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Thermoregulation in the horse exercising under hot and humid conditions

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Summary

Thermoregulation is the homeostatic control of body temperature despite fluctuations due to exercise or ambient variations. The increased muscle metabolism necessitated by exercise is energy inefficient. It results in measurable increases in stored body heat which must be shed in order to maintain exercise at the same intensity. Horses regulate body temperature primarily by evaporation of sweat from the skin surface, but the efficiency of this mechanism is compromised by high ambient humidity. Some minor heat load is lost via respiratory evaporation and convection, mechanisms which are enhanced by increased respirations under hot and humid conditions. Conductive heat loss can be enhanced by application of high volumes of cold water followed by rapid removal (sweat scraping) and reapplication.

Keywords: horse, exercise, heat, humidity, thermoregulation

Thermoregulation bei Pferden, die bei Hitze und hoher Luftfeuchtigkeit belastet werden.

Thermoregulation ist die homöostatische Kontrolle der Körpertemperatur trotz Schwankungen, ausgelöst durch Belastung oder Variation der Umgebungsbedingungen. Der durch Belastung hervorgerufene erhöhte Stoffwechsel der Muskulatur ist vom energetischen Aspekt her ineffizient. Er führt zu einer meßbaren Zunahme der sich im Körper anstauenden Hitze, welche aber unbedingt abgegeben werden muß, damit die Belastung bei unveränderter Intensität aufrechterhalten werden kann. Pferde regulieren ihre Körpertemperatur vorrangig durch die Verdunstung von Schweiß auf der Hautoberfläche. Jedoch ist die Effizienz dieses Mechanismus in einer Umgebung mit hoher Außentemperatur und Luftfeuchtigkeit herabgesetzt. Eine geringer Anteil der Hitzelast wird respiratorisch durch Verdunstung und Konvektion abgegeben. Diese Mechanismen sind bei einer gesteigerten Respiration bei Hitze und hoher Luftfeuchtigkeit erhöht. Eine Verringerung der Körpertemperatur durch Wärmeleitung kann durch Naßmachen der Pferde mit großen Mengen kalten Wassers erreicht werden, anschließend soll das Wasser schnell wieder abgezogen und die Anwedung wiederholt werden.

Schlüsselwörter: Pferd, Belastung, Hitze, Luftfeuchtigkeit, Thermoregulation

Introduction

Thermoregulation is defined as the regulation or control of body temperature through various mammalian homeostatic mechanisms. Compared to smaller, thinner mammalian athletes such as people and greyhounds, horses have an increased body mass:skin surface ratio. This increased ratio illustrates the greater difficulty with which horses shed heat, thus making successful thermoregulation even more critical to the continuation of normal athletic activity in the horse. Furthermore, because horses naturally rely so much on cutaneous evaporation as a mechanism for heat loss, increases in ambient heat and especially humidity may further hinder their ability to thermoregulate when compared to species which rely more on increased respiration (panting) for heat loss (e.g., dogs).

Generation of heat

Exercise results in a demand for increased metabolic activity by exercising muscle. Muscle metabolism is relatively inefficient, in that only about 25–30% of the stored energy which is metabolised is actually converted into increased mechanical energy (muscular movement) while the remainder (>70%) is lost as heat. This heat can be detrimental to continued normal muscle function, and it is normally transferred passively to cooler capillary blood as it traverses exercising muscle. The resultant venous blood has increased heat content reflected in increased mixed venous blood temperature which can be measured by thermistors inserted into the pulmonary artery via jugular vein catheter introducers. This increased pulmonary artery blood temperature (PAT) is considered to be the best laboratory measure of increased core temperature, and is reflective of a net increase or gain in stored body heat from exercising muscle.

Mechanisms of heat exchange

Four basic mechanisms of heat exchange are important in mammalian thermoregulation: evaporation, convection, conduction, and radiation.

Evaporation is the conversion of water or other liquid into gaseous form by heating of the liquid. Horses rely almost exclusively on evaporative heat loss through sweating. Sweat is produced in sympathetically-responsive apocrine skin glands in response to increased core temperature associated with exercise and/or increased ambient heat loads. As sweat evaporates from the skin, accumulated body heat is transferred from the skin to the air by evaporation of the water vapor which was liquid water in sweat only moments earlier. The large colon contains considerable fluid stores and probably functions as a fluid reservoir for the continuation of normal circulation and sweat production during prolonged exercise (*Carlson* 1987). Some evaporative heat loss occurs when horses increase their respiratory rate in response to increased ambient heat and/or humidity (*Kohn* and *Hinchcliff* 1995). Under conditions of high humidity, evaporation from the skin is severely limited since the water vapor gradient between skin and air is dramatically diminished. Thus, high humidity is a serious, rate-limiting condition to proper thermoregulation in exercising horses.

