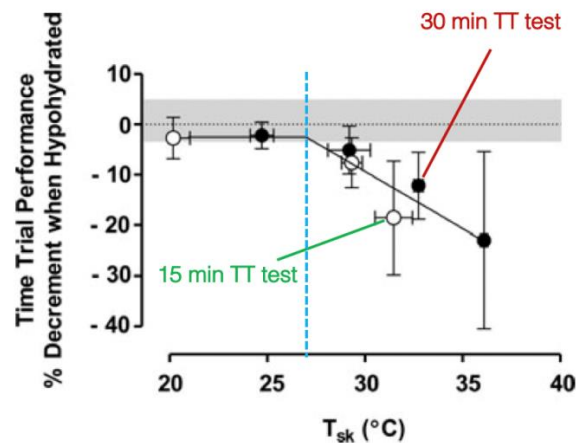


Nybo et al Comp Physiol 4: 657-689, 2014

Source: Nybo et al., 2014, <https://goo.gl/ae4Zrd>

Cheuvront, Kenefick, Montain, and Sawka (2010) proposed that impaired submaximal aerobic performance in the heat might be explained by warm-hot skin temperature reducing VO_2max . Figure 3, which contains data from a series of studies where performance was measured either through 15 or 30 minutes TT tests, shows that above skin temperatures of 27 degrees, performance starts to decline and for every 1°C rise in skin temperature, performance may decrease 1.3%. So, although core temperature is an important determinant of fatigue, skin temperature seems to play an important role too.

Figure 3: Time trial performance and temperature.



Source: Cheuvront et al., 2010, <https://bit.ly/2RtjmAg>.

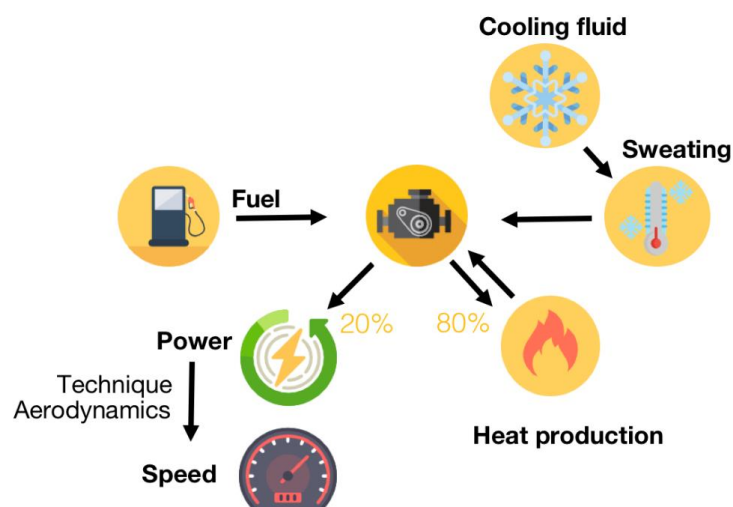
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3.1.3 Sweating

Our most important mechanism to dissipate heat in hot conditions is sweating. Let's use the analogy of an engine of a car (Figure 4).

Figure 4: Heat production and cooling. An analogy with a car

"The engine"



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Source: Jeukendrup, 2018. www.mysportscience.com

A car's engine produces heat. For every unit of energy generated for movement, 4 units of energy in the form of heat are produced (20% efficiency). For every litre of oxygen consumed during exercise such as cycling or running, approximately 16 kJ (4 kcal) of heat are produced and only about 4 kJ (1 kcal) are used to perform mechanical work. For an athlete consuming oxygen at a rate of 4 L/min during exercise, the rate of heat production in the body is about 917 kcal/h. Especially in a hot environment, only a small proportion of the heat produced in active skeletal muscle is lost from the overlying skin. Rather, most of the heat is passed to the body core by the convective flow of venous blood returning to the heart. It has been shown that the rate of temperature increase in the belly of the quadriceps muscle group is close to 1 °C/min during the initial moments of high-intensity cycling. This rate of heat storage cannot persist, because the muscle contractile proteins and enzymes would be inactivated, and heat-induced denaturation would result within 10 minutes. Thus, most of the heat generated in the muscle is transferred to the body core. (Jeukendrup and Gleeson, 2018. <https://bit.ly/2LC9XB7>).

Like a car has a cooling system the body has several cooling systems with sweating being the most important one when it is hot. Blood flow from the core to the skin will transport warm blood and evaporation of sweat will cool down the skin and the blood within it. When the blood volume decreases and skin blood flow becomes impaired, this has the same effect as running low on cooling fluid in a car.

