Thermorregulation in long distance race: Literature rewiew

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Igor Breguez
Dr., Professor of the Discipline of Physiology at the University of the UNC Contestado
Campus Porto União Santa Catarina
E-mail: igor_breguez@hotmail.com

Marco Antonio Schueda
Dr., Coordinator of the Faculty of Medicine and Professor of the Discipline of Anatomy at the University of Contestado UNC Campus Porto União - Santa Catarina
E-mail: schueda.sc@gmail.com

Anna Júlia Pelchebiski
Undergraduate student of the Medicine course at the University of Contestado UNC
Campus Porto União - Santa Catarina
E-mail: annajuliapelchebiski@gmail.com

Beatriz Ribeiro da Silva de Amorim
Undergraduate student of the Medicine Course at the University of Contestado UNC Campus Porto União - Santa Catarina
E-mail: beatriz.medicina2023@gmail.com

Rafaella Gugelmin Barros
Undergraduate student of the Medicine Course at the University of
Contested UNC Campus Porto União - Santa Catarina
E-mail: rafaella.gugelmin@gmail.com

Thaysa Bruna Gavronski
Undergraduate student of the Medicine Course at the University of
Contested UNC Campus Porto União - Santa Catarina
E-mail: thaysa101@hotmail.com

ABSTRACT

The literature review of the present study demonstrates that during physical exercise, the body produces heat through the working muscles, generating thermal stress. Through the analysis of articles mainly from the last five years, we concluded that to maintain stable body temperature, the body uses regulatory mechanisms dependent on environmental, task and personal parameters. In intense exercise and in hot environments, blood flow to the skin can increase significantly, and sweating is also increased. However, non-thermal reflexes during exercise cause the regulation of blood flow in the skin to be different from that at rest. The body adjusts the threshold for dilation of skin blood vessels to a higher core body temperature and modifies sensitivity to this temperature change. Regular training improves these adaptations, allowing athletes to dissipate heat more effectively. This review highlights the physiological mechanisms involved in thermal regulation during exercise, discusses the estimation of core temperature in humans, and presents new nutritional approaches to evaluate parameters to maintain stable core temperature.

Keywords: Physiology, Body temperature, Heat stress.

1 INTRODUCTION

The body's core temperature is normally set to 36.6°C1, but it can diverge considerably when exposed to extreme conditions. The lowest recorded core body temperature with survival by a human is 13.7°C2. In contrast, during exercise in the heat, well-trained athletes can reach core body temperatures of 41.5°C3. Core body temperature in humans is the main variable regulated in thermoregulation4. Resting core body temperature also depends on age, gender, ethnicity, ambient temperature, humidity, time of day and month of the year1. The amplitude of this diurnal variation is

0.5°C in healthy individuals5, excluding any exposure to extreme cold or heat stress, fever or exercise. The elderly have a lower resting core temperature than young adults6,7,8. The menstrual cycle significantly alters core body temperature, with an upward change of 0.4°C during the luteal phase compared to the follicular phase in premenopausal women9,10.

The skin acts as an interface with the environment, but unlike core temperature, skin temperature is not regulated11 and varies throughout the body in response to the thermal environment12,13. Even so, the average skin temperature can be categorized as cold (<30 C), hot (30-34.9 C) and hot (>35 C)14. Data indicate that changes in core temperature are much smaller than those in the skin and extremities in relation to changes in ambient temperature15,16.

Thermoregulation mechanisms include sweating, peripheral vasodilation, tachycardia, and increased respiration16.

Sweating is responsible for dissipating heat through the evaporation of sweat on the surface of the skin.

Peripheral vasodilation increases blood flow to the skin, allowing heat to dissipate through radiation and conduction.

Tachycardia and increased breathing help increase metabolic rate and heat dissipation.

In addition, the hypothalamus is the main control center for thermoregulation in the human body, monitoring body temperature and activating these mechanisms to maintain thermal homeostasis.

We will explore these mechanisms in the literature review below.

2 METHODOLOGY

The methodology chosen to carry out the following research was a literature review with an exploratory approach.

