

Sweating, dehydration and electrolyte supplementation: Challenges for the performance horse

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Abstract

The performance horse is frequently subjected to periods of heat stress, usually as a result of the metabolic heat production of exercise, and also in situations of prolonged transport or exposure to ambient heat loads when in hot, humid conditions. When heat stress periods are short the thermoregulatory abilities of the horse easily cope despite high rates of heat storage. However, when body heat storage is prolonged, such as can occur during prolonged exercise or transport, dehydration ensues due to sweat losses of water and electrolytes. Dehydration further contributes to increased stress on many physiological systems and impairs cognitive and physical performance. If continued, heat stress can develop into heat strain, which severely comprises health and wellbeing and may be life threatening. Evaporation of sweat is the primary means for thermoregulation, but at best the thermoregulatory efficiency of sweating is ~30%, resulting in high rates of heat storage when exercise is continued. With sweating rates of 15-20 L/h dehydration can rapidly ensue unless effective strategies are used to replace water and electrolytes lost through sweating. Effective electrolyte supplements provide a balanced mixture of water, sodium chloride, potassium chloride, magnesium and calcium as readily dissolved salts, and dextrose to enhance intestinal absorption of sodium and water. The effectiveness of electrolyte supplementation can be non-invasively monitored in horses using multi-frequency bioelectrical impedance analysis.

Introduction

Sweating is an innate physiological response to heat production by some homoeothermic mammals. Mammals that do sweat, such as horses, humans, camels and cattle, sweat while even at rest under normothermic conditions. Under conditions of heat stress there occurs net heat storage by the body, resulting in an increase in the temperature of the circulating blood. This increase in circulating blood temperature is sensed by the hypothalamus, which is responsible for a number of the thermoregulatory responses to heat stress

including cutaneous vasodilation, increased production of sweat by sweat glands (Gleeson 1998). In some mammals, and in horses and humans in particular, prolonged periods of sweating at high rates results in water and electrolyte losses that can lead to dehydration with ensuing poor performance and clinical signs of heat strain if unchecked (Maughan and Lindinger 1995). The purpose of this review is to provide an overview of situations leading to heat stress in horses, with an emphasis on exercise. We will consider heat production and storage, thermoregulatory responses to heat storage, sweating responses and dehydration, and strategies that can be used to prevent and recover from dehydration. The interested reader is referred to the following reviews (Lindinger and Maughan 1995, Gleeson 1998, Geor and McCutcheon 1998, Guthrie and Lund 1998, McCutcheon and Geor 1998, Lindinger 1999).

Heat Stress and Strain

Stress can be defined the normal application of forces on a subject. As such, heat stress is normal and is experienced when a horse exercises, is standing under conditions of increased ambient radiant heat (Figure 1), i.e. in the sun on a warm day, and in most confined transport situations (van den Berg et al. 1998, Friend 2000) Sometimes, situations of high psychological stress to the horse (unfamiliar, stressful situations) results in increased circulating levels of adrenaline which also acts to increase sweating rate (McConaghy et al. 1995). When stress is continued for an extended period, or increases at a high rate, strain can ensue – as such strain represents a condition of excessive stress, and this can result in injury (Figure 1).

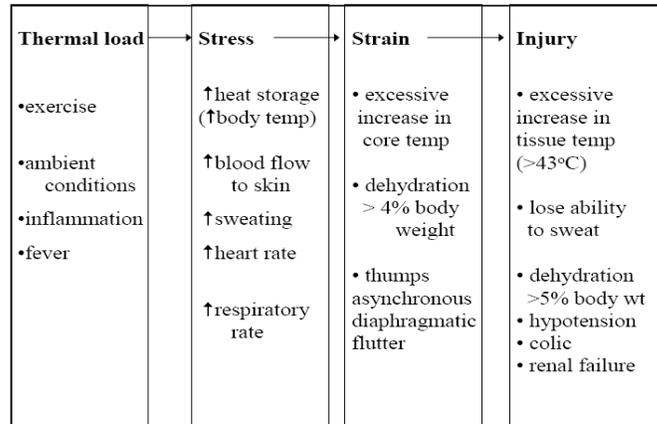


Figure 1: Progression from increasing thermal load towards heat strain and injury.