Convection is the transmission of heat in liquids or gases by circulation, or increased movement, of heated particles relative to unheated particles. Across an intact barrier such as mammalian skin, heat is transferred from the exercising body to the surrounding air if the air temperature is lower than the body temperature. Convective heat exchange can be increased by movement of air across the exercising body, such as from the wind. Such wind-related convection can be relative (when there is net positive movement of air across the body as the body moves at a measurable velocity through the air) or absolute (when the wind velocity and direction are great enough that net increased air movement occurs even when the body is standing still). When ambient temperatures are low (winter), considerable heat may be lost via convection, due to the increased temperature gradient between air and body. Longer winter hair coats minimise such convection by trapping air next to the skin and providing an insulation barrier to the colder ambient temperature. In warmer weather, the gradient diminishes, so the effectiveness of convection as a means of heat loss is similarly diminished.

Conduction is the transfer of heat from one surface or object to another through direct contact. Because air has poor thermal conductivity, this mechanism normally has minor importance in the exercising horse. Conductive heat loss can be enhanced by application of water which is colder than the skin surface, thus allowing a conductive transfer of body heat directly from the skin to the applied water. This mechanism is enhanced by use of colder water since the gradient down which the heat is transferred is made steeper. Traditionally, horsemen have countered that use of colder water causes horses' muscles to cramp, leading to exertional rhabdomyolysis or "tying-up." Recent data have shown that this conventional wisdom is probably not true (see section titled "Counteracting increased heat and humidity").

Radiation is the transfer of heat from one surface or object to another without direct contact, but rather through emission of electromagnetic radiation waves. Some radiant heat loss occurs in exercising horses, but the reverse situation, the horse absorbing excessive radiant energy, is probably of much more importance in thermoregulation. *Jeffcott* (personal communication, 1994) has described the negative effects of apparently excessive levels of radiant heat caused by reflective surfaces in riding arenas and trails at the 1994 World 3-Day-Event Championships at The Hague. *Schroter* and *Marlin* (1995) have also recently described calculations for the Wet Bulb Globe Temperature Index which accounts for ambient radiant energy level as well as ambient heat and humidity.

Effects of increased heat and humidity on thermoregulation

Due to the awarding of the 1996 Olympic Summer Games to Atlanta, Georgia USA, concern has increased regarding the effects of excessive heat and humidity on heat dissipation during exercise in horses. Of particular concern are the 3-day-event horses, who must complete over 30 km of trotting, galloping, and jumping over natural terrain with only one 10-min rest stop at Phase X. As a result of these concerns, a number of investigations have been undertaken since 1990 to characterise the normal physiological responses of 3-day-event horses, and to assess the effects on performance of various ambient weather conditions, including increased heat and humidity.

Geor and *McCutcheon* (*Geor* et al. 1995; *McCutcheon* et al. 1995) used a designated PAT endpoint of 41.5° C in a trotting treadmill test at 50% of VO_{2max}. Laboratory permutations were cool/dry (20°C/45–55% relative humidity), hot/dry (32–34°C /45–55%), and hot/humid (32–34°C/80–85%). Exercise time was significantly shortened from 37 (cool/dry) to 28 (hot/dry) to 16.5 min (hot/humid). Sweating rate was 5% and 32% higher in hot/humid trials than in hot/dry and cool/dry trials, respectively, and remained increased throughout recovery for hot trials compared to cool/dry. In order to study thermoregulation under these various conditions, temperatures in the pulmonary artery, rectum, skin (dorsal thoracic), and middle gluteal muscle were measured and were higher at all sites throughout 60 min of recovery for hot treatments compared to cool/dry. The rate of increase in PAT was higher in hot/humid treatments than in hot/dry and cool/dry treatments. Muscle temperature was higher and rectal temperature was lower in hot/humid treatments compared to the others. The PAT:skin temperature difference (gradient) was lower in both hot treatments compared to cool/dry. Throughout exercise and recovery, heart rate was elevated for hot/humid trials compared to other conditions, a further indication of the additional stress and fatigue imposed on horses exercising under hot and humid conditions. Throughout recovery, respiratory rate was higher for both hot treatments, illustrative of the horses' attempts to increase heat loss via the respiratory tract under hot conditions. It was concluded that exercise under hot conditions increased the rate of heat storage and delayed heat dissipation during and after exercise. Furthermore, the authors speculated that the impairment of heat dissipation was "probably the result of a reduced capacity for heat transfer from the skin to the environment".

