



Caring for the horse in a cold climate—Reviewing principles for thermoregulation and horse preferences

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ABSTRACT

In the Nordic countries, permanent outdoor housing of horses in winter is gaining popularity. This practice will expose the horses to harsh weather conditions. However, horses that are kept indoors at night and turned out in the cold during daytime also experience thermoregulatory challenges. With emphasis on the special challenges in a Nordic climate, this paper aims to increase the understanding of thermoregulation in horses, and ultimately to improve management practices. First, factors related to the environment and the mechanisms of heat exchange are summarised, thereafter the factors related to the horse, such as anatomy and physiological mechanisms which are important for balancing heat gain and heat loss. Human utility of horses and management practices such as clipping, the use of rugs, and provision of shelter are discussed in the light of thermoregulation in horses. The management and care for horses should take into account the principles of thermoregulation and mechanisms of heat loss and gain, and horses should be given a freedom of choice to cope with changing weather conditions. This should include space for movement, protection from sunshine, precipitation and wind, dry bedding, and appropriate feeding. Several studies indicate that the combination of cold rain and wind is a very demanding weather type, not just very low ambient temperatures. A shelter offers the horse protection from wind, precipitation and radiation which it can use when needed, and is therefore a more flexible management solution than a rug, especially when weather conditions change rapidly. In inclement weather, a rug may be a useful supplement. Too many horse owners clip their horse, which often necessitates the use of rugs on a regular basis. More knowledge is needed on how to best manage sport horses, especially when being sweaty after exercise in winter, to ensure good welfare.

1. Introduction

During the later years, it has become more common to keep horses outdoors, either in a group housing system 24/7 or for daily turnout in a paddock during the daytime. For example, in a Nordic study with 3229 respondents and involving more than 17 000 horses, 47 % of the horses were kept outdoors 24/7 (Hartmann et al., 2015a). In a Norwegian study which included 2075 horse owners, 25 % reported that they kept their horse permanently outdoors even in winter, and among the owners who stabled their horses at night, 88 % stated that the horses were kept outdoors for a minimum of 5 h per day in winter (Bøe et al., 2015). Keeping horses outdoors can challenge their thermoregulation depending on weather conditions. The Nordic climate is recognised by significant differences between seasons, and there are regional differences. For instance, the yearly mean temperature in

Norway is + 1.3 °C, with variations from − 4 °C in the mountainous areas to + 7 °C in coastal areas of southern Norway (NCCS report, 2015). In inland areas, winter temperatures may drop down to − 25 °C and even − 40 °C, usually accompanied by a clear sky and no wind. Along the coastline the winter is milder but also windier and wetter, and precipitation may change between rain, sleet and snow. The summer season is short, but temperatures may reach up to + 25, and in some instances to + 30 °C. The weather in spring and autumn is variable. Weather conditions are often difficult to predict and may change substantially and fast within the same day. With a changing climate, it is expected that the Nordic weather becomes wilder and wetter (NCCS report, 2015), meaning more precipitation and stronger winds. Hence, it can be difficult for horse owners to know how to best protect the horse when turned out under such conditions. Hartmann et al. (2017) revealed that many horse owners had severe gaps in their knowledge on

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heat dissipation mechanisms in horses. A better understanding of the factors which influence the horse' thermoregulation will help horse owners to improve their management.

This paper will give an overview of factors and mechanisms which affect thermoregulation in horses, both environmental (temperature, humidity, precipitation, wind, solar radiation) and those related to the horse (anatomical, physiological and behavioural). Thereafter, we address effects of different management practices, such as the use of rugs, on thermoregulation. Lastly, we discuss actions which can be taken by horse owners to help their horse to achieve thermal comfort under different weather conditions in a Nordic climate. In order to understand the term thermal comfort, we start by describing the term thermoneutral zone.

1.1. Thermoneutral zone

Horses are homeothermic (warm-blooded) animals, which means that the core body temperature is kept within narrow limits despite large variations in ambient temperature, and they are endothermic, meaning that heat is produced by the body (e.g. Sjaastad et al., 2016). The thermoneutral zone is commonly used for describing the span in ambient temperature within which an animal can keep the core body temperature stable, using physiological regulatory mechanisms only (e.g. Guthrie and Lund, 1998; Autio, 2008; Sjaastad et al., 2016). The classical thermoneutral zone is based on measurements made in a climate chamber, i.e. an animal at rest, in still air (Hillman, 2009). The lower end of the thermoneutral zone is called the lower critical temperature (LCT). When ambient temperature drops below LCT, the body must produce more heat by increasing the metabolism (e.g. to shiver) in order to maintain the core body temperature. At the point where the heat producing capacity is exceeded by the heat loss, the core body temperature will begin to drop. When core body temperature drops below 33–34 °C, the efficiency of the temperature regulation system decreases (Sjaastad et al., 2016). Mental and physical functions will gradually be disturbed, and consciousness will be lost at a core body temperature of 27–30 °C (Sjaastad et al., 2016). Heart fibrillation is common during severe hypothermia, and when freezing to death, heart failure is often the cause (Sjaastad et al., 2016). At the higher end of the thermoneutral zone, a further increase in ambient temperature will cause the core body temperature to rise. A homeothermic animal can only survive a core body temperature a few degrees above its normal body temperature (Sjaastad et al., 2016). The term “zone of least thermoregulatory effort” has been proposed to define the ambient temperature span under which the animal is not under thermal stress and neither needs to mobilize energy reserves, nor to pant or sweat, to keep a steady core body temperature (see discussion of terms in Hillman, 2009). In humans, the zone of least thermoregulatory effort roughly corresponds to the comfort zone, where people feel thermal comfort (Hillman, 2009).

Thermoregulation is a result of complex and sophisticated biological processes influenced by many environmental factors, not just ambient temperature (e.g. Sjaastad et al., 2016). Further, LCT is not a fixed value, but depends on animal factors such as age, breed, physiological status, acclimatisation, hair coat quality, feeding, and body condition (Autio, 2008). For example, during cold adaptation, the metabolic rate rises and may become 2–3 times higher than maintenance level (Sjaastad et al., 2016). For these reasons, LCT is only valid for the studied population. For instance, Morgan (1998) found the LCT to be +5 °C in Standardbred trotters acclimatized to 15–20 °C. McBride et al. (1985) estimated the thermoneutral zone to be between +10 and -15 °C in winter-acclimatized adult quarter horse geldings. Cymbaluk and Christison (1989) estimated the LCT of ad lib fed and cold-adapted yearling Quarter and Quarter horse crosses to be -11 °C, and Autio et al. (2007) suggested LCT to be between -9 and -16 °C in cold housed weaned foals of various breeds. In neonate foals (Thoroughbreds, Arabians, ponies) the mean LCT is found to be between +10

and +24 °C (summarised by Autio, 2008). Nevertheless, studies on LCT are valuable to demonstrate expected cold tolerance

1.2. Environmental factors

Homeothermic animals exchange heat with their surroundings when the surface body temperature deviates from air temperature and the temperature of surfaces in the environment. The speed of the heat exchange depends on the temperature gradient between the animal and the surroundings (Sjaastad et al., 2016). Not only ambient temperature *per se* but the combination with wind speed, precipitation, humidity, and solar radiation determines the magnitude of the thermoregulatory challenge for a horse. The physical mechanisms behind heat exchange are conduction, convection, radiation and evaporation, and will be explained below. In a cold environment, the non-evaporative heat loss (conduction, convection, radiation) is most important, whereas heat loss by evaporation dominates in a warm environment (Sjaastad et al., 2016).

