# Effects of hair coat characteristics on radiant surface temperature in horses

Grete Helen Meisfjord Jørgensen[a*], Cecilie Marie Mejdell[b] and Knut Egil Bøe[c]

a. NIBIO, Norwegian Institute of Bioeconomy Research, P.O. Box 34, N-8860 Tjøtta, Norway.
b. Norwegian Veterinary Institute, Section for Animal Health and Welfare, P.O. Box 750 Sentrum, 0106 Oslo, Norway.
c. Norwegian University of Life Sciences, Department of Animal and Aquacultural Sciences, P.O. Box 5003, 1432 Ås, Norway.

*Corresponding author at: NIBIO, Norwegian Institute of Bioeconomy Research, P.O. Box 34, N-8860 Tjøtta, Norway.

E-mail address: grete.jorgensen@nibio.no (G. Jørgensen).

Keywords: thermoregulation; equine; sensible heat loss; behaviour; body condition; hoof; environment.

**Abstract**

Horse owners may lack knowledge on natural thermoregulation mechanisms in horses. Horses are managed intensively; usually stabled at night and turned out during the day, some are clipped and many wear a blanket, practices which reduce the horse' ability to regulate the heat dissipation. The aim of this study was to investigate the relation between hair coat characteristics, body condition and infrared surface temperatures from different body parts of horses. Under standard conditions, body surface temperature of 21 adult horses were investigated using infrared thermography. From several readings on the same body part, a mean temperature was calculated for each body part per horse. Detailed information on horse breed, age, management and body condition was collected. Hair coat samples were also taken for analyses. A mixed statistical model was applied. Warmblood horse types (WB) had lower hair coat sample weights and shorter hair length than coldblood horse types (CB). The highest radiant surface temperatures were found at the chest 22.5 ± 0.9 °C and shoulders 20.4 ± 1.1 °C and WB horses had significantly higher surface temperatures than CB horses on the rump ($P<0.05$). Horses with a higher hair coat sample weight had a lower surface temperature ($P<0.001$) and hind hooves with iron shoes had a significant lower surface temperature than unshod hind hooves ($P=0.03$). In conclusion, individual assessment of radiant surface temperature using infrared thermography might be a promising tool to give horse owners objective management advice, based on the individual horse's actual needs at the time.

## 1. Introduction

Increasing the knowledge of owners is crucial for making good decisions for horse day to day management. In areas with unstable winter conditions this is especially important, as weather may change from wet and windy to sunny conditions in short time periods. A survey among horse owners in Sweden and Norway showed that the use of blankets is common practice and owners have little knowledge on how the natural thermoregulation of an animal works (Bøe et al., 2014; Hartmann et al., 2017). Furthermore, the survey showed that hair coat clipping was common, also in winter, and that the majority of the warmblood riding horses were clipped. Finding an objective and consistent method for assessing the individuals need for extra protection during turnout is thus needed.

When the environment is cooler than an animal's surface, temperature gradients potentiate sensible (non-evaporative) heat loss from the animal (Curtis, 1983). Hence, the sensible heat loss will increase with decreasing environmental temperature. In horses, Morgan et al. (1997) used a climatic chamber and found that the non-evaporative heat loss increased by 2.78 $W/m^2$ for every 1 ºC decrease. The size and shape of the horse further adds to the equation, as the heat dissipation is dependent on the relation of the animal's volume to its surface (review: Watt et al., 2010). This explains why large body size is advantageous in cold climate, as the ratio between: a) surface over which heat can be dissipated and b) body mass that can produce and retain heat, is lower in large animals compared to in small animals (Bligh, 1998). In addition to this, each horse breed has adapted to the climate and environment in which it has evolved (Langlois, 1994). For example, a slender body conformation (e.g. Arabian horse) gives a larger body surface to body mass ratio, compared to a more compact horse (e.g. Fjord horse).

Sport horses often are shod with shoes made of iron, which is a good conductor. Thus it is expected that the conduction of heat between the hooves and the ground is larger in shod hooves. Heat loss due to conduction is expected to lead to a reduced hoof surface temperature, at least close to the shoe and nails, when a shod horse stands on a cool, non-insulated floor.

Sport horses of breeds evolved in hot climate, live and perform as top athletes all over the world. They will, to some extent, grow winter coats that increase their external insulation when moved to a cooler climate (Curtis, 1983; Blaxter, 1989), but hair coat characteristics and thus the thermal insulance of the coat may vary considerably both between and within breeds (Morgan, 1997 a). The total insulation in an animal involve muscle, fat, skin and hair coat, while physiological responses to cold also involve piloerection and vasocontriction (Blaxter, 1989; Cymbaluk, 1994). Heat loss estimated by surface temperatures related to body condition scores has not been studied in horses previously.

Already in 1978, L.E. Mount proposed using thermography to measure surface temperatures in addition to body shape and size, in order to assess the sensible heat loss from an animal in a given environment. Since then, infrared thermography (IRT) has been used on animals, mainly as a diagnostic tool to discover inflammation, illness or sources of lameness (overview: McManus, 2016). The method has been validated for use on the horse’s body and the relative consistency in thermal pattern generated over a one-week period is promising (Tunley and Henson, 2004). Autio et al. (2006) also used the technique at low ambient temperatures and found that heat loss from the trunk and neck was higher in warmblood and light type horses than in coldblood horses. In Autio’s paper, the coldblood horses had a significantly higher hair weight than warmblood horses. The study could however not conclude whether this was due to the hair coat characteristics *per se* or because of general differences between the horse breed types (subcutaneous fat, muscle and body mass to surface ratio). In primitive horse breeds, Stachurska et al. (2015) found that the proportion of the body covered with short hair increased in April and May and decreased in September and October, and that there was a significant correlation with mean air temperature. In Icelandic horses, Mejdell and Bøe (2005) found the maximum average coat length in December (46.3 mm), shedding started in March, and minimum coat length was identified in June (5.0 mm).