Exercise increases the rate of heat storage, and the rate of increase of heat storage is proportional to the ambient conditions (Geor et al. 2000), the intensity of exercise (Scott et al. 1999), and the hydrated state (Geor and Mccutcheon 1998b). Heat storage in the body is a result of the balance between heat gain (environmental or metabolic) and heat loss to the environment. Increases in body heat storage can be estimated from increases in rectal temperature (Geor et al. 2000).

Exercise intensity. The conversion of chemical energy to the mechanical energy of locomotion in horses is at best 20% efficient, such that most of the chemical energy is converted to heat. Thus contracting skeletal muscle produces large amounts of heat at high rates (Figure 2), and the rate of heat production increases with increasing exercise intensity. When exercise intensity is high, the duration of exercise is limited by the rapid onset of fatigue and exercise stops (Nielsen and Nybo 2003). This results in a natural prevention of heat strain and excessive dehydration, unless repeated bouts of high intensity exercise are performed. Of primary concern is the dehydration and heat strain that can result from the sweat losses that occur during prolonged periods of low intensity exercise (Ecker and Lindinger 1995, Ecker and Lindinger 1995b, Lindinger and Ecker 1995) and transport (Friend 2000).

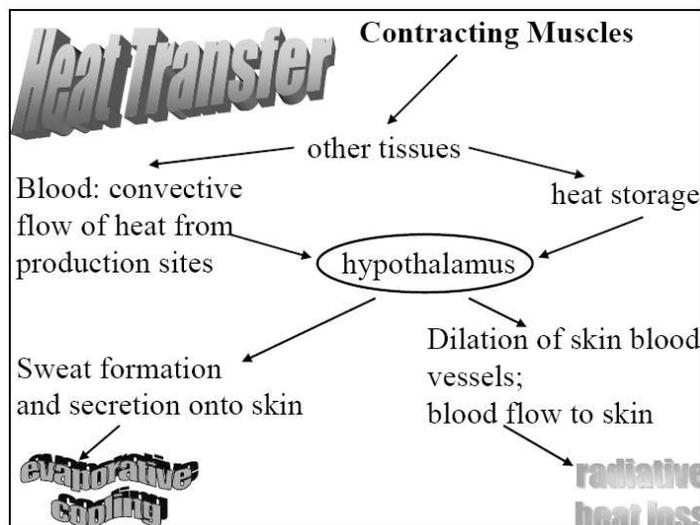


Figure 2: During exercise, contracting skeletal muscle generates large amounts of heat that are moved by convective blood flow throughout the body (net heat storage) and to the skin for dissipation to the environment. Evaporation of sweat from the skin provides the greatest cooling effect.

Ambient conditions. Because body heat storage is a function of heat loss to the ambient environment, increases in ambient heat and humidity reduces the ability of the body to dissipate heat (Geor et al. 2000). Increases in ambient temperature reduces the thermal gradient from body core to skin to environment, thus decreasing net heat transfer to the environment. Increases in ambient humidity reduces the water vapour pressure gradient, resulting in a reduced rate of evaporation of sweat from the surface of the horse, which increased amounts of sweat just running and dripping off the horse, which provides minimal cooling. During moderate intensity exercise, an increase in ambient temperature from 22°C to 33°C (both with 45% relative humidity) results in ~50% increase in the rate of heat storage (Figure 3). When 85% relative humidity is imposed with high ambient temperature (33°C), the rate of heat storage is ~2.5-fold greater than in cool dry conditions (Geor et al. 2000).

For us as caregivers to horses, it is critically important to recognize these very high rates of heat storage in horses, because they are much greater than what occurs in humans (Figure 3). Thus, even though we may perceive that warm, humid conditions are not producing undue stress or strain in us, they may certainly be resulting in strain in horses. By way of explanation, the higher rates of heat storage in horses, compared to humans, results from a greater proportion of the body that is contracting muscle in horses (~40% of body mass, compared to ~20% in running humans) and a lower skin surface area per unit body mass for dissipating heat to the environment; the body mass to surface area ratio in horses is ~100, compared to ~40 in humans. Therefore horses are capable of producing large amounts of heat at high rates but, compared to humans, are at a severe physical disadvantage to dissipating that heat (Lindinger 1999).

