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Review Article

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The Physiological Role of the Hypothalamus in Thermoregulation during Exercise.

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Abstract

The hypothalamus sometimes referred to as the central unit responsible for thermoregulation, controls numerous vital physiological functions, which is due to its ability to integrate various signals from the brain and the periphery (skin) and to elicit an adequate response. Heat loss through the body can be due to radiation, conduction convection or evaporation.

During the course an exercise, a series of heat transfer occur from the muscle to the blood and finally to the periphery. In the human body, temperature sensors located in different parts of the body, detect changes in the body temperature. To prevent damages to the deep tissues caused by an elevated body core temperature during an exercise, the hypothalamus integrates the body core temperature and the skin temperature signals and controls thermoregulatory responses.

Keywords: Hypothalamus, body core temperature, thermoregulation, exercise

1. Introduction

In human including other mammalian animals, body core temperature is maintained within some limits through behavioural or physiological regulation. Heat gain tends to occur through body exposure to the environment or physical exercise or both (Kenefick, 2007). Thermoregulation is an important function of the autonomic nervous system where it plays a role in response to cold and heat stress. This thermoregulatory physiology helps to sustain life by keeping body core temperature within a degree or two of 37 °C, which enables normal cellular function. It is thus defined as the process through which the body maintains its homeostasis while being exposed to changes in internal and external stressors (Krohn et al., 2015; Cheshire, 2016).

The increase in internal and skin temperatures and hence the rate at which sweat leaves the body and blood flowing through the skin is dependent on the extent to which exercise is performed and the body exposure to a hot environment. When physical exercise is performed for example, there is always an induction of some sorts of physiology mechanisms that promote heat loss through the release of energy in term of body heat. Before now, it was assumed that the skin temperature plays a more important role in the control of sweating than the internal temperature (Wendt et al., 2007; Shibasaki & Crandall, 2010).

The body's regulatory mechanism is stressed when exercise is performed in a condition of hot environment and high humidity. For competitive athletes and active individuals, the effective dispersal of the heat load generated by contracting muscle is of considerable importance. Any failure in the control mechanisms to effectively remove body heat during such stressed exercise would result in substantial decrease in physical performance of the athletes while posing risk for eventual circulatory collapse, brain dysfunction, and generalized organ failure (Rowland, 2008).

However, for heat loss to occur, excess heat ought to be transported from the core to the skin where heat can be lost to the environment. Because of its relatively low metabolic rate and constant blood flow, the temperature in active skeletal muscle tends to be between narrow limits of 33°C and 35°C. Consequently, at rest, heat is actually transferred from core to the skeletal muscle tissue. There is an upset in this balance once exercise sets in. The increase in heat production in this case, causes the muscle temperature to rise, leading to a reversal of the temperature gradient, between the muscle and the blood and subsequently to the body core. The rate of heat transfer from the core to the skin is in turn determined by the temperature gradient between these two and by the overall skin conductance. In the case in which the metabolic heat is subsequently being transported to the skin, heat lost is greatly accelerated by cutaneous vasodilation and sweating (Wendt et al., 2007).

In this review, the role of the hypothalamus in thermoregulation during exercise is discussed.

Firstly, factors affecting thermoregulation are stated. Secondly, the physiological role played by the hypothalamus in regulating body temperature during exercise is described and finally exercise induced heat illnesses are discussed.

2. Factors Affecting Thermoregulation

2.1 Environment

The normal temperature of the human body is about 37 °C. A little change of around 1 °C above and below this temperature set-point, the organism tends to maintain this temperature within narrow limit which occur to due to sleep circadian rhythm and/or women menstrual cycle) (Faude & Donath, 2016).

The transfer of heat between two bodies depends on their thermal temperature, the time of heat transfer and the thermal conductivity of the two bodies. Heat tends to flow from the hotter body to a cooler one. Most heat loss by radiation and convection is dependent on the maintenance of a large temperature balance called the gradient between the skin and the surrounding air. When the temperature of the air rises above 36°C, this gradient is reversed and results in the gain of heat by the body through mainly by radiation and convection (Wendt et al., 2007).