For Marconi and Lakatos (2019), literature reviews have the purpose of putting the researcher in direct contact with everything that has been written, said or filmed on the subject. It is not a mere repetition of the subject, but provides analysis of the theme from another point of view or approach, in order to reach new conclusions[17].

The research followed the recommended methods, after choosing the theme and preliminary research. The samples, were read, selected, evaluated and analyzed. The characteristics of the research were defined and then the results were discussed, interpreted and presented.

The guiding question was: How does body temperature regulation occur during physical activity in long-distance running?

For a bibliographic review of the theme, searches were carried out in printed bibliographies and digitized articles. The articles were collected, preferably, in the last five years, surveying studies specifically related to the proposed theme, which resulted in 83 articles/chapters.

In the researched articles, a pattern was noticed in the problem addressed, that is, the authors also had the same doubt as in the present study with the object of the research.

Understanding this subject is of great importance for medical professionals as well as physical educators and physical therapists.

3 RESULTS AND DISCUSSION

3.1 AUTONOMIC AND BEHAVIORAL THERMOREGULATION

The regulation of body temperature is carried out through parallel processes of behavioral and autonomic thermoregulation.

Behavioral regulation of temperature operates largely through conscious behavioral adjustments, which when in the heat include a range of coolness-seeking behaviors, such as staying in the shade, drinking cold drinks, pouring water on the head, and wearing light-colored clothing . It has also been suggested that adjustments in the rate of work during exercise in the heat constitute behavioral adjustments that contribute to regulating body temperature18.

Thermoregulatory behavior decreases the need for autonomic responses19, which operate through physiological processes independent of conscious voluntary behavior. These responses include control of vasomotor (i.e., cutaneous vasodilation) and sudomotor (sweating) function in heat, along with metabolic heat production (i.e., shivering) and vasomotor function (i.e., cutaneous vasoconstriction) in cold. Environments. A negative feedback system is typically described as the regulatory system that mediates thermoregulatory autonomic responses. This physiological control system produces graduated responses according to disturbances in a regulated variable: core body temperature. Such control structures are called proportional control systems. In humans, central (brain, spine, and gastrointestinal tract) and peripheral (skin) thermoreceptors provide afferent input to thermoregulatory centers located in the hypothalamus, where they are compared with the set[point20,21]. The set point is purely a mathematical concept used to describe the thermal control of effector responses and does not imply a specific neural model of thermoregulation or defined temperature. Instead, it describes different stages of recruitment within the magnitude of a load error, which is the difference between the input and the set[point22]. Thus, the central and peripheral thermoreceptors send information to a central integrator, located in the preoptic anterior hypothalamus[23]. The notion of central integration is supported by data describing the proportion of contributions of core temperature and skin inputs to sudomotor control24,25 and [vasomotor24,26,27]. These responses can also be altered by factors such as circadian rhythm, fever, phase of the menstrual cycle, and acclimatization to heat22,28.

The notion of central integration has evolved, with the emergence of other regulatory models. These include a model in which thermal equilibrium is achieved by regulating heat across a range of heat loads, sensing heat flow to and from the body, and defending body heat content through heat-effector responses29,30. Another model suggests that independent thermoeffector circuits coordinate their activities to regulate body temperature around an equilibrium[point11,31]. Thermoregulation during exercise in the heat is regulated in a similar way to that at rest and influenced by factors such as hydration status and environmental conditions, as well as work rate (i.e., exercise intensity) [16].

4 THERMAL EQUILIBRIUM

Human heat equilibrium refers to the balance between the internal rate of metabolic heat production and the rate of heat exchange with the surrounding environment through sensitive (i.e., convection, conduction, and radiation) and insensitive (i.e., evaporation) pathways.

Four main environmental parameters affect the biophysical properties of human thermal equilibrium: ambient temperature, humidity, air velocity, and solar radiation. In addition to environmental factors, task-dependent parameters have an impact on heat exchange: metabolic heat production rate and clothing; as well as personal parameters: body surface area, body mass, gender, age and aerobic fitness16.