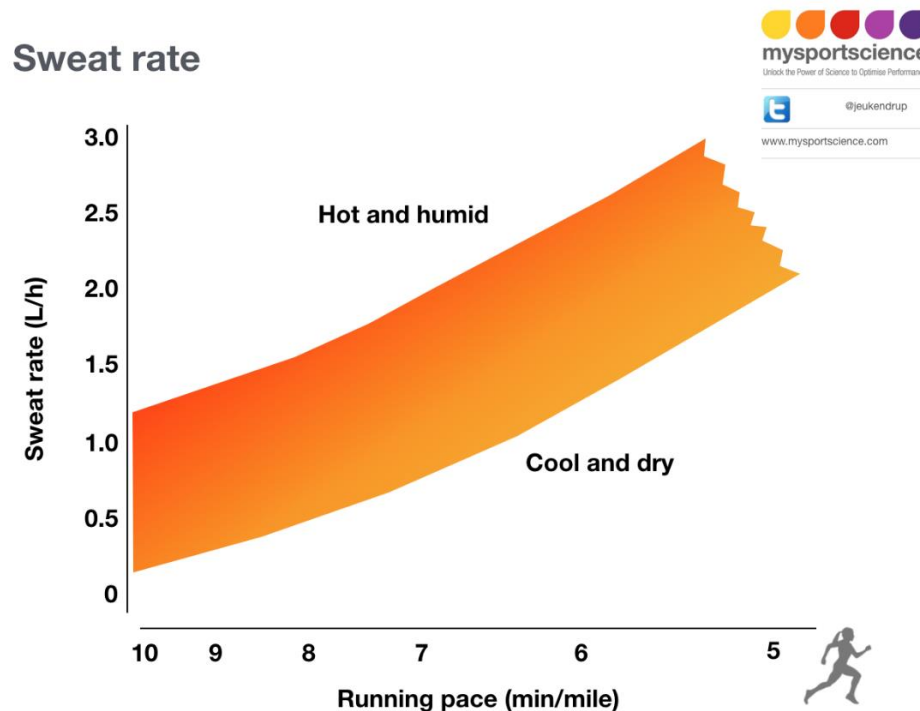
Humans have 2-4 million sweat glands, but there may be large individual differences in the number of glands and the way they are activated. This may be the explanation why some people sweat more than others. Activation of eccrine sweat glands causes sweat to be secreted onto the skin surface, thereby promoting heat loss as the water content of sweat evaporates. These glands can be found all over the body with higher densities in some areas than others. The glands are innervated by sympathetic nerves. Neural stimulation of the sweat glands elicits the secretion of sweat, which resembles blood plasma but without the proteins. Sweat, therefore, contains also some electrolytes with sodium being the most abundant one.

Sweat is hypotonic compared to plasma and this limits the losses of sodium and other electrolytes. The electrolyte concentration in sweat will decrease further with training and acclimation.

Sweat rates are typically between 0.5 and 2 L/h but can be as high as 3 L/h in extreme cases. In figure 5 you can see how sweat rate goes up with running pace and how cool and dry or hot and humid conditions affect it. For example, running at a certain pace would mean a sweat rate below 1 L/h in cool dry

conditions and over 1.5 L/h on hot and humid conditions. During intermittent exercise with breaks, it is the average intensity that is important, taking into account the rest periods.

Figure 5: Sweat rate: a function of running pace (intensity) and environmental conditions



Source: Jeukendrup. www.mysportscience.com

It is clear that a number of factors will determine sweat losses: these include:

1. exercise intensity
2. the duration of exercise
3. the number of sweat glands
4. acclimation
5. weather conditions
6. clothing

Having information about all these factors can help to predict sweat losses in athletes. How sweat losses can be predicted will be discussed in one of the following sections.

3.1.4 Dehydration and the effects on thermoregulation

When sweating becomes the primary way to dissipate heat, sweat loss must be matched by fluid intake to avoid dehydration. Although small levels of dehydration might be acceptable, larger losses may affect physiological function. As the body becomes progressively dehydrated, blood volume will decrease and this will affect both skin blood flow as well as sweat production. This in turn will result in a reduction in skin blood flow and, thus, sweat rate.

This may then result in a rise or more rapid rise in core temperature, resulting in fatigue and possible heat injury to body tissues.

Dehydration also reduces the core temperature that a person could tolerate, because core temperature at exhaustion is generally about 0.4 °C (0.7 °F) lower in the dehydrated state. The main reasons why dehydration has an adverse effect on exercise performance include:

- reduction in blood volume
- decreased skin blood flow
- decreased sweat rate
- decreased heat dissipation
- increased core temperature
- increased rate of muscle glycogen use

Reduced maximal cardiac output is the most likely physiological mechanism whereby dehydration decreases a person's running capacity. Dehydration causes a fall in plasma volume, and a decreased blood volume increases the viscosity of the blood (thickness), lowers central venous pressure, and reduces venous return of blood to the heart. During maximal exercise, these changes can decrease the filling of the heart during diastole (the phase of the cardiac cycle when the heart is relaxed and is filling with blood before the next contraction), hence reducing stroke volume and cardiac output. During exercise in a hot environment, vasodilation of the skin reduces the proportion of the cardiac output available to the working muscles.