1.2.1. Conduction

Heat loss by conduction is heat loss through direct contact between the horse and a cooler substance or object (Sjaastad et al., 2016), e.g. the surface on which the animal lies when resting. The rate of heat loss depends on the conductive property of the object as well as the temperature difference. For instance, the heat loss will be higher to a wet compared to a dry bedding material, since water is a good conductor. Air has poor conductive properties and heat loss to air by conduction is insignificant (Guthrie and Lund, 1998).

1.2.2. Convection

Convection is transfer of heat by moving air or water across the skin (Sjaastad et al., 2016). Air trapped in the hair coat is important to insulate the body, whereas wind will readily remove the warm air close to the skin and thus speed up heat loss. In rain, the hair coat and skin are flushed with water, which continuously removes heat from the horse. Mejdell and Bøe (2005) found that Icelandic horses spent more time in the shelter during rain, but not when precipitation fell as snow. Thus, precipitation as snow did not seem to have the same cooling effect as rain. This was explained by the fact that snow did not readily melt on the backs of the horses (which had a thick winter hair coat), but it rather built up as a layer (Fig. 1). Heat loss by convection also takes place from inner surfaces, i.e. in the respiratory system (Guthrie and Lund, 1998). After cold air is inhaled, it is warmed up when passing the



Fig. 1. Icelandic horses standing close together in harsh winter weather. Note that the snow does not melt on their backs, indicating a well insulating hair coat. Photo: Cecilie Mejdell.



Fig. 2. Nordland/Lyngen horses in winter, taking advantage of solar radiation by exposing a maximum skin surface area towards the sun. Photo: Grete Jørgensen.

airways, before it is exhaled, and new cold air is inhaled.

1.2.3. Radiation

Heat can be lost by radiation (electromagnetic waves) from the warm body to a cooler surface (e.g. Sjaastad et al., 2016), for instance the clear sky during night or a cold surface indoors. The magnitude of heat loss by radiation was calculated by MacCormack and Bruce (1991) in a model study during the winter in Scotland. They found that an unheated shelter with four walls and a roof reduced the climatic energy demand by 20 % compared to being outdoors without a rug on. In their model, the shelter provided protection similar to the effect of a rug: having a rug on while outdoors reduced the energy demand by 18 %. The potential for heat loss by radiation can be visualised using infrared thermography. Areas of the body with less insulation, e.g. a thinner hair coat, have a higher overall surface temperature, which indicates a larger sensible heat loss (Autio, 2008; Jørgensen et al., 2020). Horses left in the sunshine at high ambient temperatures experience increased skin and core body temperature and elevated cortisol levels, indicating heat stress (Holcomb et al., 2013). In winter, heat gain from solar radiation is actively used by horses (Fig. 2).

1.2.4. Evaporation

Heat loss by evaporation occurs when heat is taken from the body to evaporate sweat, or water from the wet skin after precipitation, as well as water vapour in expired air (Sjaastad et al., 2016). In horses, evaporation of sweat is considered the most effective physiological mechanism to get rid of excess heat (Hodgson et al., 1994; Guthrie and Lund, 1998). Evaporation is less efficient when air humidity is high (Hodgson et al., 1994). Although the absolute amount of water vapour contained in cold air is low, the relative humidity is usually high in winter (Sjaastad et al., 2016). When the relative humidity is high, the sweat production overrides the rate at which sweat evaporates, and sweat starts dripping. The benefit of evaporative heat loss is then lost (Guthrie and Lund, 1998).

1.3. Horse factors

Various autonomous functions are responsible for most of the thermoregulation; i.e. to balance the internal production of heat and the heat loss to the environment. Further, altered behaviour triggered by conscious perception of feeling too warm or too cold, also plays an important role. Social group relations may however, affect these behaviours.

1.3.1. Heat production

Heat is a by-product of metabolism in all body tissues (e.g. Sjaastad et al., 2016). Animals with a higher basal metabolism, such as growing animals, working animals, and pregnant or lactating mares, have a higher basal heat production compared to e.g. an old gelding. At rest,

60–70 % of the heat production takes place in the heart, liver, kidneys and brain although these organs only count for less than 10 % of the body mass (Sjaastad et al., 2016). Most evident is the enormous heat production during exercise. At maximum efficiency, the energy used by the muscles results in 25 % work and 75 % heat (Sjaastad et al., 2016). During sudden exposure to cold conditions catecholamines lead to a rapid increase in metabolism, whereas thyroid hormones are part of the long-term cold adaptation, in which the metabolic rate may increase 2–3 fold (Guthrie and Lund, 1998; Sjaastad et al., 2016). McBride et al. (1985) tested metabolism in winter-acclimatized adult Quarter horse geldings in a climate chamber. They found metabolism to be at its lowest between +10 and -10 °C, increasing to 142 % of basal level at -40 °C, at which the experiment was stopped due to animal welfare concerns. Neonatal animals of various species are born with another source for thermogenesis, brown adipose tissue, but it is uncertain whether this mechanism is important in foals (Ousey, 1997).

1.3.2. Anatomy

Surplus body heat is dissipated to the cooler surroundings, mainly over the skin surface (e.g. Sjaastad et al., 2016). The surface to volume ratio of the animal is therefore relevant for the thermoregulation (see e.g. Watt et al. (2010) for review). Different shapes vary regarding the surface to volume ratio. The sphere is the shape with the lowest surface relative to volume. The more elongated a shape is, the larger is the surface relative to its volume. The practical implication of this is that a horse with a slender body shape with long neck and limbs, has a larger skin area over which heat can be lost, compared to an equally heavy horse having a more compact body and shorter extremities. Foals have a relatively large surface area and will thus be prone to lose more heat than adult horses (Langlois, 1994).

The absolute body size also matters. The relationship between size and surface area can be illustrated by comparing the formula of the surface of a sphere ($4\pi r^2$) and its volume ($\frac{4}{3}\pi r^3$). The surface to volume ratio is then $3/r$, explaining that the bigger the sphere is (i.e. a large radius) the relatively smaller becomes the surface area (Watt et al., 2010). Similarly, a cube with sides S has the surface area $6S^2$ and the volume S^3 , giving a surface to volume ratio of $6/S$. From this we can deduce that when the size of the sphere or cube increases (i.e. a larger radius or longer sides) the relatively smaller becomes the surface of the object, a principle which is valid for all shapes. The practical implication is that a large horse has more mass to produce heat but a relatively smaller surface to dissipate heat, compared to a similarly built but smaller horse (Langlois, 1994).