5 ENVIRONMENTAL PARAMETERS:

Ambient temperature, humidity, air velocity, solar radiation

5.1 TASK-DEPENDENT PARAMETERS:

Metabolic heat production, clothing

5.2 PERSONAL PARAMETERS:

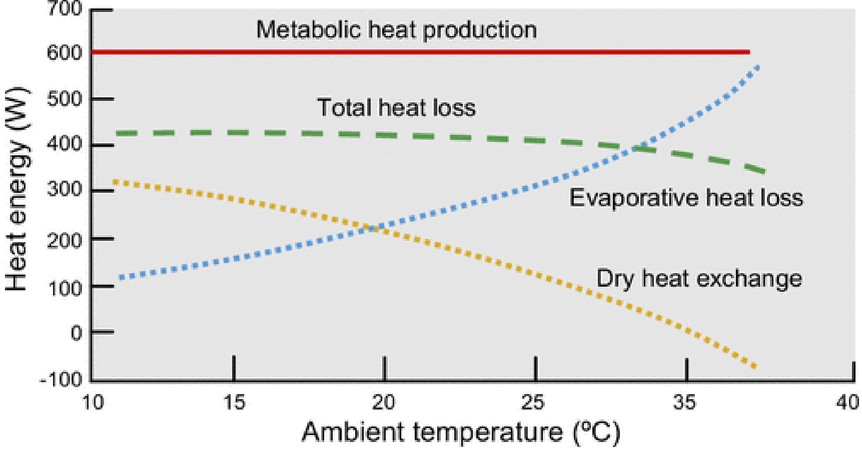
Body surface area, body mass, sex, age, and aerobic fitness

5.3 ENVIRONMENTAL PARAMETERS:

5.3.1 Ambient temperature

During exercise, ambient temperatures higher than skin temperature led to sensible (i.e., dry) heat gain, while lower temperatures led to heat loss (FIGURE 1). Environments with high ambient temperature and low humidity favor heat loss through evaporation, since sweat and mucosal moisture can evaporate more easily16.

Fig. 1 - As the ambient temperature increases and approaches the skin temperature, dry heat loss is reduced and evaporation becomes the main route of heat dissipation16.



5.3.2 Moisture

Absolute humidity refers to the amount of water vapor present in the air. In the atmosphere, absolute humidity ranges from almost zero to 30g/m3 when the air is saturated at 30O C. Air humidity is strongly related to climate. Hot, humid climates are typically found in rainforest areas, and hot, dry climates near deserts. High absolute humidity compromises the evaporation capacity of skin sweat because the difference in water vapor (i.e., moisture) between the skin surface and the environment is low[16].

5.3.3 Air speed

The standard meteorological wind speed is determined at 10 m above the ground and the highest air speed ever recorded on Earth is 113.3 m/s. Air speed during exercise depends on factors such as the direction of travel, wind direction, and terrain. The displacement of air through the body results in convective heat exchange, depending on the thermal gradient between the air and the skin. Air displacement also helps with heat loss through evaporation, as it removes the layer of saturated water vapor that can stagnate in the skin16.

5.3.4 Solar radiation

The amount of solar radiation that reaches the human body depends on the location on Earth, the time of day, the season, and the level of the exposed skin area.

The integration of environmental parameters can be used to provide an index of the severity of the thermal environment, with a combination of parameters used to calculate different indices. A meta-analysis identified more than 300 thermal indices, of which 185 were included in various statistical analyses 32. Temperature (98%), relative humidity (RH: 77%) and air velocity (72%) were the most commonly used environmental parameters to calculate the severity of the environment, with solar radiation (45%) and a combination of the four parameters (42%) being less frequently integrated into these calculations. The most commonly used index in sport and exercise is the moistbulb globe. temperature index (WBGT), which has been advocated by the American College of Sports Medicine[33] and the National Athletic Trainers' Association[34] and used by several international sports organizations (e.g., World Athletics, World Triathlon).