Older horses have increased susceptibility for overheating during exercise, due to age related alterations in physiological mechanisms important for thermoregulation (McKeever et al., 2010). Knowing that also hair coat quality (Brosnan and Paradis, 2003 a,b; Innerå, et al., 2013; McGowan et al., 2010) and the distribution of adipose tissue may change in elderly horses (McGowan, 2010), age is another individual factor to be considered when deciding how to best manage a horse in changing weather.

The aim of this experiment was to investigate the relation between hair coat characteristics, body condition and radiant surface temperatures from different body parts of horses.

We hypothesized that:

- H1: horses of warmblood breed types have lower hair coat sample weights than horses of coldblood breed types.
- H2: horses with lower hair coat sample weights have a higher overall surface temperature, indicating a larger sensible heat loss from their bodies.
- H3: horses with high body condition scores have a lower sensible heat loss from their bodies, compared to horses with low body condition scores.
- H4: hooves with iron shoes have a lower surface temperature than unshod hooves, when measured in the same cool environment.

## 2. Materials and methods

The experiment was conducted in February and November 2014 in Sandnessjøen, located at the coast in the northern part of Norway (65°N), just south of the Arctic Circle. Average annual temperature in the region is 6.7 °C (range -14 to 25 °C).

**2.1 Horses and management**

The study included a total of 21 privately owned, healthy riding horses. Most of the horses were tested both in February and November, yielding data from 16 horses in February and 15 horses in November (table 1). In the February sample, two horses were clipped (clipped in November) while no horses were clipped when sampled in November. A total of 13 horses in February and 8 horses in November had shoes. The rest were barefoot at the time (table 1).

(*Table 1 here*)

Horse body weight and body condition scores were recorded by a trained observer. Weight was estimated using a standard weight estimation band (Hööks weightband) and varied from 234 kg to 645 kg (see table 1). Body condition (points 1=emaciated to 9=obese) was scored on six different body parts making an overall mean score for each horse (Henneke et al., 1983). The total mean body condition score was 5.1 (table 1). We had no skinny (score <3) or very fat horses (>7) in the study. We created a new description of BC status by grouping the mean of scores from the six different areas of the body into five categories as follows: 1 low= < 3.5; 2 medium low= 3.6 – 4.5; 3 medium= 4.6 – 5.5; 4 medium high= 5.6 – 6.5 and 5 high= > 6.5.

Horses were stabled in individual boxes during night and turned out in individual or group paddocks during the day. They were fed three times a day with individually adjusted rations of hay and concentrates. All horses were in light training, being exercised 3 to 6 days per week according to their owners training plans. Horses were worked in dressage, show jumping, carriage driving or lunging disciplines. They were all used to wearing blankets and wore blankets during outdoor turnout in wet and windy weather.

**2.2 Hair coat characteristics**

Hair coat samples were collected once per horse in February and once per horse in November. At test days the horses were taken from their indoor boxes in the morning (before turnout) and led into a tie-stall (within the same stable). The indoor temperature was 10 °C and this was kept stable throughout the two test periods and sampling days. Hair coat samples were collected from a 3 x 3 cm large area above the gluteal muscle using a small electric clipper. Two of the 16 horses in the February dataset had been clipped in November, and hence the length of the hair was not possible to measure. The hair sample from each horse was put into a permeable teabag, weighed and dried in a laboratory drying cabinet for two days at 50 °C. After drying, the samples were again weighed on an electronic scale (Mettler Toledo, ME104; d=0,0001g). For further analysis it was expedient to divide the data on hair coat characteristics into four categories according to the weight of the sample: clipped (0.0-0.3 g, n=3), low (0.4 – 1.0 g, n=9), medium (1.1 – 2.0 g, n=11) and high (> 2.0 g, n=8). In addition, the length of most hairs and the length of the longest hairs in each hair coat sample were measured using mm paper and careful visual inspection.

**Radiant surface temperatures at different body parts**

At the same days as the hair coat sample was collected, thermal imaging of head, neck, shoulder, back, loin and hooves were taken on both sides of all horses using an infrared thermal imaging camera (Flir i50, FLIR® Systems AB, Danderyd Sweden. Manufactured

September 2008. Manual focus. Wavelength 635 nm, max output power 1 mW. Temperature range -20 – 350 ºC, 140 x 140 pixels image resolution. 0.1 ºC thermal sensitivity at 25 ºC) (figure 1). Images were taken with approximately 30 cm distance between the camera and the horse. The horses were allowed time to habituate to the camera and thermal images were collected before the hair coat samples were taken, in order not to confound with increased body temperature caused by stress. Temperature in the stable was kept at 10 ºC and images were taken between 9 a.m. and 3 p.m. Infrared images of the naked area from which the hair coat sample was taken, were collected approximately five minutes after the area was clipped.

*(Figure 1 here)*

All images were saved by date and time labels on to a memory card and the data was later downloaded and organized in a database. The images contained temperatures from the central focal point and a temperature scale illustrated by colours (figure 2). A visual inspection of all images was performed, and some images were not included in the dataset because they had reduced quality.

(*Figure 2 here*)

The temperature that could be read from each IR image was recorded and organized under the correct horse, date and body part in a spreadsheet. Average temperatures were calculated using temperatures from multiple images taken from the same horse and the same body area at the same time. Temperatures from left and right versions of the same body part was later merged into one mean temperature for that body part.

### 2.3 Data analysis

The effects of breed type on surface temperature from each body part was tested using a mixed model ANOVA with the following class variables: Horse (1-21), Breed type (WB/CB), Body condition score category (1-5), Time of year (February/November) and Hair coat category (0-3). The interaction between Haircoat sample weights and BCS was added to the model, in order to test the effect on surface temperature on the side body. Horse nested within Breed type (WB/CB) was specified as a random effect and denominator degrees of freedom were computed using the Satterthwaite's approximation. The mixed model thus accounts for repeated measures from the same individual horse. Differences between means were tested using a Tukey-Kramer test for least square means within class variables.