The larger rise in core temperature during exercise in the dehydrated state is associated with an exaggerated catecholamine response. This, in turn, may lead to increased rates of glycogen breakdown in the exercising muscle, which can contribute to earlier onset of fatigue in prolonged exercise.

Hypohydration also appears to attenuate strength, power, and high-intensity endurance by approximately 2%, 3%, and 10%, respectively, suggesting that alterations in total body water affect some aspect of force generation. Although the mechanisms are not well understood, the physiological demands of strength, power, and high-intensity endurance suggest alterations in cardiovascular, metabolic, or buffering function are responsible for the performance impairment associated with hypohydration (Jeukendrup & Gleeson, 2018). It has also been suggested that hypohydration might directly affect some component of the neuromuscular system, but this has not been investigated yet. (Jeukendrup and Gleeson, 2018. <https://bit.ly/2LC9XB7>).

Besides the effects of dehydration on the cardiovascular system and muscles, dehydration is also associated with a reduced gastric emptying rate of ingested fluids during exercise in the heat. For example, one study reported a 20- 25% reduction in gastric emptying when subjects were dehydrated by 5% of body mass (Neufer, Young, & Sawka, 1989). A reduced gastric emptying will affect the delivery of carbohydrate and fluid during match or training and is likely to cause more gastro-intestinal discomfort.

Dehydration poses a serious health risk as it increases the risk of cramps, heat exhaustion, and life-threatening heatstroke. To judge the risk of exercise-induced heat illness, it is important to have a measure of heat stress. Environmental temperature is only part of this heat stress. The heat index takes into account humidity as well and is therefore a better indicator of heat stress than temperature. However, the heat index still does not take into account all factors and radiation heat, for examples, is ignored. The heat index might therefore be suitable for shade and light wind conditions, but not for more exposed conditions. The Wet Bulb Globe Temperature (WBGT) is a more accurate measurement for situations with direct sunlight. The WBGT takes into account factors like solar radiation, as well as temperature and humidity. In order to measure WBGT one needs a WBGT meter.

Heat stress

Heat stress can be challenging for the cardiovascular system and in extreme cases can be life threatening. Several heat illnesses are distinguished with different heat cramps, heat exhaustion and heat stroke.

Heat cramps: exercise-induced muscle cramps that seem to occur more often in hot conditions. There is, however, no link with core temperature.

Heat syncope: Dehydration, fatigue, tunnel vision, pale or sweaty skin, decreased heart rate, dizziness, light headedness, fainting.

Heat exhaustion: Normal or elevated body temperature (37-40 °C), dehydration, dizziness, light headedness, headache, diarrhoea, decreased urine output, persistent muscle cramps, pallor, profuse sweating, chills, cool clammy skin, intestinal cramps, urge to defecate, weakness, hyperventilation

Exertional heat stroke: Body temperature (>40 °C), drowsiness, dizziness, behavioural changes, confusion, disorientation, light headedness, headache, diarrhoea, vomiting, dehydration, hot skin, hypotension, weakness, hyperventilation

Treatment/immediate actions

- **Heat syncope**
 - Remove from training or competition
 - Allow player to rest in shade, fan and spray water
 - Loosen or remove clothing
 - Provide sips of water
 - Monitor temperature and check for mental confusion
- **Heat exhaustion or heat stroke**
 - Immediately call for an ambulance or emergency services
 - Lay the player down in the shade with legs elevated
 - Undress the player as much as possible
 - Pour water over the player and fan
 - Cool by best means possible, water immersion, ice packs
 - If patient is conscious give sips of water
 - Monitor airways and breathing

Apart from effects on performance, heat can have an effect on health. Heat cramps (involuntary spasms of the muscle that occur more in the heat) are often reported. The most common heat illness is heat exhaustion. The cardiovascular system is adjusted but these adjustments are insufficient to regulate temperature properly, often central blood volume drops, venous blood return drop, blood pressure drops as well. Other symptoms include headache, nausea, dizziness, goose bumps, and general weakness.

Below are some recommendations for organizers of races or, in this case, for football trainers. These are the guidelines from US Soccer (Figure 6). First, WBGT should be calculated from data obtained from the weather forecast. This table can be used for recommendations on how to schedule practice. There are two regions in the USA, southern regions where the players will be more

acclimated to the heat can tolerate slightly higher temperatures (CAT3), but northern regions should take action at slightly lower temperatures. The advice is to have more breaks, reduce the duration of practices or move practices to a cooler part of the day.