5.4 TASK-DEPENDENT PARAMETERS

5.4.1 Metabolic heat production

Human metabolism is the sum of resting metabolism (65 W/m2) and exercise. Oxidation of substrates during exercise contributes significantly to increasing the body's core temperature, as only 20 to 25%[35,36] of metabolic energy is converted into mechanical work, most of which is released as heat. The highest maximum oxygen uptake rate ever recorded (VO2max) is 96.7 ml/kg/min37. Although not sustainable over a very long period, this level of oxygen consumption is equivalent to 2,500 W of metabolic heat production, which underlines the large contribution of exercise-induced heat production to human thermal balance16.

5.4.2 Garments (clothing)

Clothing acts as a barrier between the skin and the environment, altering heat exchange properties in relation to environmental conditions. The properties of the material and the fit of a garment can affect thermal stress during exercise, reducing heat dissipation and promoting heat conservation38. As such, the insulating properties and water vapour resistance of garments worn while exercising in the heat should be as low as possible. The water absorption capacity of the material should also be low, as the sweat trapped in the clothing does not evaporate and does not provide cooling. In addition, the reflective properties of a garment are important in high radiative load scenarios (i.e., direct sunlight). It is not so much the color of the clothing that is important, but the reflective properties of the dyes used in the clothing. Ventilation in the air layer between the skin and clothing (i.e., bellows effect) is important for heat loss during exercise in the heat39. An example of the bellows effect is seen in the desert, where no difference in skin temperature was observed when wearing loose black or white clothing (i.e., robes), despite a 60C difference in the surface temperature of clothing (black: 47 C; white: 41 C)[40,41,42].

5.5 PERSONAL PARAMETERS

5.5.1 Body surface area

The heat generated during metabolism is lost on the surface of the body to prevent excessive heat storage. Body surface area is calculated using a formula based on height and weight: surface area = 0.20247 height (m)0.725 weight (kg)0.42543, which has been validated using three-dimensional scanning techniques44. A large body surface area is beneficial for heat loss through evaporation, as the number of active sweat glands is proportional to the surface area45. Dry heat loss is also increased by having a larger body surface area when the ambient temperature is lower than the skin temperature46. Thus, for a given thermal environment, the potential for heat loss is greater in those with a large body surface area47.

5.5.2 Body surface area-to-mass ratio

Individuals with a high body surface area-to-mass ratio experience less heat storage during exposure to noncompensable heat than those with a lower ratio, due to the larger area for dry and evaporative heat loss relative to body mass47. The body surface/mass ratio decreases with increasing body mass and to a greater extent in women48. Thus, for heavy women it is more difficult to release body heat than for equally heavy men. This was confirmed in a study in which a thermal model was used to assess core body temperature in women of different body morphologies, showing that relatively fat women achieve considerably higher body temperatures during exercise in a hot/humid environment than their thinner women[49].

5.5.3 Sex

Men and women differ in body size, with men generally being heavier, taller, and exhibiting higher VO2max. However, when standardized for body surface area, metabolic heat production during various tasks is similar between genders50.

5.5.4 Age

Aging impacts both thermoregulatory capacity and fluid regulation51,52. Older individuals (>60 years) have a lower resting core body temperature, attenuated cutaneous vasodilator capacity, less effective sweat response, and decreased thermoreceptor sensitivity compared to younger individuals[51-53]. The elderly also have a higher thirst threshold54,55, lower total body water level56,57, reduced renal function56,58 and impaired regulation of plasma vasopressin at rest and after dehydration59,60. These regulatory functions deteriorate with advancing age61 and increase the risk of developing hyperthermia and dehydration [51,52,60,62,63]. However, older individuals in good shape retain better thermoregulation capacity and can improve thermoregulatory capacity with training59.