The effect of shoeing status (shod/unshod) on hoof temperatures was investigated using a similar mixed model ANOVA with Horse (1-21), Breed type (WB/CB) and Time of year (February/November). Horse nested within Breed type (warm/cold) was specified as a random effect.

The correlations between Breed type (WB/CB) and actual hair coat sample weights and mean whole-body condition score points  was investigated using a Spearman correlation test (Proc Corr Spearman command). All analyses were performed using SAS software, Version 9.4 of the SAS system for Windows version 6.2.92002 (Statistical Analysis System Institute Inc, Cary, NC, 2011)

## 3. Results

### 3.1 Hair coat characteristics

Even if the weight of the hair coat samples were significantly higher in November (mean ± STD; 2.1 ± 1.2 g) than in February (1.2 ± 1.0 g), there was no effect of time of year on the mean length of the hairs and longest hairs (table 2). WB horses (mean ± SE; 1.1 ± 0.5 g), had lower hair coat sample weights than CB horses (2.3 ± 1.4 g). Also the mean length of the hair and length of longest hair was significantly longer for CB than for WB horses (table 2). Especially among CB horses the individual variation was large.

(*Table 2 here*)

There was a significant correlation between hair coat sample weights and body condition scores (Spearmans $\rho$= 0.4; $P$=0.008; figure 3), showing that horses with a low BCS also had lower hair coat sample weights.

*(Figure 3 here)*

**3.2 Radiant surface temperatures**

The mean surface temperatures did not change significantly from February to November, for any of the body parts investigated in this study (e.g. neck: February 19.9 ± 3.1 vs. November 19.2 ± 3.3; $F_{1,20}$=1.6; $P$=0.22). The highest radiant surface temperatures were found at the chest and shoulders, whereas body parts with more hair cover, like the side and loin, had the lowest radiant surface temperatures (table 3). In general, WB-horses had higher radiant surface temperatures than CB-horses, but differences were significant only for the side body and rump (table 3). The lowest temperature was found on the hooves, and there was no effect of breed on this measure.

There was a mean temperature difference of nearly 8 °C between the naked area where the hair coat sample had been taken and the area right next to it, still with a complete hair cover (table 3). There was no significant difference in radiant surface temperature at the naked skin area between CB and WB horses (table 3).

Horses with a higher hair coat sample weight also had a lower surface temperature (figure 4).

(*Figure 4 here*)

The surface temperatures measured from the neck, chest, side body, back, loin and rump decreased as the hair coat sample weights increased (table 4).

(*Table 4 here*)

Horses with a lower body condition score had a higher surface temperature on their back, suggesting that they lost more heat to their surroundings than horses with high body condition scores (Spearmans $\rho$=-0.53; $P$=0.026). However, BCS ranged from 3-7, so there were no skinny or fat horses in the study.

*(Figure 5 here)*

Horses with iron shoes had a significantly lower surface temperature on their hind hooves (14.3 ± 1.4 °C) compared to horses without shoes (20.0 ± 2.0 °C) ($F_{2,4}$=9.4; $P$=0.031). The surface temperature of front hooves showed the same trend, but the difference was not significant (shod horses: 14.7 ± 4.4 °C vs. unshod horses: 20.1 ± 1.9 °C; $F_{2,4}$= 5.0; $P$=0.081) (figure 6).

*(Figure 6 here)*

# 4. Discussion

## 4.1 Hair coat characteristics

As we hypothesized (H1), the WB horses had lower hair coat sample weights than CB horses. It is also interesting to notice that variation in weight of the hair samples were much higher in CB than in WB types. The hair coat samples were collected in November and in February, just before spring shedding, hence when the hair coat was assumed to be at the thickest. Still, the weight of the hair coat samples were significantly higher in November than in February. Our finding is supported by Osthaus et al (2018) who found that the weight of the hair samples in horses were highest in December and significantly lower in March. Also earlier results from Norwegian conditions correspond well with this (Mejdell and Bøe, 2005).

The mean hair length was found to be 2.4 cm, regardless of horse breed type or sampling month. This correspond well to the findings of Bocian et al. (2017). The mean hair length and length of the longest hairs in the present study were significantly longer in CB than in WB breed types. Our findings concur with previous studies (e.g. Langlois 1994).

Morgan (1997 b) found that a dry winter coat had a thermal insulance of 0.123 m2 K W-1 in a cold and calm environment. Horses with a thick hair coat have been observed to spend more time outdoors during winter, compared to horses with a thinner hair coat (Jørgensen et al., 2016). This insulance might however vary considerably with differences in the hair coat characteristics. The chest and shoulders are areas vulnerable to chafing and hair coat damage due to excessive use of rugs and blankets, further reducing the quality and cover of the hair coat. In the present experiment, only two horses were noted to have some hair coat damage on the chest, from wearing blankets.

**4.2 Radiant surface temperatures**

As hypothesized (H2), our study found that horses with a thinner hair coat had a higher overall surface temperature. This indicates a larger sensible heat loss and supports the idea that insulation properties of a thick (heavy) hair coat exceeds a thin (light) hair coat. Measuring this in day-to-day management and knowing when the horse might need extra protection is however challenging. Horses kept outside or in non-insulated buildings, will be exposed to a range of climatic conditions. In contrast to horse owners' assumptions, Mejdell et al. (2019) showed that horses generally preferred to stay without a blanket during turnout at moderately cold and mild temperatures without precipitation and wind. Furthermore, acclimatized Icelandic horses have been kept outside in winter at temperatures of -30°C, without health problems, behavioural signs of discomfort or increased secretion of thyroid hormones (Mejdell and Bøe, 2005).