Figure 6: Heat guidelines for football training by US Soccer

CAT I	ALERT LEVEL	WBGIT BY REGION (°F)			EVENT CONDITIONS	RECOMMENDED WORK TO REST RATIOS (ACTIONS & BREAKS)
		CAT 1	CAT 2	CAT 3		
>31°C	BLACK	>86.2°	>89.8°	>92.0°	Extreme Conditions	No Outdoor Training, delay training until cooler, or Cancel Training.
29-30°C	RED	84.2-86.1°	87.8-89.7°	90.1-91.9°	High Risk for Heat Related Illness	Maximum of 1 hour of training with 4 by 4 minute breaks within the hour. No additional conditioning allowed.
27-29°C	ORANGE	81.1-84.1°	84.7-87.7°	87.1-90.0°	Moderate Risk for Heat Related Illness	Maximum of 2 hours of training with 4 by 4 minute breaks each hour, OR a 10 minute break every 30 minutes of training.
25-27°C	YELLOW	76.3-81.0°	79.9-84.6°	82.2-87.0°	Less than Ideal Conditions	3 Separate 4 minute breaks each hour, OR a 12 minute break every 40 minutes of training
<25°C	GREEN	<76.1°	<79.8°	<82.1°	Good Conditions	Normal Activities. 3 Separate 3 minute breaks each hour of training, OR a 10 minute break every 40 minutes



US Soccer Recognize to Recover: Heat guidelines

Source: U.S. Soccer, 2018. <https://bit.ly/2Q9UiK5>

3.2 Beat the heat

3.2.1 Effects of dehydration on performance

Definitions

Euhydration refers to the maintenance of “normal” baseline body water content, while the terms “hypohydration” and “hyperhydration” refer to body water deficits and excesses beyond euhydration, respectively.

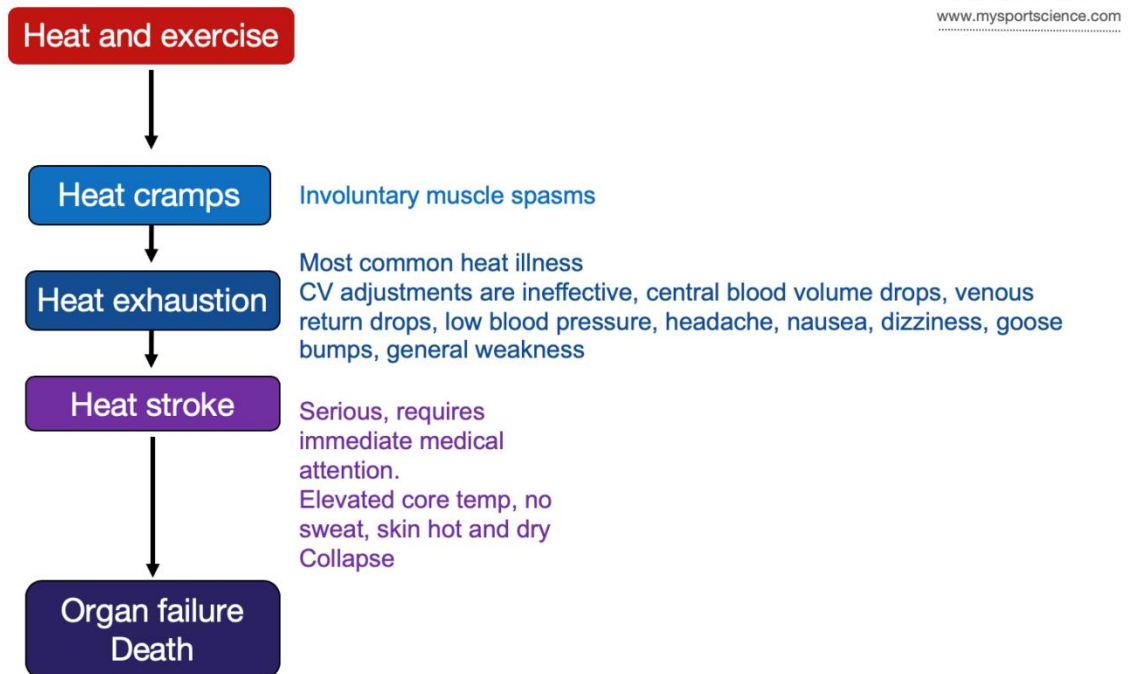
Dehydration is defined as the process of the dynamic loss of body water or the transition from euhydration to hypohydration.