Kohn and coworkers (1994) developed a standardised exercise test not unlike the first 3 phases of speed-and-endurance day. Their horses trotted initially for a warm-up, then galloped, and then trotted a much longer period similar to Phase C. In the latter trotting phase, however, horses were allowed to continue only until their PAT rose to an experimental endpoint of 41°C. Three ambient temperatures and 2 levels of humidity were studied. It was concluded that high temperature and high humidity caused a 50% shortening in the time to reach a PAT of 41°C in the second trotting phase. It was postulated, therefore, that the efforts required on speed-and-endurance day should be decreased by approximately 50% in Atlanta where daily maximum July temperatures approach 31–32°C at midday and daily maximum humidity levels reach 70–90% earlier in the morning.

Similar results were observed in hot and humid treadmill tests in England (*Marlin* et al. 1994; *Harris* et al. 1995a; *Harris* et al. 1995b) and the USA (*Foreman* et al. 1995; *Foreman* et al. 1996a). These experiments are reviewed in greater detail elsewhere in these proceedings (*Foreman* 1996b). Phase C, the second trotting phase of a 3-day-event, was designed both as a recovery phase after steeplechase and as a further endurance test. From the data cited above, it is apparent that Phase C does not serve any function as a recovery phase under hot and humid conditions. In fact, it serves only to add to the accumulated heat burden of horses as they continue on course. A third trotting phase, Phase E, was actually abandoned in the 1960's when it was apparent that additional endurance testing was not necessary as part of a 3-day-event and in fact, may have been detrimental to the performance of participants on the third day (stadium jumping).

Counteracting increased heat and humidity

Further research has focused on how to counteract or combat the adverse effects of increased heat and humidity on equine thermoregulation and performance. At least 3 methods will be employed for the Olympic Summer Games in Atlanta: decreasing the severity of the speed-and-endurance test for the 3-day-events, increased external cooling, and preventing the adverse effects of increased ambient heat and humidity by preventative oral fluid loading.

Decreased test severity

Shortening the distances required and adding additional rest stops are the most expedient methods for decreasing the heat load generated and/or retained during equine exercise under conditions of increased ambient heat and humidity. Research has shown positive benefits, but not a complete return to cool weather performance, by shortening Phase B (steeplechase) by 50% but not by 25% (*Foreman* et al. 1995; *Foreman* et al. 1996a). It should be recalled that this 50% reduction in severity of the test is similar to the limits discovered by *Kohn* et al. (1994) and *Geor* et al (1995) under hot and humid laboratory conditions.
The juxtaposed problem, however, is that management and competitors all want a rigorous, competitive test which will truly sort out the best horse/rider pairs. Thus, there are the nearly opposite goals of having a less rigorous test for safety reasons and a more difficult test for competitive reasons. For Atlanta, the standard maximum distances for CCI**** have been shortened; one or more new rest stops called C Halt have been inserted early in Phase C; and Phase X has been lengthened to 15 min. These solutions have been discussed elsewhere in these proceedings *Foreman* 1996b). Field applications of these recommended modifications have already shown that they result in acceptable responses in 3-day-event horses competing under hot and humid conditions (*Kohn* and *Hinchcliff* 1994; *Kohn* et al. 1995; *Hinchcliff* et al. 1995).