The use of non-invasive thermography has gained value in several areas of application (Dèsirè et al., 2002; Boissy et al., 2007), from studying lameness in cows (Alsaaod et al., 2014) to emotions in chickens (Moe et al., 2017). We also suggest the technique being applied for assessing individual horses need for extra protection, in addition to behavioural signs of thermal discomfort. It is however important that the operator is trained and knows how to use the camera and interpret the images. A standard distance between the horse surface and the camera should be maintained for all images taken, and horses should be allowed time to habituate to the procedure.

### 4.3 Individual differences

For several body regions, we did not find any significant breed effect on radiant surface temperature (table 3). A series of Polish studies found that transepidermal water loss from horses varied between different body regions (Szczepanik et al., 2012; 2013) and found only three body regions where water loss did not differ between horse breeds (Szczepanik et al., 2016). Our results indicate that individual differences in radiant surface temperature were larger than differences between breed types. Another study by Szczepanik et al. (2018) concur with this finding; large variations in transepidermal water loss were found in unclipped body regions of horses of the same breed. We acknowledge that water loss and radiant surface temperature is not the same but find it very interesting that the individual differences in hair coat characteristics show similar trends. The length of hair in healthy horses is influenced by season (number of daylight hours) and temperature. Also, genotype, quality and quantity of feed and human management system (blanketing, stabling) will affect the hair coat properties of individual horses (Cymbaluk and Christison, 1989; Bocian, et al., 2017).

A correlation between lower body condition scores and higher surface temperature measured on the horses' back was found. This supports the hypothesis that subcutaneous fat tissues have insulating properties that affect surface temperatures in horses (H3), and the fact that fat tissue is three times more insulating than other tissues have been demonstrated earlier (e.g. Guyton, 1991). We could however not find any difference between breed types in surface temperature on the naked hair coat sample area. So, the subcutaneous fat tissues (BCS) may be another factor with large individual differences, rather than being mostly breed dependent.

We also found a correlation between BCS and hair coat sample weights (figure 3). This might be because well fed horses also grow a healthy hair coat. On the other hand, we found that WB horses grew lighter hair coats than CB horses. A statistical test to find interaction effects between haircoat sample weights and individual BCS did however not uncover a significant effect. The thermoneutral zone of an animal can be defined as the range of temperature at which an animal maintains body temperature in the short term, with little to no additional energy expenditure (Mount, 1973). Our results show that hair coat thickness and body condition may be important factors to consider in thermoregulation research as well as modelling (Morgan, 1998). Further studies on the insulation effect of subcutaneous fat should therefore be made.

### 4.4 Shod and unshod hooves

As hypothesized (H4), we found that shod hooves had lower surface temperature than unshod hooves. To our knowledge, no similar results have been reported earlier. It is well known that iron is a good conductor material, but our measurements were done on the front middle of the hoof and not close to the shoe and nails. Outdoors, in temperatures well below the freezing point, heat loss by conduction via shod hooves, might be a major factor to consider.

## 5. Conclusion

We found an effect of breed type on hair coat length and weight, but also BCS affects hair coat quality. This affects radiant surface temperature and therefore also the gradient for sensible heat loss.  Horses with iron shoes had a significantly lower radiant surface temperature on their hind hooves, compared to horses without shoes. This is important knowledge for owners keeping horses outdoors in cold climate. It is difficult to know when to provide extra protection for your horse. We recommend that for every individual horse, its hair coat characteristics, body condition and age is evaluated together with housing facilities, feeding and weather when deciding the need for blankets or rugs.

**Authors' declaration of interests**

No competing interests have been declared.

**Ethical animal research**

The experiment involved no invasive treatments of horses. The study was reviewed and approved by the local ethics committees at the  Norwegian Institute of Bioeconomy Research NIBIO (Dr. Scient. Svein Morten Eilertsen). Owners gave informed consent for their horses' inclusion in the study.

**Source of funding**

Funded via Stiftelsen Hästforskning, a joint Swedish and Norwegian horse research fund, administered through the Norwegian Research Council (project no. 218961).

**Acknowledgements**

The authors would like to thank Torfinn Torp for statistical advice. The stable owner Lillian Jensen and all horse owners are acknowledged for providing access to their horses and facilities.

**Authorship**

G.H.M. Jørgensen contributed to study design, data collection and study execution, data analysis and interpretation. C.M. Mejdell and K.E. Bøe contributed to study design, data interpretation and all authors contributed to preparation of the manuscript.

**Bibliography**

| | |
|---|---|
|  | Dr Grete Helen Meisfjord Jørgensen – is a researcher at the Norwegian Institute of Bioeconomy research NIBIO, Division of food and society, Department of feed and livestock. She gained her Ph.D. in Ethology at the Norwegian University of Life Sciences in 2010. Her Masters degree in Animal Science was completed at the same University in 2005. She has worked with a range of animal species, focusing on animal behaviour, housing, animal environment and welfare issues. |
|  | Dr. Cecilie M. Mejdell – is a veterinarian and senior researcher at the Norwegian Veterinary Institute in Oslo, Section for Animal Health and Welfare. Her main responsibility is research and advisory work regarding animal welfare. She also work with horse health and thermoregulation in horses. She is acknowledged as a European Veterinary Expert (Diplomate) in Animal Welfare Science, Ethics and Law. |
|  | Professor Knut Egil Bøe – is a researcher and lecturer at the Norwegian University of Life Sciences (NMBU). He gained his PhD at NMBU on behaviour and housing of sheep and the dr. agric. degree on weaning in pigs. He has worked on housing and behaviour of different farm animal species and a main focus has been cold housing and thermoregulatory behaviour. |

## References

Alsaaod, M., Syring, C., Dietrich, J., Doherr, M.G., Gukan, T., Steiner, A., 2014. A field trial of infrared thermography as a non-invasive diagnostic tool for early detection of digital dermatitis in dairy cows. The Vet. J. 199, 281-285. https://doi.org/10.1016/j.tvjl.2013.11.028.