As we have seen before, exercise in the heat can affect performance but can also result in heat illnesses (cramps, heat exhaustion and heat stroke). Sweat losses and inadequate fluid intake will result in dehydration and dehydration will exaggerate the effects of exercise in the heat. It will decrease performance and increase the risk of developing cramps, heat exhaustion and heat stroke.



Figure 7: Dangers of exercise in the heat

Dangers of exercise in the heat



Source: Jeukendrup. www.mysportscience.com

In Figure 7 you can see a rough indication of the development of heat and dehydration related issues. Within 2% body weight, loss performance should not be affected provided the athlete started in a euhydrated state. When the athlete loses 3% of body weight or more, endurance capacity may be compromised and also the risk of GI problems will increase during prolonged exercise. When athletes lose 4-6% they are at risk of losing muscle strength, endurance is almost certainly compromised and heat cramps may occur. With 6% or more, there is increased risk of heat exhaustion, and even heat stroke, coma and eventually death. Therefore, it is important to prevent extreme dehydration. As we will discuss later, this is best done by putting a hydration strategy in place that takes into account the predicted sweat losses. It must also be noted that such large fluid losses are highly unlikely to happen in football, even in extreme conditions.

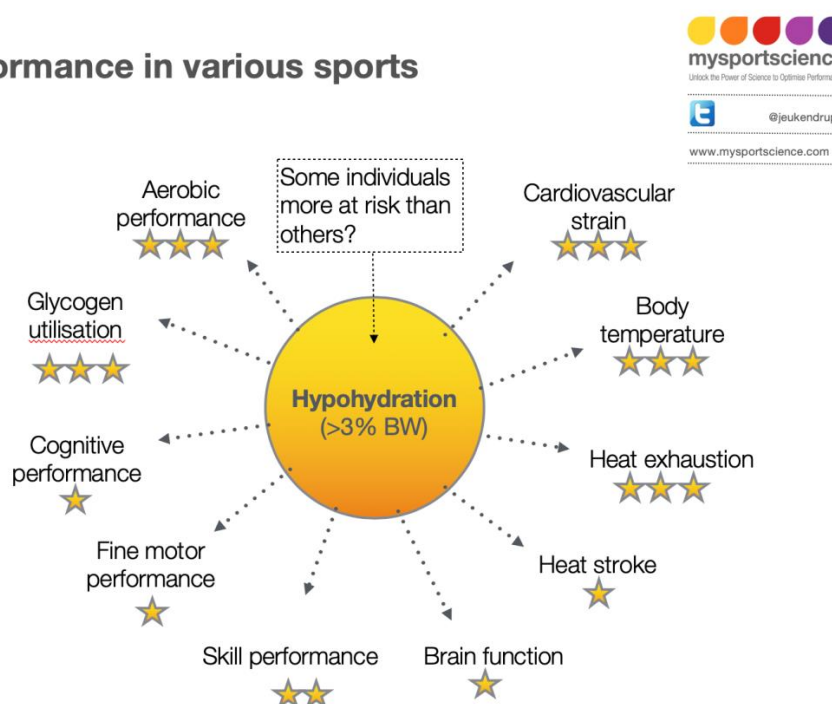
Cheuvront, Carter, Castellani, and Sawka (2005) "tested the effect of hypohydration on aerobic performance using a 30-minute exercise preload at ~50% VO_2max , followed by a 30-minute TT in temperate and cold environments. Hypohydration by 3% body mass impaired performance by 8% in the temperate ($T_{sk} \sim 29^\circ\text{C}$) but not in the cold environment ($T_{sk} \sim 20^\circ\text{C}$)."

There has been much debate about the effects of dehydration on performance. And although no one dismisses the fact that dehydration can affect performance, the discussion is about what level of dehydration will result in performance losses. In a review article, selected studies were presented and divided into time to exhaustion tests and time trials. It was argued that time trials which are more relevant to real world competitions generally show very small effects or no effects at all. Although this is true, and although some studies may have exaggerated the effects of dehydration by selecting extreme temperature, low wind cooling etc., most studies still show an effect on performance. Some individuals may tolerate larger levels of dehydration better than others, but in hot conditions dehydration to 3% BW or more can affect physiology and performance.

Dehydration may not only affect endurance performance but also other aspects of performance. In figure 8, we can see the various aspects of performance that might be affected and, depending on the sport, these may be more or less important for overall performance. The stars indicate the level of evidence. Please note that these are our personal interpretations of the literature: they are not based on a carefully conducted meta-analysis or consensus document.

Figure 8: Effects of dehydration on various aspects of performance

Performance in various sports



Source: Jeukendrup. www.mysportscience.com

The stars indicate the strength of evidence. One star very little evidence, 2 stars increasing evidence, 3 stars convincing evidence.