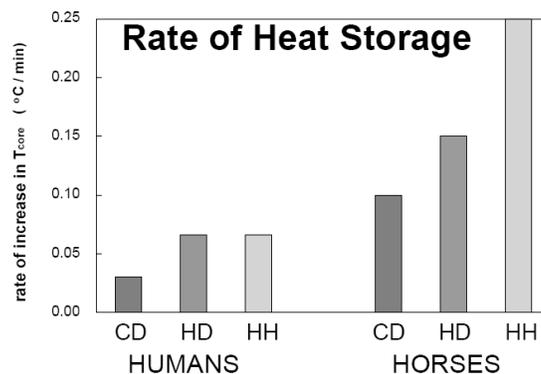


Figure 3: The rate of increase of core body temperature (T_{core}) or heat storage as a function of ambient conditions in humans and horses. CD = cool dry; HD = hot dry; HH = hot humid). Human data from Christianson et al ; Equine data from Geor et al. 2000.

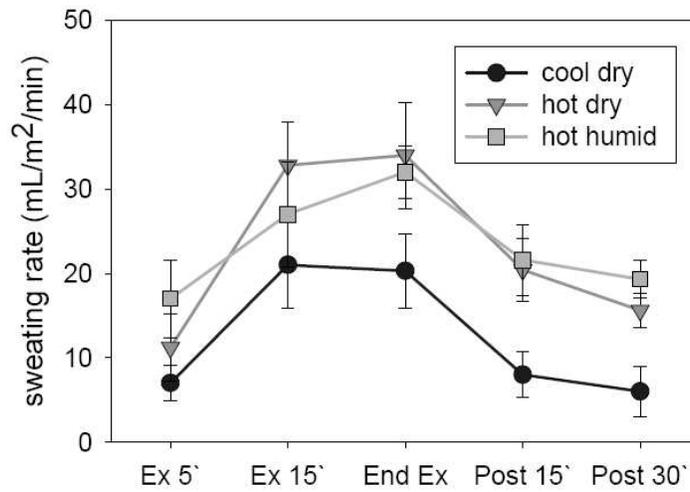


Figure 4: Sweating rates in horses performing moderate intensity exercise and during 30 minutes of recovery in cool dry, hot dry and hot humid conditions. (Data from McCutcheon et al. 1995, 1999).

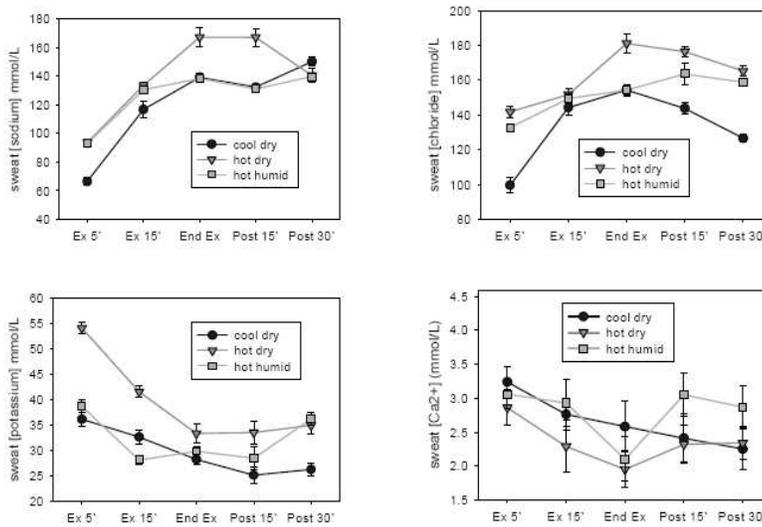


Figure 5: Time course of sweat ion concentrations during moderate intensity exercise in cool dry, hot dry and hot humid conditions. Adapted from McCutcheon et al. 1995).

Hydrated state. With respect to hydrated state, conditions of dehydration are associated with increased cardiovascular stress and strain (Geor and McCutcheon 1998), with increased competition of blood flow to contracting muscles to remove heat from heat producing muscles and blood flow to the skin to remove heat (McConaghy et al. 2002).

Thermoregulatory sweating

Thermoregulatory sweating may be defined as the increase in sweating that occurs in response to an increase in core body temperature to, or above, the hypothalamic thermal set point (Gleeson 1998). This is distinct from the sweating that may occur in response to increased circulating adrenaline (McConaghy et al. 1995) or pseudorific effects of some foods (Pearson et al. 2000).