Horses have a “radiator system” in the limbs. Arteries and veins run close together in the legs in a counter-current way, so that warm arterial blood from the body core warms up the cooler blood (i.e. heat transfer by conduction) in the returning veins (Sjaastad et al., 2016). This reduces the temperature of the distal limbs and also reduces total heat loss.

1.3.3. Other morphological traits

Different characteristics of the horse’ body may influence insulation properties and thus heat loss. The hair coat, skin thickness, and subcutaneous adipose tissues constitute the “outer shell” of the animal (Sjaastad et al., 2016). These traits are often a consequence of natural or artificial selection, but environmental factors also contribute. For instance, there are genetic differences among horses and horse breeds in their ability to grow a thick winter coat (Langlois, 1994). Although shedding and hair regrowth is mainly regulated by day-length, the coat quality is influenced by the local climate conditions and management factors, such as whether the horse is stabled or routinely wears a rug. Cymbaluk (1990) found that the hair coat weight of cold-housed (mean ambient temperature -5 °C) Standardbred colts were twice that of colts kept at +10 °C, both groups having 4 h daily outdoor access. Bocian et al. (2017) studied 10–15 years old geldings (Mapolski horses and Felin ponies) and demonstrated that low air temperature in the stable

resulted in a winter coat with longer hairs, especially in the ponies, and an accelerated shedding by 25 days in spring. Horses of the cold-blood breed types (more heavily built horses) are more adapted to a cold climate than horses of warmblood breed types (more slender horses) (Langlois, 1994). Cold-bloods have generally more protective hairs (mane and fetlock hairs) and a thicker skin, develop a thicker winter hair coat, more easily build up body fat reserves when feed is abundant, and have a more even distribution of the subcutaneous adipose tissue, compared to warm-bloods (Langlois, 1994). Jørgensen et al. (2020) reported an average hair length in a sample taken from the rump to be 3.3 cm (range 2.4–4.5) and 2.0 cm (range 1.0–3.0) in cold-blood and warmblood breed types, respectively. In Icelandic horses kept outdoors in a cold climate in inland Norway, the hair coat at the side of the neck was measured at its maximum in December to be 4.6 ± 0.9 cm, in contrast to the minimum of 0.5 ± 0.0 cm in June (Mejdell and Bøe, 2005). Horses with a good insulation (e.g. a dense hair coat) can be seen with a layer of snow on their backs, which do not melt, and this illustrates the insulation property of a good winter coat (Fig. 1).

A dark hair coat colour absorbs solar radiation more than light colour (Langlois, 1994; Sjaastad et al., 2016), meaning that a dark horse gains more heat from the sun. The grey gene, causing horses to turn whitish as they age, thereby reflecting solar radiation, is more widespread in horse breeds with an origin in areas with a warm climate (Langlois, 1994).

1.3.4. Physiology

There are thermoreceptors both in the skin and in the body core, e.g. in large veins and viscera, which send information to the temperature control centre in the hypothalamus (Sjaastad et al., 2016). Several short-term autonomous regulatory mechanisms are responsible for maintaining the core body temperature within narrow limits. Vasoconstriction of blood vessels in the skin and extremities will reduce the flow of warm blood to the surface of the horse and thus reduce the heat loss. Vasodilation in the same vessels increases the blood flow, warms up the skin and will increase the heat loss. In horses with a thin skin, the dilated blood vessels are easily visible on hot days or under/after training. Wallsten et al. (2012) demonstrated the change of limb skin temperature from heat conservation as the horse was taken outdoors into the cold, to heat dissipation when horses were exercised.

Piloerection means raising the hairs, thus trapping more air in the coat and thereby increasing the insulation property. Morgan (1997a) calculated the thermal insulance of an intact dry winter hair coat to be $0.12 \text{ m}^2 \text{ K W}^{-1}$ on average in Standardbred trotters in a cold and calm environment. She estimated the maximum thermal insulance to be 0.36 K W^{-1} with an estimated insulance of the boundary layer of air trapped in the coat to be 0.14 K W^{-1} . This resembles the insulating property of a rug. A wet hair coat insulates less well than a dry coat (McArthur and Ousey, 1996; Sjaastad et al., 2016).

Sweating is a very effective way of cooling, as evaporation demands energy which is removed from the skin surface. Horses have the highest sweating rates of any endotherm, and twice that of humans (Hillman, 2009). Sweating can dissipate 2/3 of the metabolic heat load during exercise, and a sweat loss of more than 10 L/h has been reported (Hodgson et al., 1994). Evaporation of 1 L sweat dissipate 2.4 mJ of heat, which is equivalent to the heat produced during 2 min high intensity work or 6 min endurance exercise (Guthrie and Lund, 1998). In an exercising horse, the heart rate will increase in order to supply oxygenated blood to the working muscles, and at the same time transport excessive heat to the skin and fluid for sweat production (Guthrie and Lund, 1998).

In contrast to many other species, horses are unable to breathe through the mouth and therefore they do not pant. However, a high respiration rate is a way to increase heat loss by expiration of humid, warm air. During exercise, respiration rate may reach 200 breaths/min and 25 % of the metabolic heat load can be dissipated from the respiratory tract (Hodgson et al., 1994). Morgan (1997b) reported that

respiration rate increased when adult, Standardbred horses, acclimated to $15 - 20^\circ$, were exposed to temperatures above 20°C in a climate chamber. In cold conditions, the respiration appeared deep and slow and in warm conditions shallow and fast. Morgan (1997b) suggested that the shallow breathing pattern is largely a dead space ventilation (i.e. not for gas exchange) which facilitates heat loss.

Shivering is involuntary muscle contractions at a frequency of 10–20/s and serves no other function than to produce heat (Sjaastad et al., 2016). Shivering may increase heat production by a factor of five within few seconds. On the other hand, the body movements of shivering (or exercise) may literally shake out the warm air trapped in the hair coat, thus increasing heat loss by convection and reducing the thermal insulance of the coat (McArthur, 1991). McBride et al. (1985) reported shivering in adult winter-acclimated adult Quarter horse geldings in a climate chamber at -20°C and lower. In a flock of acclimated Icelandic horses kept outdoors in winter (with shelter access) in air temperatures down to -30°C , shivering was only observed once, on a day with $+5^\circ \text{C}$ combined with heavy rain (Mejdell and Bøe, 2005). Also, Jørgensen et al. (2016) observed shivering only a few times and then on winter days with ambient temperatures above 0°C combined with rain or sleet. Morgan (1997b) found that a dry, clipped horse placed in a climate chamber started to shiver at $+6^\circ \text{C}$. In a climate chamber the horse has very restricted space to move, which may necessitate shivering thermogenesis at a higher ambient temperature than in situation where the horse can move freely (Morgan, 1997b).