There is significant evidence that dehydration (>3%) can affect aerobic performance and increase glycogen use, cardiovascular strain, body temperature and the risk of heat exhaustion. There is less evidence that this level of dehydration is a risk factor for heat stroke; you probably need to be more dehydrated.

Hypohydration can also have detrimental effects on cognitive performance (short-term memory, attention, and visual-motor tracking) and ratings of mental fatigue and mood, especially when the body water deficit is combined with environmental heat stress (Cian, Barraud, Melin, & Raphel, 2001). In general, hypohydration >2% of body mass loss, typically induced by exercise and/or heat stress, degrades cognitive function. Some have even suggested that even milder levels of hypohydration can adversely affect some aspects of mood and cognitive performance (Baker & Jeukendrup, 2014). For example, Ganio et al. (2011) found that 1.6% hypohydration degraded visual vigilance and visual working memory and increased ratings of fatigue and tension/anxiety in healthy young men. Furthermore, there is some evidence that cognitive performance is degraded in a dose-dependent manner with graded levels of hypohydration (Lieberman, 2007). These effects have the potential to negatively impact the capacity to perform work involving mentally demanding or skilled tasks in everyday life as well as in occupational, military, and sports settings.

Baker et al (Baker, Dougherty, Chow, & Kenney, 2007) demonstrated that progressive dehydration resulted in deterioration of skill performance. The players performed a sequence of continuous basketball drills designed to simulate a fast-paced game. The measurements of skill performance during the 80-minute game included (1) total time to complete basketball-specific movement drills (sprinting, defensive slides, sprinting-defensive slides combination, and repetitive jumping drills) and (2) total number of shots (foul-line and baseline jump shots, layups, three-point, 15-ft, free throws) made per game. Performance decreased more as dehydration progressed from 1 to 4%. The threshold, or % dehydration at which the performance decrement reached statistical significance, was 2% for combined timed and shooting drills.

In conclusion

- It is important to avoid a core temperature that is too high, but skin temperature also plays a role.
- Dehydration may affect many aspects of performance, including running performance, cognitive function (decision making) and skill performance.
- There is still debate about the exact level of dehydration that is permissible, and this level may vary from 2% in very hot conditions to slightly higher levels in cooler conditions.
- Sweat rates are highly individual and losses can amount up to 3 L/h.

- Electrolytes are lost in sweat, but it is highly unlikely that significant losses can be incurred in 90 minute match play.

3.2.2 Drinking

The views on fluid intake have changed drastically. In road cycling drinking was frowned upon and it was generally thought that it would impair performance. This view changed as more studies demonstrated the effects of dehydration. The number of aid stations at marathons in 1953 was two. This was increased to four in 1967 and then to a minimum of 8 in 1977. Nowadays marathons have to provide at least 9 aid stations and most major marathons will provide many more. It is also obvious that the location of the first aid station has been brought forward and nowadays you can expect at least one aid station in the first 5 km. Guidelines were developed, is the ACSM position stand on fluid replacement published in 2007 (American College of Sports et al., 2007). A new guideline about nutrition and exercise performance was published recently, but fluid intake guidelines have not changes significantly (Thomas, Erdman, & Burke, 2016). You are encouraged to read these guidelines carefully.

In football there are FIFA rules about drinking. Generally, there are not a lot of drink breaks, but a referee can add drink breaks if required in hot conditions. Normally players will have to go to the side line when the game is interrupted. Drinks can only be handed out from the dugout, and thus, the players on the far side of the pitch are less likely to get these opportunities. In any case, it is impossible to plan these drink breaks, but it is possible to be prepared for them.

Drinking to thirst is probably an appropriate strategy for a lot of players, although this is difficult for obvious reasons when access is limited. Especially if intensities are not high and fluid is readily available (i.e. some training) this approach can work. However, drinking to thirst is not “a strategy”, and it is difficult to plan for. Drinks may not be available when you want them. It is better to prevent thirst to some degree by working out how much fluid you will need and start to drink early. By delaying the drinking start (to when you become thirsty), you may miss a valuable part of the race or competition where the GI tract is working very well and can absorb fluids and carbohydrate without problems. During the latter part of a match, blood volume may be redistributed away from the intestine, making absorption sometimes problematic, and also this is the time when stomach discomforts develop. In addition, thirst does not always reflect accurately the level of dehydration. For many, thirst is also a learned response; it is not just a physiological response to dehydration. The advantages and disadvantages of drinking to thirst have been discussed in a recent review by Kenefick (2018).

In order to give good advice on how much someone has to drink, it is important to know how much someone is going to sweat with reasonable

accuracy. Only when we have an idea of sweat rates can we make informed decisions.