As far as we know, the onset of sweating in horses is governed as it is in humans: by a hypothalamic thermal setpoint that is sensitive to increases in circulating blood (and hence core) temperature (Gleeson 1998, Nielsen and Nybo 2003). In horses, sweating rate also increases in proportion to the rate of heat storage, such that with moderate intensity exercise sweating rate is higher in warm, dry conditions than in cool dry conditions (McCutcheon et al. 1999). However, when exercise intensity is greater than about 70% of peak VO_2 , the blood-borne transfer of heat to the skin may be impaired compared to blood flow to contracting muscle (Scott et al. 1999). At most exercise intensities, there is competition between the skin and contracting muscle for cardiac output (McConaghy et al. 2002). The rate of sweating also appears to be sensitive to the degree of hidromeiosis (skin wettedness; Candas et al. 1980). The more wet the skin, the lower the sweating rate – this effect is seen in both humans and horses. In horses, for example, moderate intensity exercise in warm, humid conditions results in a marginally lower sweating rate than when exercising in warm, dry conditions (Figure 4; McCutcheon et al. 1995, 1999). The highest sweating rates in Figure 4 translate to a rate of dehydration of 12 Litres of body water per hour; sweating rates in excess of 15 L per hour have also been reported. With clinical dehydration defined as a dehydration of 5% of total body water (15 L for a 450kg horse), it is clear that exercise for greater than 1 hour duration requires consideration of strategies for preventing dehydration from becoming severe during period of prolonged exercise.

Sweating rate (Fig. 4) and composition (Fig. 5) are also sensitive to the duration of exercise. Sweating rate, together with $[\text{Na}^+]$ and $[\text{Cl}^-]$ increases during the first 5-20 minutes of exercise, before levelling off; as exercise progresses, these may subsequently decrease. In contrast, sweat $[\text{K}^+]$ and $[\text{Ca}^{2+}]$ tend to decrease during exercise.

Again, it is instructive to provide a comparison to humans, because this exemplifies the great rate of ion losses incurred by horses during exercise. Peak sweating rates in humans are ~3 L / hour compared to ~20 L / hour in horses. At the same time sweat $[\text{Na}^+]$ and $[\text{K}^+]$ average 40 and 4 meq/L in humans compared to 120 and 60 meq/L in horses, respectively. Sweat $[\text{Cl}^-]$, which balances the positive charge of sweat cations, is ~50 me/L in humans compared to 180 meq/L in horses. Therefore in horses, the combination of high sweating rates and high sweat ion concentrations contribute to very high rates of ion losses during periods of heat stress. These losses need to be directly addressed if we are to sustain a state of high performance in equine athletes.

Strategies for Helping the Horse Thermoregulate

The ideal strategy for preventing performance decrements during or following periods of heat stress is one that ultimately prevents dehydration. This can only be accomplished by timely and adequate provision of balanced electrolyte solutions to replace water and electrolytes lost through sweating. This will help the horse to thermoregulate by ensuring adequate body fluids to sustain sweating rates and cardiovascular function. Additional strategies that can be used to aid thermoregulation include provision of shade, exposure to wind or cooling fans, repeated application of cold water (Kohn et al 1999, Jeffcott and Kohn 1999), avoiding the use covers and blankets, and keeping the hair coat short (Morgan et al. 2002).

With an appreciation of the high rates of water and electrolyte losses incurred by the heat stressed horse, we will now focus on requirements for maintaining hydration. For a 450 kg horse, the total body water (TBW) volume is ~300L, divided between intracellular fluid volume (ICFV) of ~200L and extracellular fluid volume (ECFV) of ~100L. About 20L of the ECFV is plasma volume. The main cation associated with maintaining ICFV is K^+ (intracellular $[\text{K}^+]$ of ~140 meq/L, while the main cation associated with maintaining ECFV is $[\text{Na}^+]$ ($[\text{Na}^+]$ of ~140 meq/L). Because sweat $[\text{K}^+]$ is ~60 meq/L and there is minimal net loss of ECF $[\text{K}^+]$ during exercise, this means that nearly all the K^+ lost through sweating comes from the intracellular compartment, of which skeletal muscle comprises the greatest share. Thus effective prevention of cellular dehydration requires the presence of K^+ in electrolyte supplements.