Langlois (1994) mentioned the ability of horses to sleep while standing, and that the work of these postural muscles produce heat. In contrast, REM-sleep, during which horses must lie down, generally takes place in the sun around mid-day when the temperature and solar radiation is at its peak (Fig. 3).

1.3.5. The role of behaviour

Behavioural changes in the cold include heat-producing and heat retaining mechanisms (Autio, 2008). An animal's conscious feelings can be regarded as adaptive ways to motivate the animal to act in order to avoid damage and to maintain homeostasis (Broom, 1998), including a stable core body temperature. In the same way as hunger motivates animals to search for feed and eat, the unpleasantness of feeling too warm or too cold will motivate the animal to do something about it. The subjective feeling of thermal comfort and thus motivation to seek this state within the thermoneutral zone, can be measured by observations of behaviour.

When feeling too cold, horses can alter their body posture, e.g. stand down-wind with a tucked tail (Ingólfssdóttir and Sigurdjónsdóttir, 2008), start running (Autio, 2008), find shelter from wind and precipitation (e.g. Mejdell and Bøe, 2005; Snoeks et al., 2015; Jørgensen et al., 2016), or aggregate with other individuals (Ingólfssdóttir and Sigurdjónsdóttir, 2008) (Fig. 1). For example, horses benefit from solar radiation on cold days by exposing the largest possible area of the skin



Fig. 3. Icelandic horses sleeping in recumbent position on a sunny winter day during. They minimise heat loss from conduction by lying on straw and at the same time exploiting heat gain from solar radiation. Photo: Cecilie Mejdell.

towards the sun (Mejdell and Bøe, 2005) (Fig. 2).

Horses do make use of human made shelters. Many studies, of different breeds, support that horses seek shelter when the ambient temperature is lower than usual, and especially during rain and wind. Heleski and Murtazashvili (2010) studied shelter seeking behaviour in Arabian and some draught horses over a 12 month period in Michigan, USA. On days with precipitation and wind the number of horses using the shelters increased. In snow and wind > 4.9 m/s horses were observed inside the shelter in as many as 62 % of the observations. Mejdell and Bøe (2005) studied a flock of 40 young Icelandic horses during a Norwegian winter with temperatures down to -30 °C. They found that the horses showed a strong preference for resting in a recumbent position indoors on straw, and that rain, wind and very low ambient temperatures increased the shelter use. Christensen et al. (2018) found that Icelandic horses kept outdoors during the Danish winter spent more time inside the shelter at night, when ambient temperature dropped below 0 °C, and when it was raining. In Finland, Autio and Heiskanen (2005) found that weanling foals spent on average 51 % of their time in the open but also made use of an insulated sleeping hall as well as a non-insulated shelter. Their use of the indoor areas did not change much as ambient temperatures dropped from 0 to -20 °C. In southern Sweden, low ambient temperatures (-10 °C) increased the young Thoroughbred horses' use of shelter (Michanek and Ventorp, 1996). In a Northern coastal climate, Jørgensen et al. (2016) studied horses, which were stabled at night, while they were turned out in a paddock with access to a two-compartment shelter. One of the compartments had an infrared heater. In winter weather, horses spent more time inside a shelter on days with precipitation and changed from the unheated to the heated compartment as weather changed from dry and calm to wet and windy (Jørgensen et al., 2016). In Belgium, Snoeks et al. (2015) studied shelter use of 426 horses (different breeds, age, gender, and colour) on 166 pastures at ambient temperatures ranging from -4 to +37 °C. Horses used the shelter more at ambient temperatures below +7 °C, and rain induced a significant rise in shelter use.

When feeling too warm, horses can seek shade, move to a windy place, or drink cold water. For instance, a Swedish study found that Icelandic horses kept in a large enclosure containing a forest area, hardly used the shelter in the winter, even at days < -20 °C, but did so on warm days and days with insect harassment (Sundquist and Broström, 2007). In a Swedish study from the summer season with temperatures ranging from +16 to +25 °C, warmblood horses spent time in the shelter, especially when there were more insects and less wind (Hartmann et al., 2015b). Snoeks et al. (2015) found that horses increased their use of man-made shelters when ambient temperature was higher than 25 °C, and when insect loads were high. The authors noted that at +31 °C, the temperature was 5.5 °C cooler inside the shelter and 2.7 °C cooler under a tree. Heleski and Murtazashvili (2010) concluded that draught horses benefited more than Arabian horses from the shade provided by shelters on warm days.

Increased thermogenesis in cold environments leads to a corresponding rise in appetite and feed intake (Sjaastad et al., 2016). In hot weather, horses will lose appetite and cease feeding (Morgan, 1997b). The heat production from eating depends not only on the energy content but also on the texture of the feed. Heat production is higher when horses eat roughage compared to concentrates (Kleiber, 1961, in Guthrie and Lund, 1998), which is probably explained by more chewing and more contractions by the smooth muscles in the intestine walls when digesting long fibered feed.

Horses are social animals, and when kept in a group, social dynamics may influence individual horses' actual freedom of choice. If there is shortage of a valued resource, the animal with the higher rank has priority. Ingólfssdóttir and Sigurjónsdóttir (2008) studied groups of Icelandic horses kept outdoors on winter pasture. They found that individuals with high rank placed themselves in the middle of a huddle and thereby got shield from the other horses when standing in the wind.

The horses with higher rank spent relatively more time eating hay and less time grazing compared to the subordinates, while the total time spent eating was the same. The high ranked individuals gained weight during winter, while the low ranked horses dropped in body condition. Thus, it is important to prevent valued resources being monopolized by a few horses in the group. Social rank seems to be less important in groups of young horses, as studies show that they are more willing to share shelter space (Heleski and Murtazashvili, 2010; Ingólfssdóttir and Sigurjónsdóttir, 2008).

1.4. The human factor

The facilities horses are kept in, management routines of the owner (or livery stable manager) and how the horses are exercised greatly influence the ability of horses to cope with thermal challenges, by using physiological and behavioural mechanisms for heat conservation or heat dissipation.