It is possible to follow some general guidelines like the ones sometimes used (i.e. drink 400-800 ml of fluid per hour) but, unfortunately, this does not take into account the individual differences that may exist. You can see how sweat rates increase with exercise intensity and with increasing temperature, but for more accurate predictions it is important to perform measurements in conditions similar to those of a match.

So here are a few guidelines to follow:

- Identify players who are at risk by measuring sweat rates during training (and competition when possible).
- Perform sweat rate measurements in a range of conditions (intensities and weather conditions).
- Estimate sweat rates for individuals and allow 2% weight loss at the end of the match.
- If extra time is an option, take this into account as well.
- Calculate a volume to drink to prevent 2% weight loss with the predicted sweat rate.
- Prepare a drink that also includes carbohydrate and some sodium (or deliver the components carbohydrate, sodium, water) in different forms (gel plus water for example).
- When performance or quality of training is less important, or when the intensity is low, water will suffice.

3.2.3 So how would we measure sweat rates?

The simplest way to get an estimate of sweat rates is by measuring body weight. Although this technique is not without limitations (during prolonged exercise, you may also lose carbohydrate and fat weight and not just fluids, and it does not actually give you a measure of hydration as fluids may be in bladder or intestine). Overall, however, this method gives a great guideline to those who like to personalize their fluid intake. Simply measure body weight before training and after training and express this as a percentage of pre-exercise weight. This percentage is your percentage body weight loss. The target then is to try to prevent sweat losses greater than 2-3%.

Of course, when the athlete is drinking fluid or eating, this must be taken into account. In figure 9, the model of weight loss is corrected for volume consumed and a sweat rate can be estimated. Urine losses also need to be taken into account and during prolonged exercise, estimations of carbohydrate and fat use.

Figure 9: Sweat rate calculation

How to calculate sweat rate

Make sure everything is expressed in kg or liters.
Urine loss, if not measured, may be estimated at 0.3L



A Weight before	-	B Weight after	=	C Weight loss		D Duration of exercise (in h)
X Bottle weight before	-	Y After	=	Z Volume consumed		U Urine loss
Sweat rate (Liters per hour) = $\frac{\text{C} + \text{Z} - \text{U}}{\text{D}}$						

Source: Jeukendrup. www.mysportscience.com

Estimating your Sweat Rate

1. Empty your bladder and record your weight (ideally nude or with minimal clothing). (A)
2. Perform training (or match) and record/memorize exactly how much is consumed (drink volume). Weigh bottle before (X) and after (Y) and calculate the difference (1 gram = 1 millilitre) (Z). (B)
3. After exercise: Towel dry, empty bladder and then record body weight (nude (preferred) or with underwear). (B)

Measure or estimate urine losses if this is relevant (U)

Now subtract post-exercise weight from pre-exercise weight to get the weight you lost during exercise. Correct for drink consumed and urine loss.

This will give the net weight loss over the entire duration. Divide the net weight loss by the duration of the activity in minutes and multiply by 60 to get an hourly sweat rate.

As mentioned above, it is important to note that a small portion of body mass loss during activity occurs due to substrate oxidation, that is, non-waterly mass. Therefore, estimations in water loss based on change in body mass should be corrected for this non-water mass loss during exercise lasting several hours (e.g., > 3 h) (American College of Sports et al., 2007). The reader

is referred to papers that discuss the topic of hydration assessment in greater detail (Armstrong, 2007; Maughan, Shirreffs, & Leiper, 2007).

Of course, we assume that the athlete starts the exercise session hydrated. To assess basal hydration state, we have a number of techniques available. Some like total body water (TBW) are not always practical, but measurements of urine specific gravity or osmolality become more manageable in a practical setting. Simply looking at urine colour is another practical guideline that athletes can often do themselves. Euhydration cut-off values for various biomarkers of hydration status are displayed in Table 1.

Table 1: Biomarkers of hydration status

Table 1 Biomarkers of Hydration Status

	Practicality	Validity	Euhydration cut-off
Total body water	Low	Acute and chronic	<2%
Plasma osmolality	Medium	Acute and chronic	<290 mOsm/kg
Urine specific gravity	High	Chronic	<1.020 g/mL
Urine osmolality	High	Chronic	<700 mOsm/kg
Body weight	High	Acute and chronic*	<1%

Source: Derived from Baker & Jeukendrup, 2014)

So far, we only discussed the role of hydration, during exercise in the heat. There are also differences in substrate use. There is a trend for greater carbohydrate and lower fat oxidation in the heat. Several studies have demonstrated that glycogen use is higher in the heat (about 25% higher) (Jentjens, Wagenmakers, & Jeukendrup, 2002). In one study (Jentjens et al., 2002), subjects received a carbohydrate drink during exercise and exogenous carbohydrate oxidation was measured. Despite the fact that there was greater carbohydrate reliance in the heat, less exogenous carbohydrate was used. This is likely because during exercise in the heat there is a redistribution of blood flow with blood moving from the gastrointestinal tract to muscle and skin and this may compromise intestinal absorption of the carbohydrate. It also suggests that more carbohydrate remains in the intestinal tract and this has been associated with increased gastro-intestinal problems. We know from many studies that gastro-intestinal problems are more common in hot conditions in long endurance events especially and this may be one of the reasons.