Autio, E., Neste, R., Airaksinen, S., Heiskanen, M.-L., 2006. Measuring the heat loss in horses in different seasons by infrared thermography. J. Appl. Anim. Welf. Sci. 9, 211-221. https://doi.org/10.1207/s15327604jaws0903_3.

Bligh, J., 1998. Mammalian homeothermy: an integrative thesis. J. Therm. Biol. 23, 143-258.

Bocian, K., Strzelec, K., Janczarek, I., Jablecki, Z., Kolstrung, R., 2017. Length of winter coat in horses depending on husbandry conditions. Anim. Sci. J. 88, 339-346. https://doi.org/10.1111/asj.12587.

Boissy, A., Manteuffel, G., Jensen, M.B., Moe R.O., Spruijt, B., Keeling, L., Winckler, L., Forkman, B., Dimitrov, I., Langbein, J., Bakken, M., Veissier, I., Aubert, A., 2007. Assessment of positive emotions in animals to improve their welfare. Physiol. Behav. 92, 375-397. https://doi.org/10.1016/j.physbeh.2007.02.003.

Blaxter, K., 1989. Energy metabolism in animals and man. First ed. Cambridge University Press, New York, USA.

Brosnan, M.M., Paradis, M.R., 2003 a). Demographic and clinical characteristics of geriatric horses: 467 cases (1989-1999). J. Am. Vet. Med. Assoc. 223, 93-98. https://doi.org/10.2460/javma.2003.223.93.

Brosnan, M.M., Paradis, M.R., 2003 b). Assessment of clinical characteristics, management practices, and activities of geriatric horses. J. Am. Vet. Med. Assoc. 223, 99-103. https://doi.org/10.2460/javma.2003.223.99.

Bøe, K.E., Jørgensen, G.H.M., Mejdell, C.M., 2014. Use of blankets in horses in Norway. Results from a web-questionnaire in 2014. Original title: Bruk av dekken på hester I Norge. Resultater fra en nettbasert spørreundersøkelse i 2014. Norwegian Veterinary Institute Report nr 15 / 2014. 15 pages. ISSN: 1890-3290.

Curtis, S.E., 1983. Environmental management in animal agriculture. The Iowa University Press, 410 pp.

Cymbaluk, N.F., Christison, G.I., 1989. Effects of diet and climate on growing horses. J. Anim. Sci. 67, 48-59. https://doi.org/10.2527/jas1989.67148x.

Cymbaluk, N.F., 1994. Thermoregulation of horses in cold, winter weather: a review. Livest. Prod. Sci. 40, 65-71. https://doi.org/10.1016/0301-6226(94)90266-6.

Désiré, L., Boissy, A., Veissier, I., 2002. Emotions in farm animals: a new approach to animal welfare in applied ethology. Behav. Proc. 60, 165 – 180. http://dx.doi.org/10.1016/S0376-6357(02)00081-5

Guyton, A.C., 1991. Body temperature, temperature regulation and fever. In Textbook of Medical Physiology, 8th ed. Saunders Company, Philadelpia. Pp. 797-808.

Hartmann, E., Bøe, K.E., Jørgensen, G.H.M., Mejdell, C.M., Dahlborn, K., 2017. Management of horses with focus on clipping practices reported by members of the Swedish and Norwegian equestrian community. J. Anim. Sci. 95, 1104-1117. https://doi.org/10.2527/jas.2016.1146

Henneke, D.R., Potter, G.D., Kreider, J.L., Yeates, B.F., 1983. Relationship between condition score, physical measureements and body fat percentage in mares. Eq. Vet. J. 15, 371-372. https://doi.org/10.1111/j.2042-3306.1983.tb01826.x.

Innerå, M., Petersen, A.D., Desjardins, D.R., Steficekt, B.A., Rosser Jr., E.J., Schott, H.C., 2013. Comparison of hair follicle histology between horses with pituitary pars intermedia dysfunction and excessive hair growth and normal aged horses. Vet. Dermatol. 24, 212-218. https://doi.org/10.1111/j.1365-3164.2012.01080.x.

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, 720 – 726. https://doi.org/10.1111/evj.12522.

Langlois, B., 1994. Inter-breed variation in the horse with regard to cold adaptation; a review. Livest. Prod. Sci. 40, 1-7. https://doi.org/10.1016/0301-6226(94)90260-7.

McGowan, T.W., Pincbeck, 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. https://doi.org/10.1111/j.1751-0813.2010.00638.x.

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. Eq. Vet. J. 42, 220-227. https://doi.org/10.1111/j.2042-3306.2010.00259.x.

McManus, C., Tanure, C.B., Peripolli, V., Seixas, L., Fischer, V., Gabbi, A.M., Menegassi, S.R.O., Stumpf, M.T., Kolling, G.J., Dias, E., Batista, J., Costa Jr., G., 2016. Infrared thermography in animal production: An overview. Comp. Electron. Agric. 123, 10-16. https://doi.org/10.1016/j.compag.2016.01.027.

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. https://doi.org/10.1016/j.applanim.2019.02.001

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. https://doi.org/10.4141/A04-066.

Moe, R.O., Bohlin, J., Flø, A., Vasdal, G., Stubsjøen, S.M., 2017. Hot chicks, cold feet. Phys. Behav. 179, 42–48. https://doi.org/10.1016/j.physbeh.2017.05.025.

Morgan, K., Ehrlemark, A., Sällvik, K., 1997. Dissipation of heat from standing horses exposed to ambient temperatures between -3 ºC and 37 ºC. J. Therm. Biol. 22, 177-186. https://doi.org/10.1016/S0306-4565(97)00007-7.