5.5.5 Aerobic fitness

Regular resistance exercise leading to improved aerobic fitness (i.e., VO2max) has been shown to increase the ability to lose heat. Aerobic training activates cutaneous vasodilation at a lower core temperature and increases skin blood flow to a certain core temperature64-66. The increase in blood flow to the skin is largely mediated by the expansion of blood volume and higher cardiac output that characterize the training state [67]. Resistance training has also been reported to lower the internal temperature threshold for the onset of sweating, increase the sweat rate at a given core temperature, and increase the maximum sweat rate65,68. Modelling suggests that an increase in VO2max induced by exercise training of 12 to 17% should reduce the internal temperature threshold for sweat onset by 0.1°C69. However, the improved sweating function associated with aerobic fitness may also be related to regular resistance training, providing a repeated thermal challenge that leads to improvements in thermoregulatory capacity70,71. Core body temperature can be measured at different locations on the body, depending on the type of equipment and need for accuracy.

5.5.6 Exertional heat illness (EHI)

Heat production often exceeds the heat dissipation capacity. Although the thermophysiological responses to exercise in the heat are well understood, individual responses vary substantially72,73. The severity of HIE varies along its continuum, with mild complaints after exercise-associated muscle cramps, to more serious concerns during heat syncope and heat exhaustion, and life-threatening risks during heat stroke34,74-76.

Dehydration and intake of specific medications (i.e., diuretics) may further increase the risk of heat syncope, while blood volume expansion induced by heat acclimatization may reduce the risk.

The fact that exertional heat stroke continues to be the third leading cause of death in athletes in the United States, after cardiac disorders and head and neck trauma77,78, further emphasizes the need for early recognition of HIE symptoms by health professionals, appropriate equipment to treat heat stroke victims (i.e., ice baths) and education of race participants. Studies considering heart rate and sweat rate, two practical (non-invasive) variables, have shown greater predictive power in the prevention of HIS79.

6 WATER BALANCE CORPORAL[16]

The total volume of body water represents approximately 60% of body mass (range: 45 to 75%) and depends on age and sex, with lower values for the elderly and women. Body water can be divided into intracellular and extracellular fluid compartments. The intracellular compartment accounts for approximately (~) 40% of body mass, while the extracellular compartment can be segmented into the interstitial (~15% of body mass) and intravascular (i.e., plasma volume, ~5% of body mass) subcompartments.

When moderate- to high-intensity exercise is initiated, a vasoconstrictor-mediated reduction in skin blood flow occurs, which contributes to providing additional blood to working skeletal muscles. Shortly thereafter, cutaneous vasodilation is initiated to aid in the dissipation of metabolically generated heat. Splanchnic and renal vasoconstriction may contribute 600 to 800 ml/min−1 of blood to this response. The internal temperature threshold at which active cutaneous vasodilation occurs is linked to exercise intensity, with an increase in work rate delaying the threshold relative to rest.

The change in cutaneous vasodilation threshold during exercise results in lower cutaneous blood flow for a given core temperature compared to rest. This response is exacerbated when exercising in cold environmental conditions compared to hot environmental conditions, as lower skin temperatures suppress the active vasodilator response to increased internal temperature, thereby increasing the temperature threshold for vasodilation. Factors such as time of day, phase of the menstrual cycle in women, and plasma osmolality have also been shown to influence the threshold of onset of cutaneous vasodilation.

Acute dehydration is associated with decreased glycemic regulation, worsening mood, blunting of blood pressure control, reduced cerebral blood flow during sympathoexcitation, and orthostatic intolerance.

Hypohydration and dehydration may reduce the responsiveness of the central neural structures that regulate heat loss by evaporation, with an increase in sweating onset threshold associated with a hyperosmolality-induced inhibition of heat-sensitive neurons within the hypothalamus (i.e., median preoptic nucleus). In analysis, body water losses not replenished (i.e., hypohydration) or inadequately replaced (i.e., dehydration) during exercise under heat stress reduce blood volume and increase osmolality, with the severity of these responses impacting thermoregulatory capacity.

7 NUTRITION [80,81,82]

The primary source of energy for humans is carbohydrate (CHO), which is made up of molecules of carbon, hydrogen, and oxygen atoms. They are classified into: monosaccharides, oligosaccharides and polysaccharides, whose energy value is equal to that of proteins, which provide 4 kcal for every[80] grams.

Despite being the main source of energy, they have a variety of beneficial effects on the body, including those on hormone and neurotransmitter production, metabolism, metabolic efficiency, insulin sensitivity, and gut microbiota[80].