In very hot conditions, it may be worth considering using slushies. Apart from providing fluids, slushies may be able to help to reduce core temperature or thermal sensation. Also, menthol has been used as a means to improve

thermal comfort. Several studies also show performance improvements with these cooling techniques.

3.2.4 Acclimation

Perhaps the most effective way to combat the effects of heat and to fight the detrimental effects of heat on performance is through acclimation or acclimatization. In an ideal world, the athlete would prepare by living in the same climate as the competition. This is called acclimatization. If this is not possible, one can simulate the conditions by training in an environmental chamber. The exact conditions can be simulated in such chambers: temperature humidity and, in some chambers, even radiation and wind speed. If this is not possible, the athlete can simulate the conditions at home with a heater and a humidifier fairly well. Lastly, it has also been shown that passive heating, for example in a sauna or even a hot bath, can also have some positive effects. So, there are many ways in which an athlete can prepare for competition in hot environments.

Five to ten days of heat acclimation have marked effects on physiology and the perception of effort. We discuss below some of the physiological effects that can be observed with acclimation.

A consensus paper has been recently published (Racinais et al., 2015). This paper provides some background and guidelines on heat acclimation. Different adaptations may happen with different speeds, but with ten days, almost all these adaptations are near complete and after only five days of heat acclimation most of the effect is already obtained.

Even more recently, a review added some more practical considerations (Daanen, Racinais, & Periard, 2018). Although acclimation may be complete in as few as 5 days, every day without heat exposure resulted in a decay of 2.5% of these adaptations. By increasing the duration of daily heat exposure, it is possible to improve the adaptations in core temperature. In order to sustain adaptations in sweat rate, longer acclimation periods give better results. In other words, the adaptations of sweat responses are sustained for longer.

Summary

- Performance is affected in hot, cold and high altitude environments (here we focussed on hot conditions only).
- There are a number of ways to express heat stress (heat index, WBGT) and these measurements should guide the training intensity, duration and timing.
- Advise on training to be conducted by an individual depending on the heat (by changing work-rest intervals, time of day, etc.).
- Heat exposure results in marked changes in physiological responses.
- Exercise in the heat increases the risk of heat illness and dehydration can exacerbate this effect.

- The effects of dehydration on performance are dependent on the environmental temperature.
- Drinking to thirst can work in some conditions, but in many others, it is better to predict your sweat rate and have a strategy.
- Heat acclimation is an effective strategy to prepare for exercise in the heat.
- Monitor pre-exercise hydration and prevent dehydration prior to the start of training or competition.
- Measure sweat responses and be able to predict sweat losses with reasonable accuracy.
- Develop a hydration strategy that prevents under- as well as over-hydration.
- Develop a strategy to make sure glycogen depletion is prevented or at least delayed.
 - Athletes planning to compete in hot ambient conditions should heat acclimatize (i.e., repeated training in the heat) to obtain biological adaptations lowering physiological strain and improving exercise capacity in the heat.
 - Heat acclimatization sessions should last at least 60 min/day, and induce an increase in body core and skin temperatures, as well as stimulate sweating.
 - Athletes should train in the same environment as the competition venue, or if not possible, train indoors in a hot room.
 - Early adaptations are obtained within the first few days, but the main physiological adaptations are not complete until ~1 week. Ideally, the heat acclimatization period should pass 2 weeks in order to maximize all benefits. (Racinais, S., Alonso, J. M., Coutts, A. J., Flouris, A. D., Girard, O., Gonzalez-Alonso, J., Hausswirth, C., Jay, O., Lee, J. K., Mitchell, N., Nassis, G. P., Nybo, L., Pluim, B. M., Roelands, B., Sawka, M. N., Wingo, J. E., Periard, J. D. 2015. <https://bit.ly/2ETri87>)
- Follow hydration guidelines.
- Consider pre-cooling strategies (e.g., application of iced garments, towels, water immersion or fanning) and internal (e.g., ingestion of cold fluids or ice-slurry) methods. It is important to make sure that muscle temperature is optimal whilst cooling the body. Otherwise cooling could have a negative effect on performance.

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