Morgan, K., 1997 a). Effects of short-term changes in ambient air temperatures or altered insulation in horses. J. Therm. Biol. 22, 187-194.

Morgan, K., 1997 b). Thermal insulance of peripheral tissue and coat in sport horses. J. Therm. Biol., 22, 169-175. https://doi.org/10.1016/S0306-4565(97)00009-0.

Morgan, K., 1998. Thermoneutral zone and critical temperatures of horses. J. Therm. Biol. 23, 59-61. DOI: 10.1016/S0306-4565(97)00047-8

Mount, L.E., 1973. The concept of thermal neutrality. In J.L. Monteith and L.E. Mount (Eds.) Heat loss from animals and man (pp. 425-439). London, UK, Butterworths.

Mount, L.E., 1978. Heat transfer between animal and environment. Proc. Nutr. Soc. 37, 21-27. https://doi.org/10.1079/PNS19780005.

Osthaus, B., Proops, L., Long, S., Bell, N., Hayday, K., Burden, F., 2018. Hair coat properties of donkeys, mules and horses in a temperate climate. Eq. Vet. J. 50, 339-342. https://doi.org/10.1111/evj.12775.

Szczepanik, M.P., Wilkołek, P.M., Pluta, M., Adamek, Ł.R., Pluta, M., Golyński, M., Sitkowski, W., Taszkun, I., 2018. Influence of hair clipping on transepidermal water loss in horses: a pilot study. Pol. J. Vet. Sci. 21, 35-38. DOI 10.24425/119019

Szczepanik, M.P., Wilkołek, P.M., Pluta, M., Adamek, Ł.R., Pluta, M., Golyński, M., Sitkowski, W., Kalisz, G., Taszkun, I., Pomorski, Z.J., 2016. Influence of horse breed on transepidermal water loss. Pol. J. Vet. Sci. 19, 859-864. DOI 10.1515/pjvs-2016-0107

Szczepanik, M.P., Wilkołek, P.M., Pluta, M., Adamek, Ł.R., Golyński, M., Pomorski, Z.J., Sitkowski, W., 2013. The examination of biophysical skin parameters (transepidermal water loss, skin hydration and pH value) in different body regions in Polish ponies. Pol. J. Vet. Sci. 16, 741-747. DOI 10.2478/pjvs-2013-0105

Szczepanik, M.P., Wilkołek, P.M., Pluta, M., Adamek, Ł.R., Pomorski, Z.J.H., 2012. The examination of biophysical parameters of skin (transepidermal water loss, skin hydration and pH value) in different body regions of ponies. Pol. J. Vet. Science. 15, 553-559. DOI 10.2478/v10181-012-0081-8

Stachurska, A., Robovsky, J., Bocian, K., Janczarek, I., 2015. Changes of coat cover in primitive horses living on a reserve. J. Anim. Sci. 93, 1411-1417. https://doi.org/10.2527/jas.2014-8668.

Tunley, B.V., Henson, F.M.D., 2004. Reliability and repeatability of thermographic examination and the normal thermographic image of the thoracolumbarregion in the horse. Eq. Vet. J. 36, 306 – 312. https://doi.org/10.2746/0425164044890652.

Watt, C., Mitchell, S., Salewski, V., 2010. Bergmann's rule; a concept cluster? Oikos 119, 89-100. doi: 10.1111/j.1600-0706.2009.17959.x

## Tables

Table 1. Details on horses included in the study. Ten of the 21 horses were measured both in February and in November.

| **Number** | | **February n=16** | | **November n=15** | |
|---|---|---|---|---|---|
| **Mean (range)** | **Total** | **WB** | **CB** | **WB** | **CB** |
| Mares | 11 | 3 | 6 | 3 | 6 |
| Stallions/geldings | 10 | 6 | 1 | 5 | 1 |
| Age (yr) | 11.3<br>(1 - 21) | 11.7<br>(4 - 21) | 13.0<br>(4 – 7) | 10.4<br>(1 – 21) | 10.3<br>(2 - 20) |
| Body weight (kg) | 436.5<br>(269 - 645) | 507.6<br>(396 - 645) | 409.5<br>(269 – 596) | 490.8<br>(378 - 603) | 338.1<br>(269 - 420) |
| Body condition score | 5.1<br>(4.0 – 7.0) | 4.6<br>(4.0 – 5.1) | 5.8<br>(4.8 – 6.7) | 5.0<br>(4.3 – 6.3) | 6.0<br>(5.4 – 7.0) |

| **Shoeing status** | **Total** | **February n= 16** | **November n=15** |
|---|---|---|---|
| Shod | 13 horses /<br>21 samples | 13 horses | 8 horses |
| Unshod | 8 horses /<br>10 samples | 3 horses | 7 horses |

Table 2. Weight of hair coat samples and hair length of horses included in the study.

| Number | | February n=16 | | November n=15 | | Effect of breed | | Effect of time of year | |
|---|---|---|---|---|---|---|---|---|---|
| **Mean (range)** | Total | WB | CB | WB | CB | F-value | P-value | F-value | P-value |
| Weight of dried hair sample (g) | 1.6 (0 - 4.7) | 0.9 (0.1 - 1.9) | 1.7 (0 - 4.1) | 1.3 (0.8 - 1.9) | 3.0 (1.8 – 4.7) | $F_{1,19}$=10.7 | 0.0038 | $F_{1,12}$=6.26 | 0.027 |
| Mean length of hair (cm) | 2.4 (0.9 – 5.0) | 1.9 (0.9 – 3) | 2.5 (0.9 – 5.0) | 2.0 (1.0 – 3.0) | 3.3 (2.5 – 4.5) | $F_{1,16}$=7.8 | 0.012 | $F_{1,17}$=2.0 | ns |
| Length of longest hairs (cm) | 3.1 (1.5 – 7.0) | 2.6 (2.0 – 4.0) | 3.5 (0.9 – 6.0) | 2.2 (1.5 - 3.0) | 4.3 (3.0-7.0) | $F_{1,18}$=7.3 | 0.014 | $F_{1,15}$=0.02 | ns |