Increased cooling

Cooling can be increased by increased convection (fans) and evaporation (fans) and increased conduction (repeated application and removal of cold bathing water).
Various mechanisms may be employed to increase convective heat loss for horses exercising under hot and humid conditions. In the early spring, before horses have shed naturally, hair coats may be clipped to allow greater convective heat transfer. In very hot weather such as that expected in Atlanta, convective heat loss may be increased by use of electric fans, both above or in front of horses' box stalls and at various points around the 3-day course where horses will stop for rests. Such rests include C Halt, Phase X (the veterinary box), and the end of Phase D. At these points, large misting fans have been utilised in some North American competitions in recent years to aid in convective and evaporative heat loss. *Allen* (personal communication, 1993) studied the effects of fans on cooling on 3-day-event horses at the North American Young Riders Championships in Wadsworth, Illinois in August 1993. Large flow fans were placed around the Phase X veterinary examination box. Observers felt subjectively that the fans made the air within the rest area feel more comfortable. Actual ambient temperature measurements documented that ambient temperature was 10–15°C cooler in the path of the fan than away from the fan. Such fans have been used subsequently at the AHSA/Kimberly Clark Field Trial in Chatsworth, Georgia in August 1994 and at the Olympic test event, The Atlanta Cup, in Conyers, Georgia in August 1995. In Conyers, fans have been placed under a shaded recovery area outside the dressage and stadium jumping arena, C Halt, Phase X, and at the end of Phase D.
Conductive heat transfer can be aided by use of repeated application and removal of cold bathing water. *Williamson* and coworkers (1995) demonstrated under field conditions that post-exercise application of cold (9°C) water over the entire body surface decreased horses' rectal temperature more quickly than did tepid water of ambient temperature (31°C). No signs of myopathy were apparent from physical examination and from determination of serum muscle enzyme concentrations after "hypercooling."
Kohn et al. (1995) showed similar cooling results in horses exercised on a treadmill with laboratory conditions of 29–33°C and 70–85% relative humidity. In a switchback design during 30 min of recovery, horses were either washed with 12°C water or were allowed to cool passively with no external bathing. Pulmonary artery temperature, gluteal muscle temperature, heart rate, and rectal temperature were significantly lower for bathed horses than nonbathed horses by 4, 7, 15, and 18 min of recovery, respectively. Rectal temperature increased in nonbathed horses during recovery. No ill effects from cold water bathing were apparent on physical examination.
Foreman (unpublished data, 1994) studied the effects of one or two new stops inserted early into Phase C in a treadmill simulation of Phases A, B, C, and X. Cold water baths (4°C) were used at each new rest stop with significant decreases in PAT and heart rate. No adverse clinical effects were apparent during the remainder of Phase C trotting nor after exercise. In fact, horses trotted more readily after bathing stops.

Preventative oral fluid loading

Oral fluid loading by nasogastric tube has been advocated both as a measure for overcoming transport and heat stress while horses acclimatise and as a method of preventing excessive fluid losses during 3-day-event exercise (*D. Frappier*, personal communication, 1994). *Geor* and *McCutcheon* (1996) studied the effects of administration before (10 L) and during exercise (10 L) of water, electrolyte solution, or nothing orally to horses trotting under hot (33–34°C) and humid (50–60%) laboratory conditions. Electrolyte solution maintained plasma volume better than did water only. In both treatment groups, there was a thermoregulatory advantage (illustrated by a lower rate of increase of body temperature) due to the additional fluid when both treatments were compared to trials with no fluid added. The result was "a longer period in which horses can safely exercise before reaching a stage of hyperthermia which would require cessation of exercise."
Sosa Leon and coworkers (1995 and 1996) "hyperhydrated" horses before prolonged treadmill exercise under temperate labora-

tory conditions. In one crossover design (*Sosa Leon* et al. 1995), they administered either 17.5 L of isotonic fluid (approximately 4% body weight) or nothing prior to exercise. Horses then trotted at 30% VO_{2max} for 90 min. Fluid administration resulted in lower plasma protein, Na, Cl, and HCO_3. Fluid administration did not affect other measured cardiorespiratory or thermoregulatory variables. In a second crossover design (*Sosa Leon* et al. 1996), they administered either 26 L of isotonic fluid (approximately 6% body weight) or nothing before exercise. Horses then performed treadmill-simulated Phases A, B, C, X, and D over a total of 108 min. Fluid loading resulted in lower total plasma protein, higher heart rate, decreased body weight loss, and lower pH and HCO_3, but no differences in PAT. From both experiments, they concluded that hyperhydration maintained plasma volume above that of nontreated horses throughout exercise. Hyperhydration did not aid in thermoregulation and may even have been detrimental in its effects on acid-base balance in the second experiment, but they studied horses under normothermic conditions rather than under hotter laboratory conditions in which additional fluid might have been of benefit (*Geor* and *McCutcheon* 1996).

Conclusions

Exercise under hot and humid conditions results in increased core temperature due to inadequate transfer of heat from core to skin because of impaired evaporation of sweat from skin to surrounding air. Heart rate, respiratory rate, sweat rate, and muscle, core, skin, and rectal temperature are increased under hot and humid conditions. Mechanisms which may help to combat the adverse effects of heat and humidity on equine thermoregulation include: shortening the demands of the exercise test; insertion of additional rest stops; repeated application and removal of cold water to increase the internal to external temperature gradient; and perhaps hyperhydration prior to exercise.

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