1.4.1. Stables, turn-out and exercise

Horses in cold climates used for work, sports, or leisure activities meet special challenges regarding thermoregulation. These horses are often exposed to very different thermoregulatory demands within the same day (Morgan, 1997b). For example, in winter, sport horses which are kept indoors in a warm environment during the dark hours are turned out for some hours in daytime at ambient temperatures well below 0 °C, often in barren paddocks which do not motivate free movement. In addition, they receive high intensity exercise for a short period, several times a week. Wallsten et al. (2012) nicely illustrated how the physiological thermoregulatory mechanisms change as horses are taken out in the cold, exercised, and during the restitution phase after exercise. The study included three horses: A New Forest pony mare (14 years), a Gotland pony gelding (24 years) and a mixed breed gelding (11 years). The temperature in the stable was low (0.5–2.8 °C). On test days, outdoor temperature varied from -1.1 to -8.7 °C with light snow, and the relative humidity was 91–99 %. When taken out, physiological mechanisms for handling the chill took place. The skin temperature of the legs dropped from around +30 °C to as low as +17 °C (in a clipped horse). Under exercise, the regulatory mechanisms switched to meet the demands of muscular work and heat dissipation: increased respiration and heart rate, and, after a delay an increase in skin temperature of the legs (up to 35 °C) and neck due to vasodilatation. After the exercise had ended, heart rate quickly returned to basal, but skin temperature and respiratory rate continued to be elevated because heat dissipation was still needed, before slowly returning to pre-exercise values.

Horses kept permanently outdoors are not exposed to such sudden changes in ambient temperatures as stabled horses. They will acclimatise to the outdoor situation, meaning that their metabolism, feed intake and hair coat thickness (if left natural) adjust to the environment (Sjaastad et al., 2016). However, when exercised, they easily become sweaty and wet, because heat production overrides the capacity of both sensible and evaporative heat loss mechanisms (Guthrie and Lund, 1998). Evaporation is less effective at low winter temperatures with high relative humidity, resulting in a wet hair coat which implies reduced insulation properties (Sjaastad et al., 2016). Further, utility horses are groomed, which may remove fat in the hair coat and thus reduces the water resistance (Langlois, 1994). There is a lack of knowledge on how to best care for outdoor-housed sport horses, and research-based guidelines for hair coat management in the cold winter air outdoors, is demanded.

1.5. Enclosure and shelter

The outdoor enclosure for horses should provide shade and protection against precipitation and wind. In moderate climates, natural shelters, e.g. vegetation, may be sufficient. According to Norwegian

legislation, horses which are kept permanently outdoors beyond the grazing season shall have access to a man-made shelter (FOR-, 2005-06-02), whereas at summer pasture there is no legal claim for provision of shade. The shelter must have at least three walls and a roof, and a dry and insulating bedding, so the horse can rest in a recumbent position without losing heat by conduction.

The design of the shelter matters greatly. For instance, Christensen et al. (2018) found that two entrances increased the use of the shelter and lowered the faecal cortisol metabolite levels in horses, whereas a partition inside had no effect on stress levels or utilisation. Mejdell and Bøe (2004) interviewed 25 owners who had at least 25 Icelandic horses, about the horses' use of man-made shelter. The authors found that the following factors were associated with little or no use of a shelter: Shelter placed low in the terrain; entrance(s) away from activity and traffic area; mud in front of the opening(s); narrow entrance; small indoor area; and alternative natural shelter in the same enclosure, providing protection from weather. The authors concluded that horses should be able to use the shelter without sacrificing other important needs, i.e. having an overview of the surroundings, contact with conspecifics and at the same time not risking being "trapped" inside by higher ranked horses. Another aspect to consider is the thermal properties of the building materials.

1.5.1. Use of rugs and clipping

Many horse owners routinely wrap their horses in rugs to keep them warm or to protect them from insect bites. Hammer and Gunkelman (2020) examined changes in skin temperature of four adult stock-type horses (~500 kg) wearing rugs of different insulation; no fiberfill, 200 g fill or 400 g fill, and controls without rugs. Horses were let outdoors for 1 h at an ambient temperature of -23 °C (with a wind chill effect of -32 °C), then taken in and un-rugged before the lumbar skin temperature was immediately measured. Whereas surface temperature was 22.3 °C in the controls, a rug resulted in higher surface temperatures of 26.8, 30.3 and 31.5 °C, for the three weight categories, respectively. The difference between the two filled rugs was not significant. The study showed that a rug adds to the horse's natural insulation and helps to keep it warm. In a study gathering information on management practices from 4122 horse owners in Sweden and 2075 in Norway, as many as 90.9 % and 83.7 % reported to use a rug on the horses during turnout, and 73.7 % and 59.1 % when stabled, respectively for the two countries (Hartmann et al., 2017). Clipping of the horse's hair coat to keep it short even in winter, was done on a regular basis by 68.5 % of Swedish respondents and 35.2 % of the Norwegians. The two main reasons given for clipping in this study, were that horses dry up faster after training and that the horse's performance increases. Clipping often necessitates the use of rugs (Morgan, 1997b), and 96.1 % of clipped Swedish horses wore rugs. In a German online study (comprising 373 owners) more than 90 % of those who clipped the horse put on a rug day and night (Steinhoff-Wagner, 2018).

A full winter coat hampers heat dissipation at high ambient temperatures, as tested in a climate chamber (Morgan, 1997b). Wallsten et al. (2012) compared heat dissipation during exercise and recovery in the same three individual horses with intact winter hair coat, clipped coat, or rug, at mean outdoor temperatures from -1 to -8.7 °C. At onset of exercise, unclipped horses showed heat dissipation responses (higher surface temperatures, caused by vasodilatation under the skin), whereas clipped horses showed cold-defence mechanisms (lower skin temperatures, indicating vasoconstriction). Respiratory rate and surface temperature took longer to return to basal levels in horses with intact hair coat and/or wearing a rug, compared to clipped horses. Thus, heat dissipation of horses which are exercised at high intensity may benefit from clipping, whereas recovery is delayed if the horse is equipped with a rug straight after. Despite the scientific documentation from these Swedish researchers, Hartmann et al. (2017) revealed that many horse owners did not understand mechanisms for thermoregulation. For instance, 44.7 % of the 4122 Swedish respondents were neutral or

disagreed with the statement "Clipped horses have greater heat loss capacity during exercise", and 50.6 % were neutral or disagreed with "blanketing after exercise increases recovery time".

Given the extensive use of rugs, owners should be aware that even in the resting horse, a rug worn in sunshine may hamper the cooling effect of natural, physiological heat dissipation mechanisms such as skin blood vessel dilation and sweating as the ambient temperature rises. Further, even a well-fitted rug may over time induce pressure, causing skin chafing or sores (Clayton et al., 2010). In order to examine whether horses like or dislike wearing a rug, Mejdell et al. (2016) trained horses to use a simple "sign language" to communicate their preferences for wearing rugs. The horses were tested for their preference during different weather conditions, which included temperatures from +23 to -16 °C, wind speed up to 14 m/s and heavy rain (Mejdell et al., 2019). Among the 23 horses studied, the authors found no indication that wearing a rug was perceived as unpleasant, and the preferences shown by the horses corresponded well to predictions of thermoregulatory challenges. No horses indicated that they preferred to wear rug in sunny spring and summer weather, whereas most asked for a rug in chilly weather combined with rain and wind. At a windy (14 m/s) and rainy day +6 °C, 100 % of the tested horses wanted to wear a rug (Mejdell et al., 2016). At air temperatures below -10 °C, horses wanted to wear a rug in 80–90 % of the tests, and when air temperature exceeded 20 °C, all horses tested wanted to be without a rug (Mejdell et al., 2019). At +10 °C, 5% of the horses without a rug blanket asked for one and 34 % of the horses which already had a blanket, preferred to keep it on. Rain, wind and sunshine had marked effects on the probability estimates for the choices (Mejdell et al., 2019). At moderate weather conditions, there were individual differences, and some individuals had preferences that contrasted owner routine management.