Carbohydrates are categorized based on the degree of structural complexity, are ingested in the form of complex molecules (starch) or simple molecules (glucose) and invariably transformed by digestion into monosaccharides (simple carbohydrates): glucose, fructose and galactose80.

The importance of using carbohydrates as a source of energy during the practice of various sports has been recognized since the beginning of the last century. This macronutrient is the largest source of energy in the human diet, representing about 40 to 80% of the total energy consumed, and its use as an ergogenic resource to increase sports performance is indicated because it is a determining substrate in increasing performance[80].

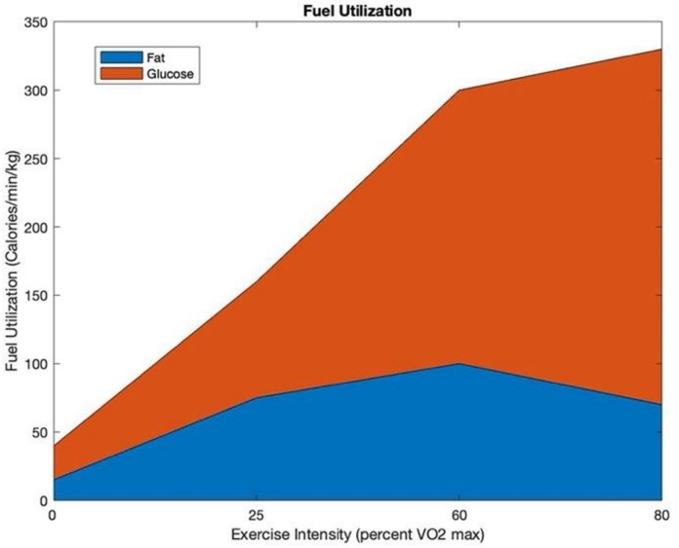
The first known study demonstrating the usefulness of glucose as a key energy source for long-distance runners was conducted in 1924. Marathon runners developed hypoglycemia with exhaustion, according to the study. Since then, several studies have stated that glucose is an important macronutrient for maintaining performance in long-term activities80.

Consuming carbohydrates during exercise is a common practice in many sports, especially endurance sports like running. When compared to a regular (50%) and low-carbohydrate (10%) diet, a high-carbohydrate diet (70% of CHO's dietary energy) and large muscle glycogen stores appears to increase endurance capacity. Although knowledge of human physiology and nutrition, as well as dietary changes and nutrient supplementation80.

When carbohydrate-rich foods are consumed, they reach the stomach, where they are broken down and a product called glucose is released through a process called gluconeogenesis81,82. In anaerobic metabolism, the body uses only glycogen for energy through the creation of glucose81,82. This process, called glycolysis, produces energy quickly, but only two molecules of ATP (energy) are obtained81,82. On the other hand, aerobic metabolism uses fat and glycogen as energy and creates 38 ATP molecules through a more time-consuming process81,82. The aerobic and anaerobic systems occur in separate cellular compartments (mitochondria and cytoplasm, respectively) and often at different rates, involve different reactants and products81,82. It is not only of interest to allocate the two separate energy processes, but also which fuel is being used81,82. Glucose and fatty acids provide most of the fuel needed for energy production in skeletal muscles during aerobic exercise, while glucose is the main source of energy in anaerobic exercise81,82.

The body has significantly more energy available in the form of fat, but the utilization rate of this form of energy cannot be increased at high intensities of exercise when anaerobic metabolism is the primary mechanism81,82. Thus, the body is able to use mainly fatty acids as a source of energy at low levels of intensity81,82. When not exercising, 30% of the body's energy comes from glycogen and 70% from fat reserves81,82. These percentages change as the intensity increases, as does the number of calories burned. Glucose is preferred because it is readily available and rapidly metabolized, but it is limited81,82.