Table 3. Mean temperatures (°C) for different body parts, and the effect of horse breed. Samples were collected indoors under stable conditions at 10 °C.

| Body part Mean ± SE °C | Number of samples | General mean IR temperature | Horse breeds | | Effect of breed | |
|---|---|---|---|---|---|---|
| | | | CB | WB | F-value | P-value |
| Head | 25 | 18.7 ± 1.0 | 16.4 ± 2.2 | 20.3 ± 0.5 | 0.1 | NS |
| Neck | 26 | 19.6 ± 0.6 | 18.3 ± 1.1 | 20.5 ± 0.7 | 0.4 | NS |
| Chest | 25 | 22.5 ± 0.9 | 20.0 ± 1.8 | 24.2 ± 0.8 | 0.1 | NS |
| Shoulder | 18 | 20.4 ± 1.1 | 16.4 ± 1.9 | 21.8 ± 1.0 | 2.2 | NS |
| Side body | 28 | 17.3 ± 0.7 | 15.1 ± 1.0 | 19.1 ± 0.7 | 4.1 | 0.055 |
| Back | 17 | 18.2 ± 0.6 | 16.3 ± 0.9 | 19.5 ± 0.6 | 2.1 | NS |
| Loin | 26 | 18.0 ± 0.8 | 15.3 ± 1.1 | 20.0 ± 0.6 | 3.5 | 0.07 |
| Front hoof middle | 26 | 16.4 ± 1.2 | 16.2 ± 1.9 | 16.5 ± 1.6 | 0.1 | NS |
| Hind hoof middle | 26 | 16.0 ± 1.2 | 15.6 ± 1.9 | 16.4 ± 1.6 | 0.0 | NS |
| Rump | 26 | 17.5 ± 0.7 | 14.6 ± 0.7 | 19.6 ± 0.6 | 10.6 | 0.004 |
| Naked hair coat sample area | 25 | 25.5 ± 0.5 | 24.5 ± 0.7 | 26.3 ± 0.6 | 1.4 | NS |

Table 4. Mean temperatures °C for different body parts and the effect of hair coat sample weight category. Number of samples (horses) within each category is given in parenthesis.

| IR temperature ± SE °C | Hair coat categories[1] | | | | | |
|---|---|---|---|---|---|---|
| **Body location** | **0 Clipped** (2) | **1 Low** (10) | **2 Medium** (11) | **3 High** (8) | **F-value** | **P-value** |
| **Head** | 16.8 ± 0.0 | 21.5 ± 1.1 | 18.7 ± 1.1 | 15.2 ± 2.8 | 0.9 | NS |
| **Neck** | 21.5 ± 0.2 a | 22.3 ± 0.6 a | 18.6 ± 0.6 bc | 15.6 ± 1.3 c | 9.2 | 0.0005 |
| **Chest** | 25.1 ± 1.3 a | 25.6 ± 0.9 ab | 22.3 ± 1.3 ab | 17.0 ± 2.3 b | 3.4 | 0.038 |
| **Shoulder** | - | 22.8 ± 1.4 | 20.0 ± 1.4 | 15.4 ± 2.4 | 1.4 | NS |
| **Side body** | 21.2 ± 1.0 a | 20.0 ± 1.0 ab | 17.2 ± 0.8 bc | 12.9 ± 0.9 c | 8.1 | 0.0007 |
| **Back** | - | 19.8 ± 0.6 | 17.5 ± 0.9 | 14.4 ± 1.1 | 3.6 | 0.058 |
| **Loin** | 23.5 ± 0.0 a | 20.7 ± 0.7 b | 18.2 ± 0.9 bc | 13.4 ± 0.8 c | 7.5 | 0.0013 |
| **Rump** | 20.0 ± 0.0 | 20.3 ± 1.2 | 17.6 ± 0.6 | 13.7 ± 0.6 | 4.9 | 0.009 |
| **Naked hair coat sample area** | - | 25.2 ± 1.1 | 26.4 ± 0.7 | 24.4 ± 0.9 | 0.5 | NS |

[1] 0 Clipped: 0.0 g, n=2; 1 Low: 0.1-1.2g, n=10; 2 Medium: 1.3-1.7g, n=11; 3 High: >1.8g, n=10.

## Figures

Figure 1.