Light weight rugs are commonly used in the summer season, and one reason given is to protect the horse against insect harassment (Hartmann et al., 2017). These rugs often have a light colour to reflect solar radiation. Padalino et al. (2019) tested whether light-coloured cotton rugs could substitute shade in the Australian summer. The horses were tied outdoors in direct sunlight for 2 h at air temperatures > 25 °C, then half of them were equipped with the rug. All horses stayed out in the sun for another 2 h, while being monitored. Respiratory rate and sweat score were significantly lower in the non-rugged horses, but they swished the tail more, indicating more insects. The authors concluded that under the tested conditions, a light-coloured rug is not an adequate substitute for shade.

1.6. Iron shoes

The potential effect of iron shoes on heat loss has received very little attention. Jørgensen et al. (2020) documented that the surface temperature of shod hooves was lower than that of unshod hooves. Whether this has any effect on hoof health and therefore should have consequences for management of horses in a cold climate, remains to be studied.

2. What can the horse owners do to accommodate thermal comfort?

In a Nordic climate, weather conditions change through the seasons of the year, but also substantially for one day. Weather conditions are beyond human control. However, horse owners or livery stable managers do have control over the resources they offer their horses, such as enclosures for turn-out, shelters, feed and feeding management, and rugs. With good planning and the right priorities, the owner can provide important resources which will help horses to self-adjust and cope with the thermal challenges throughout the year and thus reduce the risk of thermal stress. Whereas a high wind speed and rain will help the horse to get rid of surplus heat in a warm summer, it will exaggerate the heat loss in cold weather. The task is therefore to give the horse a

choice, i.e. to provide alternatives so that horses can utilise their full repertoire of physiological and behavioural adjustments to achieve thermal comfort.

2.1. Shelters and enclosures

A large enclosure which allows horses to move freely around will increase the heat production from the contracting muscles, which is advantageous in a cold climate. Distribution of valuable resources such as feed, water, natural and/or artificial shelters, and company from other horses, will increase the motivation for moving around. For example, this is done in a systematic way in the system “Active Stable”, which make horses walk 5–10 km per day (Claudi and Hoy, 2013). The welfare of subordinate horses needs special consideration when planning enclosures, housing conditions and management routines, as these horses will be the losers in a competition situation.

Not only very low ambient temperatures, but wind and rain above 0 °C have been documented to be challenging for horses in the winter season, as have been illustrated by their use of shelters (e.g. Autio, 2008; Heleski and Murtazashvili, 2010; Jørgensen et al., 2016) as well as their expressed wish for wearing rugs (Mejdell et al., 2019). Low ambient temperature *per se* seems to be less of a challenge (Mejdell and Bøe, 2005). Thus, a focus on terms such as lower critical temperature (LCT) may attract too much attention towards absolute temperature values at the expense of these other, important environmental factors that greatly modify thermoregulation challenges. Horses should have protection from the adverse effects of cold precipitation and wind. This can be done by providing access to shelters or to put on a rug. In a Norwegian winter study (Jørgensen et al., 2019), wearing a rug reduced the horses’ use of a man-made shelter, but did not make the shelter redundant. In contrast to wearing a rug, the horse can choose to stay inside or outside a shelter as the weather changes from rainy to sunny conditions. A shelter is therefore a more flexible solution than a rug, which relies on human intervention. Further, the shelter protects against solar radiation on warm days and may offer relief from insect harassment (Hartmann et al., 2015b).

2.2. Clipping and blankets

The very high percentage of clipped horses (Hartmann et al., 2017; Steinhoff-Wagner, 2018) suggests that clipping is a fashion, rather than reflecting the number of competition horses which benefit from clipping in order to prevent heat stress and reduced performance during high intensity work (Morgan et al., 2002). The extensive use of rugs on horses, both indoors and outdoors, which often is a consequence of clipping, needs to be addressed. Clipping and subsequent clothing interferes with natural thermoregulatory mechanisms and makes the horse’ thermal comfort too dependent on humans, i.e. the human caretakers’ knowledge and capacity to at all times provide a rug with the appropriate insulation.

2.3. Feed and water

In the cold winter, the energy demand of the horse increases to counteract the heat loss to the surroundings. Thus, horses kept outdoors in the cold season need more feed to avoid catabolism of body tissues. McBride et al. (1985) estimated that adult Quarter horses need 2.5 % more energy for maintenance for each degree C below the LCT, which in their study was -15 °C. For young, growing Quarter and Quarter horse crossbreds, Cymbaluk and Christison (1989) calculated an extra 1.3 % energy for maintenance per degree C below 0, and a daily extra 0.7 % in order to have a moderate weight gain. Ad libitum access to a roughage of a suitable nutritive value for the horses in the group provides them the opportunity to freely adjust feed intake. Horses that become too fat with free access could still get some straw or branches to chew on, since the act of digestion itself produces heat (Sjaastad et al.,

2016). Access to frost-free water should be provided, and horses which sweat need a supply of salt. Heated drinking water is shown to increase water intake compared to water near the freezing point (Kristula and McDonnell, 1994).

2.4. Acclimatisation

When owners plan to keep horses outdoors in winter, they should allow the horses to acclimatise. This can be done by continuing to keep the horses outdoors from summer through autumn. This will help the horse to gradually adjust their metabolism to the gradually colder environment by eating more and to develop a thicker hair coat (Langlois, 2014). Horse owners and veterinarians should be aware of the risk of heat stress if a cold-acclimatised horse has to be kept in a heated environment, e.g. in a veterinary clinic (Morgan, 1997b).

2.5. Horses with special needs/elderly horses

Rugs are well suited to protect horses under especially harsh weather conditions, and for horses with special needs. For instance, the thermoregulatory ability decreases as the horse ages: The elderly horse has a reduced metabolic rate, often loses muscle mass and eats less, and the risk of diseases increases (Sjaastad et al., 2016). The impaired cardiovascular function in elderly horses also increases the risk of hyperthermia during exercise (McKeever et al., 2010). Further, horse owners report on changes in hair coat quality, stiffness, loss of body condition and weight (McGowan et al., 2010; Ireland et al., 2011), which make them less prepared for cold weather (Jørgensen et al., 2020).