Because the body has gained heat, the most effective way of cooling is now through evaporation of sweat from the skin. The effectiveness of this evaporative cooling system by the skin is dependent on the humidity between the skin and the surrounding environment and the air movement over the skin. This implies that as the relative humidity in the air is low i.e. a period of dry air, the skin will cool faster due to evaporation of sweat than when the relative humidity of the surrounding air is high i.e. when the air is cool (Wendt et al., 2007; Faude & Donath, 2016).

2.2 Dehydration

Dehydration is another factor that affects thermoregulation. Dehydration occurs when the body's ability to lose water through evaporation is more than its replenishment through drinking of water and this is what happens when exercise is performed in a hot environment (Wendt et al., 2007).

Dehydration results in a pronounced decrease in the body's physical activity in hot environment as compared to the temperate region, and it also appear that the thermoregulatory system plays an important role in the reduced exercise performance mediated by a decrease in body water content. It has been reported previously that dehydration reduces both the flow of blood under the skin and sweating responses during exercise (Wendt et al., 2007).

A decrease in the body's water content due to loss of water by dehydration has an adverse effect on the volume of blood plasma. Furthermore, the flow of blood to the exercising muscles and hence, oxygen and the availability of substrate is also directly reduced. Hence, Dehydration has a pronounced affect on thermoregulation as the flow of blood under the skin as well as sweating response (Zinner & Sperlich, 2016).

3. Role of the hypothalamus

From rostral to caudal, the hypothalamus it made up of the preoptic area (POA), the anterior hypothalamus, the tuberal hypothalamus, and the mammillary region. Nonetheless, the hypothalamus could be inferred as consisting of periventricular, medial, and lateral zones as these regions are said to function in a different way (Zoccoli et al., 2011).

The POA is a region at the junction of the telencephalon and diencephalon of the vertebrate brain that plays an important role in many functions including thermoregulation. It is said to be the primary thermoregulatory center, first reported in the late 1800s (Bicego et al., 2007; Shibasaki & Crandall, 2010). It is known to receive afferent input from both the thermoreceptors situated in the hypothalamus and skin. The importance of this area for thermoregulation has been reported in animal models whereby local warming of the preoptic area elicits such responses as cutaneous vasodilation, panting, sweating, and behavioral modifications to increase heat loss (Smith et al., 2016).

To initiate appropriate thermoregulatory responses to changes in environmental temperature before they affect body core temperature, the POA needs to receive feedforward information on environmental temperature which is sensed by thermoreceptors in the cutaneous terminals of primary somatosensory neurons (Nakamura & Morrison, 2008).

The two main physiological mechanisms for heat dissipation are an increase in skin blood flow and sweating. The central role of the hypothalamus in the control of several vital physiological functions is due to its ability to integrate numerous signals from the brain and the periphery and to deliver an adequate response and hence it is often called the central unit responsible for thermoregulatory responses (Taouis, 2016).

The input to the hypothalamus comes from peripheral as well as central thermoreceptors, both of which has two subtypes: those responding to cold and those responding to warmth. Peripheral thermoreceptors are located in the skin, where cold receptors are more abundant than warm receptors. On the other hand, the warm central thermoreceptors, found in the hypothalamus, spinal cord, viscera, and great veins, are more numerous than cold thermoreceptors. The impact of central thermoreceptor activation is most significant in terms of core temperature, and it seems that the activation of warm thermoreceptors causes inhibition of cold receptors (Tansey & Johnson, 2015).

The thermoregulatory machinery ensures that there is a balance between the production of heat and its dissipation so that the body can be maintained at a temperature near a set limit of 36.5°C. This machinery consists of the central and peripheral thermoreceptors, affection conducting system, a central control unit for thermal impulse integration and an efferent responses system that lead to a compensatory responses (Gomes et al., 2013).

Numerous theories and concepts have been propended to explain the mechanism of thermoregulation during exercise. Heat generation during muscle contraction during exercise causes an increase in the internal temperature with a compensatory increase in sweat rate (Shibasaki & Crandall, 2010).

There is a high density of heat-sensitive neurons coupled with a lesser amount of cold-sensitive neurons in the preoptic, anterior part of the hypothalamus. These neurons ensures that the blood temperature in the brain is always in checks. In addition, afferent feedback from thermoreceptors distributed throughout the whole organism is collected by the hypothalamus. This information from the periphery as well as from the brain is integrated and compared. When temperature increases, the hypothalamus sends inhibitory signals to motor control centers (Nakamura, 2011; Zinner & Sperlich, 2016; Lim., 2008).