Virtually all of the Na^+ lost through sweating arises from the ECF compartments, and effective prevention of extracellular dehydration requires Na^+ in electrolyte supplements. The main anion associated with K^+ and Na^+ is Cl^- , so this should be present to balance these cations. Small amounts of Ca^{2+} and Mg^{2+} are also lost, and because these are important for cellular function, they should also be replaced. Based on the sweat data provided above, it is clear that prevention of dehydration during exercise requires ingestion of about 15 L

of water with an appropriate mixture of electrolytes. This is indeed a daunting task, however we have observed elite endurance horse / rider combinations to be successful in achieving this over 100 mile distances (Ecker and Lindinger 1995b, Lindinger and Ecker 1995). In this context it is noteworthy that all horses incur net losses of water and electrolytes during the first 1-2 hours of exercise, and effective supplementation during mandatory and voluntary rest breaks restores hydration as exercise continues.

It is very important to provide an appropriate balance of water and electrolytes when providing electrolyte supplementation. Provision of water alone results in a dilution of electrolyte concentrations within body fluid compartments. In studies conducted in humans (Shirreffs and Maughan 2000) it has been shown that dilution of the ECF associated with ingestion of water is sensed by the kidneys as a volume overload, resulting in renal excretion of water with additional electrolytes – thus the electrolyte depleted and dehydrated horse becomes further dehydrated when drinking only water. In contrast, if concentrated electrolyte solutions (slurries and pastes) are given to horses, these are highly unpalatable and when ingested cause a net flux of water from the ECF compartment into the upper G.I. tract. In this situation water is initially moving in the wrong direction, resulting in further ECF dehydration. Later, as water and electrolytes are absorbed in the small intestine (primarily), ECFV can only be partially restored, and ECF electrolyte concentrations will increase. These increases can be sensed as an electrolyte overload by the kidneys and skeletal muscle, resulting in increased renal excretion of water and electrolytes – again an undesirable outcome in a dehydrated horse. Balance of water and electrolytes is therefore crucial for effective rehydration and prevention of dehydration.

What Should be in a Good Electrolyte Product?

It is now evident that the electrolyte mixture in an effective electrolyte supplement needs to replace what was lost in sweat. In horses (Rainger and Dart 2006), as in humans (Schedl et al. 1994), provision of water and electrolytes given as oral supplements depends on the rates of gastric emptying and duodenal – jejunal water and ion transport. Intestinal rates of water, Na⁺ and Cl⁻ transport can be increased by the provision of dextrose (D-glucose) to a concentration of ~6% within the electrolyte solution. The presence of fructose (~2%) may enhance the intestinal absorption of K⁺ and improves palatability. All electrolyte salts should easily dissolve in water (at ~20°C), as those that do not dissolve will likely just pass through the G.I. tract and eliminated in the manure. This is particularly true of the divalent cations Ca²⁺ and Mg²⁺; Ca²⁺ should be given as calcium or magnesium lactate, acetate or citrate and not as oxalate or carbonate (limestone, dolomite). Sucrose and flavouring agents can also be added to enhance palatability. When a balance electrolyte solution is dissolved in the appropriate volume of water, the amount of dextrose present will result in a

modest increase (1-2 mmoles/L) in plasma [glucose], but will not result in increased insulin release during exercise. The amount of glucose given is negligible in terms of meeting the energy demands of exercise, but is present solely to enhance intestinal absorption of water and electrolytes. The highest drinking rates appear to occur when the temperature of the solution is ~20°C (Butudom et al. 2004).

Getting a horse to drink a balanced electrolyte solution can be a challenge. Most successful horse – rider combinations have spent considerable time training the horse to drink electrolyte solutions. Initially, the horse can be weaned onto a dilute electrolyte solution made by dissolving a small amount in the drinking water, and this provided as the sole drinking choice. The concentration of the electrolyte solution can be gradually increased over a period of weeks. When riding longer distances, and a rest break for drinking is desirable, similarly prepare an electrolyte solution and remain until the horse has taken a drink – the horse will learn that the activity will continue once a drink has been taken. Clearly, patience and diligence are required on the part of the rider.

Non-Invasive Assessment of Hydration

It is now possible to non-invasively monitor the hydrated state of a horse using multi-frequency bioelectrical impedance analysis (MFBI). This instrument, by injecting and then sensing a small current sent through electrodes strapped onto fore and hind limb leg muscles, determines TBW as well as the proportion of fluid in the ECF and ICF compartments. Therefore, when the measurement is repeated over time, a time course of hydration status can be obtained (Lindinger et al 2004, McKeen and Lindinger 2004, Waller and Lindinger 2005, Waller and Lindinger 2006, Fielding 2007).

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