2.6. Utility horses and full winter coats

An intact winter coat may be a prerequisite for a successful thermoregulation in outdoor housing solutions, but at the same time this results in sweaty/wet horses during exercise (Wallsten et al., 2012). Further, a clean hair coat is imperative to keep the piloerection and water-repellent functions in order, but too much grooming and washing may reduce the fat in the hair coat layers and thus reduce its insulating capacity (Langlois, 1994). So, there is a trade-off between a large degree of self-management which rely on the thermoregulation ability of the horse itself and the practicalities when using the horse for sport and leisure activities.

There is a knowledge-gap on how to best care for horses which are sweaty after exercise in winter. Immediately after exercise they need to get rid of excess heat (Wallsten et al., 2012). However, more research is needed to obtain knowledge on whether horses cope well if they are let out in the cold or are better off if provided with a rug or placed in the stable to dry up. Some horse owners suggest that rugs made of fleece have the ability to dry up wet horses, even when it rains, but confirmation of this requires further investigation.

2.7. Knowledge and attitudes

In a review on the relationship between owner attributes and the welfare of recreational horses, Hemsworth et al. (2015) list a range of underlying factors, including the level of knowledge on husbandry and management practices, which may result in mismanagement of horses. A large number of studies show the sequential relationship between human attitudes (including knowledge) and animal welfare in various species of livestock (Hemsworth and Coleman, 2010). Hemsworth et al. (2015) suggest that this also may be the case for horse owners, although little research is done so far. A very important task for researchers is to disseminate scientific knowledge and especially the practical implications of research to the horse community.

3. Conclusions

Horses in a Nordic climate will experience differing thermal challenges during the year and often within the same day. Several studies indicate that not only low temperatures, but the combination of cold rain and wind, is a very demanding weather type. The management and care for horses should be based on the principles of thermoregulation and mechanisms of heat loss and gain. Management of horses should aim to help horses to cope with changing weather conditions by providing them a freedom of choice. This should include space for movement, protection from sunshine, precipitation and wind, dry bedding, and appropriate feeding management. When horses are kept in a group, social dynamics must be considered, so that all individuals get sufficient access to the resources. A rug is a useful supplement for horses in inclement weather. However, too many horse owners clip their horses, which often necessitates the use of rugs on a regular basis. More knowledge is needed on how to manage sport horses in winter.

Our hope is that a deeper understanding of thermoregulation mechanisms in horses will lead to better management and improved horse welfare.

Declaration of Competing Interest

None.