The physiological temperature regulation occurs through a number of processes such as sweating, changes in skin flood flow, and metabolic heat production such as shivering or altering running pace. Heat loss occurs by a combination of evaporation, radiation, convection and conduction (Kenefick & Cheuvront, 2016; Kenefick et al., 2007).

The critical threshold temperature in the hypothalamus above or below which thermoregulatory processes are initiated to the increase in heat production or loss is =37°C. All other temperature control mechanisms tend to bring the body temperature back to this set limit of 37°C. This regulated level of core temperature varies by a degree because of the circadian rhythm of body temperature and the influence of the women monthly menstrual cycle and body temperature distribution (Wendt et al., 2007).

During the course of a physical activity such as an exercise for example, there is a series of transfer of heat from the active muscle tissues down to the blood and ultimately to the periphery. Temperature sensors are located both centrally (within blood vessels, abdomen and hypothalamus) and peripherally (skin). The hypothalamus integrates and controls both the body core temperature (BCT) and the skin temperature signals and controls thermoregulatory responses. If the BCT signal deviates from the normal set point due to an increase in temperature for example, an error signal is detected within the hypothalamus and appropriate effector responses are elicited at the periphery including events such as activation of sweating and cutaneous vasodilation to increase evaporative and dry heat loss (Kenefick & Cheuvront, 2016; Nakamura & Morrison, 2008; Romanovsky, 2007).

4. Exercise Induced Heat Illness

Heat illness arises because of the failure of the body to maintain homeostasis due to the production of excess heat or a decreased heat transfer to the environment (Jardine, 2007). Three main exercise-related heat illnesses have been are described namely; heat cramps, heat exhaustion and heat stroke (Wendt et al., 2007).

4.1 Heat cramps

Heat cramps are severe muscle spasms, which effects the muscles of the leg. The exact cause of this heat illness is unknown but it is assumed to arise due the combined effect of calcium and other electrolyte imbalance at tissue level or plasma volume depletion and tissue acidosis in the light of respiratory alkalosis from hyperventilation, and altered neuromuscular control system related to exertion. They are sometimes not considered as being a form if heat illness, due to the fact that they tend to occur without been exposed to a heat and typically resolve rapidly (Hofmeyr & D'Alton, 2017).

4.2 Heat Exhaustion

Heat exhaustion, defined as mild dehydration that may result with or without sodium abnormalities including hypernatremia or hyponatremia. It is also said to be a condition that may lead to the collapse of an athlete in the course of performing an exercise in the heat or afterwards. Body core temperature in this condition is usually between 100.4°F (38°C) and 104°F (40°C). Some of the symptoms associated with heat exhaustion include intense discomfort, confusion, thirst, nausea, and vomiting and may eventually lead to heat stroke if left untreated (Krohn et al., 2015; Wendt et al., 2007)

4.3 Heat stroke

Heat stroke results when cellular injury is caused by excess body temperature. It is often characterized by a core temperature greater than 105.8°F (41°C). Because of the elevated temperature, proteins are denatured, and injured cells undergo either apoptosis (programmed cell death) or necrosis (Jardine, 2007). Clinical signs of heat stroke include and not limited to confusion, disorientation, decreased level of consciousness, inappropriate behaviour, ataxia or collapse, tachypnoea, and tachycardia. It becomes a risk factor for brain, renal, hepatic and other organ damage as the systemic protein denaturation begin to occur at a temperature greater than 42°C (Hofmeyr & D'Alton, 2017).

Conclusion

The physiology role played by the hypothalamus during the thermoregulation in exercise as been described. The hypothalamus being the primary control center for homeostasis contains some special neurons that detects changes in the sets limit for body core temperature. Any detectable variation from this threshold value will elicits responses that tend to bring the body back to its normal level. Any failure in this mechanism leads to heat illness.

The knowledge of the role played by the hypothalamus in regulating temperature during exercise will go a long way in deepening our understanding about the functions of the hypothalamus. The knowledge gained will be useful to students and instructors.

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