FIG. 2 - Fuel Utilization: allocation of calories per minute per kilogram used as a function of percent VO2max [81,82]



It is also well established that an increase in exercise intensity mediates an increase in glycogenolysis and carbohydrate oxidation and a decrease in fat oxidation. This progressive change in the mobilization and utilization of the energy substrate during exercise in hot environmental conditions may represent the maintenance of a gradually increasing relative exercise intensity, mediated by a hyperthermia-induced decrease in maximal aerobic capacity16.

7.1 CONTEMPORARY NUTRITIONAL STRATEGIES TO OPTIMIZE PERFORMANCE IN LONG-DISTANCE RUNNERS AND WALKERS[83]

Distance events in athletics include cross country, 10,000 m track race, half marathon and road marathon and 20 km race and 50 km race walking events in different terrain and environmental conditions.

Race times for elite athletes range from 26 minutes to >4 hours, with the key factors for success being high aerobic power, the ability to exercise at a large fraction of that power, and high running/walking economy. Nutrition-related contributors include body mass and anthropometry, ability to use fuels, particularly carbohydrates (CHO) to produce adenosine triphosphate economically over the duration of the event, and maintenance of

reasonable hydration status in the face of sweat losses induced by exercise intensity and the environment. Race nutrition strategies include CHO-rich eating in the hours of the days leading up to the event to store glycogen in sufficient amounts for the event's fuel needs, and in some cases, CHO and fluid consumption during the race to make up for losses in events.

Beneficial CHO intake ranges from small amounts, including mouthwash in the case of shorter races, to high intake rates (75–90 g/h) in longer runs. A personalized and practiced nutrition plan should balance the benefits of the fluids and CHO consumed within the practical opportunities, in relation to the time, cost, and risk of intestinal discomfort. In hot environments, hyperhydration or pre-race cooling strategies can provide a small but useful compensation for accumulated thermal challenge and fluid deficit. Sports foods (beverages, gels, etc.) can help in training/race meetings nutrition plans, with caffeine and perhaps nitrate being used as evidence-based performance supplements83.

7.2 ADJUSTMENTS TO THE THERMOREGULATORY FUNCTION[16]

The rate of total body sweat during physical activity is determined by exercise intensity and weather conditions, but typically ranges between 0.5 and 2.0 L·h−1, with some athletes (∼2%) sweating >3.0 L·h−1. Gradual reductions in body mass (e.g., 2 to 5%) due to fluid deficit result in marked reductions in plasma (≥10%) and blood (≥6%) volume. Loss of plasma volume with exercise leads to a state of hyperosmotic hypovolemia that is proportional to the decrease in total body water. Although the composition of the precursor secretory fluid contained in eccrine sweat glands is similar to that of plasma, a considerable amount of ions (e.g., sodium and chloride) within the fluid are reabsorbed as it passes through the gland duct, leading to a sweat osmolality of approximately half that of plasma. The increase in intravascular osmotic pressure resulting from plasma hyperosmolality causes a change in fluid from the intracellular to the extracellular compartment, which helps to defend the plasma volume. However, at high rates of total body sweat, the volume of fluid mobilized from the intracellular compartment to the vasculature is insufficient to restore plasma volume and leads to intracellular dehydration[16].

Increased core temperature during exercise in the heat with hypohydration (2 to 7% loss of body mass). Several studies have shown that hyperosmotic hypovolemia induced by hypohydration delays thermoregulatory sweating and cutaneous vasodilation at rest and during exercise and reduces the sensitivity of the relationship between thermoeffector responses and core temperature. Although both hypovolemia and hyperosmolality influence these responses, the increase in plasma osmolality seems to be more strongly correlated with the reduction of sweating during exercise-heat stress than the decrease in blood volume [A.17.]

8 CONCLUSION

To keep body temperature stable, the body uses regulation mechanisms dependent on environmental, task, and personal parameters. In intense exercise and in hot environments, blood flow to the skin can increase significantly, and sweating is also elevated. However, non-thermal reflexes during exercise cause the regulation of blood flow in the skin to be different from that at rest. The body adjusts the threshold for the dilation of the skin's blood vessels to a higher core body temperature and modifies the sensitivity to this temperature change. Regular training improves these adaptations, allowing athletes to dissipate heat more effectively.

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