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References

- Autio, E., 2008. Loose Housing of Horses in Cold Climate: Effects on Behaviour, Nutrition, Growth and Cold Resistance. PhD Thesis. Department of Biosciences at the University of Kuopio, Finland.
- Autio, E., Heiskanen, M.L., 2005. Foal behaviour in a loose housing/paddock environment during winter. *Appl. Anim. Behav. Sci.* 91, 277–288.
- Autio, E., Heiskanen, M.L., Mononen, J., 2007. Thermographic evaluation of the lower critical temperature in weanling horses. *J. Appl. Anim. Welf. Sci.* 10, 207–216.
- Bocian, K., Strzelec, K., Janczarek, I., Jablęcki, Z., Kolstrung, R., 2017. Length of winter coat in horses depending on husbandry conditions. *Anim. Sci. J.* 88, 339–346.
- Bøe, K.E., Mejdell, C.M., Jørgensen, G.H.M., 2015. Hvordan holdes hester i Norge? (How horses are kept in Norway). *Norsk veterinærtidsskrift* 127, 291–297.
- Broom, D., 1998. Welfare, stress and the evolution of feelings. *Stress and Behaviour. Advances in the Study of Behaviour* Vol. 27. pp. 371–403.
- Christensen, J.W., Olczak, K., Palme, R., Thodberg, K., 2018. The effect of shelter design on shelter use by Icelandic horses in the winter period. *J. Vet. Behav.* 27, 47–54.
- Claudi, K., Hoy, S., 2013. Measurements of distances moved by horses in an active stable by GPS. *Tieraerztliche Umschau* 68, 486–490.
- Clayton, H.M., Kasier, L.J., Nauwelaerts, S., 2010. Pressure on the horse's withers with three styles of blanket. *Vet. J.* 184, 52–55.
- Cymbaluk, N.F., 1990. Cold housing effects on growth and nutrient demand of young horses. *J. Anim. Sci.* 68, 3152–3162.
- Cymbaluk, N., Christison, G.I., 1989. Effect of diet and climate on growing horses. *J. Anim. Sci.* 67, 48–59.
- FOR-2005-06-02-505. Norwegian Ministry of Agriculture and Food. Directive for horse welfare.
- Guthrie, A.J., Lund, R.J., 1998. Thermoregulation. Base mechanisms and hyperthermia. *Vet. Clin. North Am. Equine Pract.* 14, 45–59.
- Hammer, C., Gunkelmann, M., 2020. Effects of different blanket weights on surface temperature of horses in cold climates. *J. Equine Vet. Sci.* 85, 102848.
- Hartmann, E., Bøe, K.E., Christensen, J.W., Hyyppä, S., Janssen, H., Jørgensen, G., Ladewig, J., Mejdell, C.M., Norling, Y., Rundgren, M., Särkijärvi, S., Søndergaard, E., Keeling, L.J., 2015a. A Nordic survey of management practices and owners' attitudes towards keeping horses in groups. *J. Anim. Sci.* 93, 4564–4574.
- Hartmann, E., Hopkins, R.J., Blomgren, E., Ventorp, M., von Bromssen, C., Dahlborn, K., 2015b. Daytime shelter use of individually kept horses during Swedish summer. *J. Anim. Sci.* 93, 802–810.
- Hartmann, E., Bøe, K.E., Jørgensen, G.H.M., Mejdell, C.M., Dahlborn, K., 2017. Management of horses with focus on blanketing and clipping practices reported by members of the Swedish and Norwegian equestrian community. *J. Anim. Sci.* 95, 1104–1117.
- Heleski, C.R., Murtazashvili, I., 2010. Daytime shelter-seeking behavior in domestic horses. *J. Vet. Behav. Clin. Appl. Res.* 5, 276–282.
- Hemsworth, P.H., Coleman, G.J., 2010. Human-livestock Interactions: The Stockperson and the Productivity and Welfare of Intensively Farmed Animals, 2nd edition. CAB International, Oxford.
- Hemsworth, L.M., Jongman, E., Coleman, G.J., 2015. Recreational horse welfare: the relationships between recreational horse owner attributes and recreational horse welfare. *Appl. Anim. Behav. Sci.* 165, 1–16.
- Hillman, P.E., 2009. Thermoregulatory physiology. Chapter 2. In: DeShazer, James A. (Ed.), *Livestock Energetics and Thermal Environmental Management*. The American Society of Agricultural and Biological Engineers, pp. 23–48 ISBN 1-892769-74-3.
- Hodgson, D.R., Davis, R.E., McConaghy, F.F., 1994. Thermoregulation in the horse in response to exercise. *Br. Vet. J.* 150, 219–235.
- Holcomb, K.E., Tucker, C.B., Stull, C.L., 2013. Physiological, behaviour and serological responses of horses to shaded or unshaded pens in a hot, sunny environment. *J. Anim. Sci.* 91, 5926–5936.
- Ingólfssdóttir, H.B., Sigurdjónsdóttir, H., 2008. The benefits of high rank in the winter time – a study of the Icelandic horse. *Appl. Anim. Behav. Sci.* 114 (3–4), 485–491.
- Ireland, J.L., Clegg, P.D., McGowan, C.M., McKane, S.A., Pinchbeck, G.L., 2011. A cross-sectional study of geriatric horses in the United Kingdom. Part 2: health care and disease. *Equine Vet. J.* 43, 37–44.
- Jørgensen, G.H.M., Aanensen, L., Mejdell, C.M., Bøe, K.E., 2016. Preference for shelter and additional heat when exposed to Nordic winter conditions. *Equine Vet. J.* 48 (6), 720–726.
- Jørgensen, G.H.M., Mejdell, C.M., Bøe, K.E., 2019. The effect of blankets on horse behaviour and preference for shelter in Nordic winter conditions. *Appl. Anim. Behav. Sci.* 218, 104822.
- Jørgensen, G.H.M., Mejdell, C.M., Bøe, K.E., 2020. Effects of hair coat characteristics on radiant surface temperature in horses. *J. Therm. Biol.* 87, 8.
- Kristula, M.A., McDonnell, S.M., 1994. Drinking water temperature affects consumption of water during cold weather in ponies. *Appl. Anim. Behav. Sci.* 41, 155–160.
- Langlois, B., 1994. Inter-breed variation in the horse with regard to cold adaptation: a review. *Livest. Prod. Sci.* 40, 1–7.
- MacCormack, J.A.D., Bruce, J.M., 1991. The horse in winter – shelter and feeding. *Farm Building Progress* 105, 10–13.
- McArthur, A.J., 1991. Metabolism of homeotherms in the cold and estimation of thermal insulation. *J. Therm. Biol.* 16, 149–155.
- McArthur, A.J., Ousey, J.C., 1996. The effect of moisture on the thermal insulation provided by the coat of a Thoroughbred foal. *J. Therm. Biol.* 21, 43–48.
- McBride, G.E., Christopherson, R.J., Sauer, W., 1985. Metabolic rate and plasma thyroid hormone concentration of mature horses in response to changes in ambient temperature. *Can. J. Anim. Sci.* 65, 375–382.
- McGowan, T.W., Pinchbeck, G., Phillips, C.J.C., Perkins, N., Hodgson, D.R., McGowan, C.M., 2010. A survey of aged horses in Queensland, Australia. Part 2: clinical signs and owners' perceptions of health and welfare. *Aust. Vet. J.* 88, 465–471.
- McKeever, K.H., Eaton, T.L., Geiser, S., Kearns, C.F., Lehnhard, R.A., 2010. Age related decrease in thermoregulation and cardiovascular function in horses. *Equine Vet. J.* 42, 220–227.
- Mejdell, C., Bøe, K.E., 2004. Rimelige driftsopplegg for hest – utedrift. (Keeping horses outdoors under Nordic winter conditions). *Planteforsk. Report series Grønn kunnskap* 8 (5), 32.
- Mejdell, C., Bøe, K.E., 2005. Responses to climatic variables of horses housed outdoors under Nordic winter conditions. *Can. J. Anim. Sci.* 85, 301–308.
- Mejdell, C.M., Buvik, T., Jørgensen, G.H.M., Bøe, K.E., 2016. Horses can learn to use symbols to communicate their preferences. *Appl. Anim. Behav. Sci.* 184, 66–83.
- Mejdell, C.M., Jørgensen, G.H.M., Buvik, T., Torp, T., Bøe, K.E., 2019. The effect of weather conditions on the preference in horses for wearing blankets. *Appl. Anim. Behav. Sci.* 212, 52–57.
- Michanek, P., Ventorp, M., 1996. Time spent in shelter in relation to weather by two free-ranging thoroughbred yearlings during winter. *Appl. Anim. Behav. Sci.* 49, 104.
- Morgan, K., 1997a. Thermal insulation of peripheral tissue and coat in sport horses. *J. Therm. Biol.* 22, 169–175.
- Morgan, K., 1997b. Effects of short-term changes in ambient air temperature or altered insulation in horses. *J. Therm. Biol.* 22, 187–194.
- Morgan, K., 1998. Thermoneutral zone and critical temperatures of horses. *J. Therm. Biol.* 23, 59–61.
- Morgan, K., Funkquist, P., Nyman, G., 2002. The effect of coat clipping on thermoregulation during intense exercise in trotters. *Equine Vet. J.* 34 (Suppl. 34), 564–567.
- NCCS Report, 2015. Klima i Norge 2100. Kunnskapsgrunnlag for klimatilpassing oppdatert 201. Report no. 2, 2015. (Accessed 20 May 2020. https://cms.met.no/site/2/klimaservicesenteret/rapporter-og-publikasjoner/_attachment/6616?_ts=14ff3d4eeb8).
- Ousey, J.C., 1997. Thermoregulation and the energy requirements of the newborn foal, with reference to prematurity. *Equine Vet. J. Suppl.* 24, 104–108.
- Padalino, B., Loy, J., Hawson, L., Randle, H., 2019. Effects of a light-colored cotton rug use on horse thermoregulation and behavior indicators of stress. *J. Vet. Behav. Clin. Appl. Res.* 29, 134–139.
- Sjaastad, Ø.V., Sand, O., Hove, K., 2016. Chapter 18 regulation of body temperature. *Physiology of Domestic Animals*, 3rd edition. Scandinavian Veterinary Press, Oslo, pp. 767–794 and Aging in animals, p 891.
- Snoeks, M.G., Moons, C.P.H., Ödberg, F.O., Aviron, M., Geers, R., 2015. Behavior of horses on pasture in relation to weather and shelter – a field study in a temperate climate. *J. Vet. Behav. Clin. Appl. Res.* 10, 561–568.
- Steinhoff-Wagner, J., 2018. Coat clipping of horses: a survey. *J. Appl. Anim. Welf. Sci.* 22, 1–17.
- Sundquist, M., Broström, H., 2007. En grupp hästers nyttjande av ligghall. (The use of a built weather protection for a group of horses). *Svensk Veterinär Tidning* 7, 21–24.
- Wallsten, H., Olsson, K., Dahlborn, K., 2012. Temperature regulation in horses during exercise and recovery in a cool environment. *Acta Veterinaria Scandinavica*. 54, 42.
- Watt, C., Mitchell, S., Salewski, V., 2010. Bergmann's rule; a concept cluster? *Oikos* 119, 89–100.