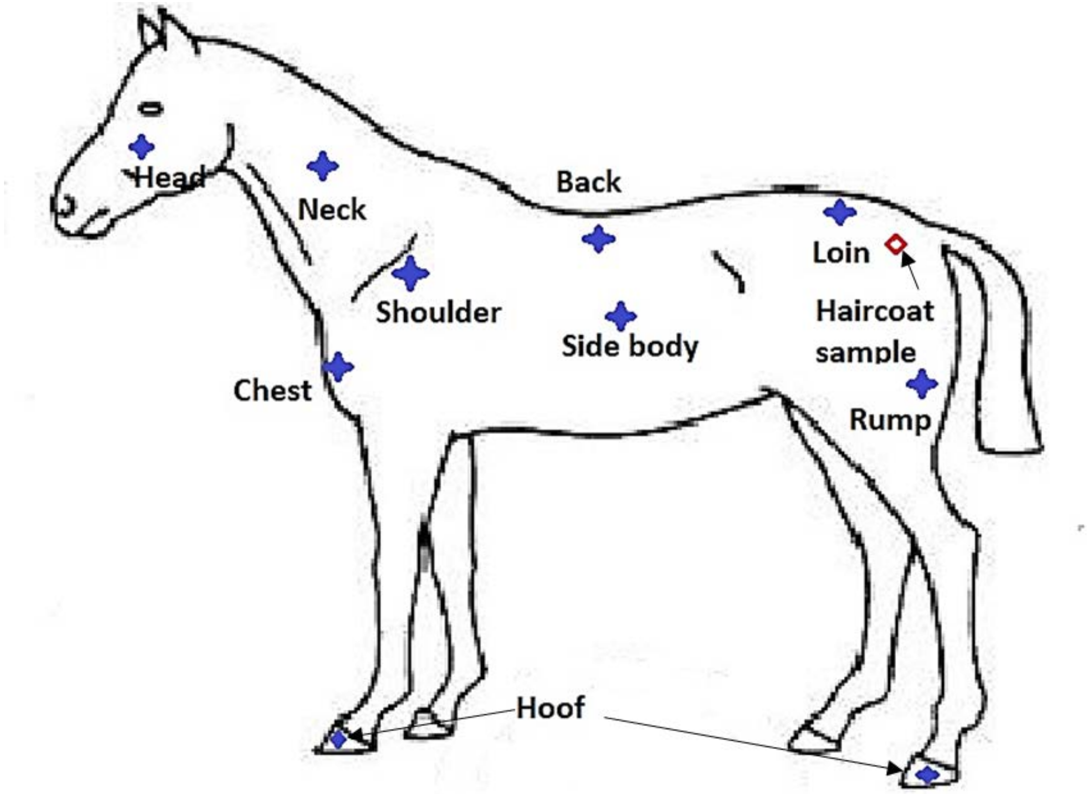


Figure 1. Sketch of horse and points where thermal images where collected (blue points). The red point at the horses hindquarters indicate where the hair coat sample was collected.

Figure 2.

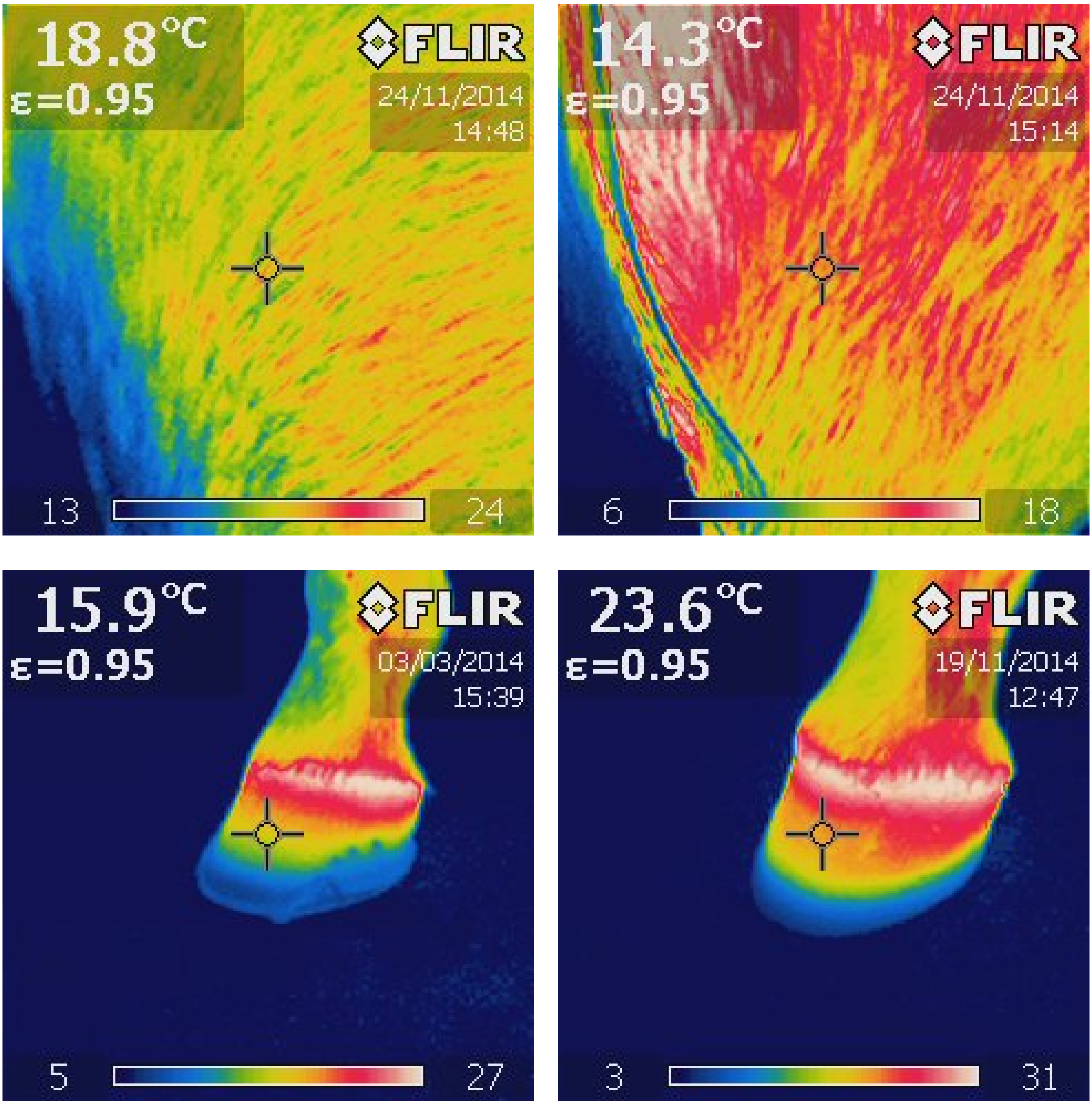


Figure 2. Pictures from the infrared camera showing temperature measures of the rump of a warmblood horse (left) and a coldblood horse (right). Pictures below show surface temperature measured on a shod hoof (left) and an unshod hoof (right).

Figure 3.

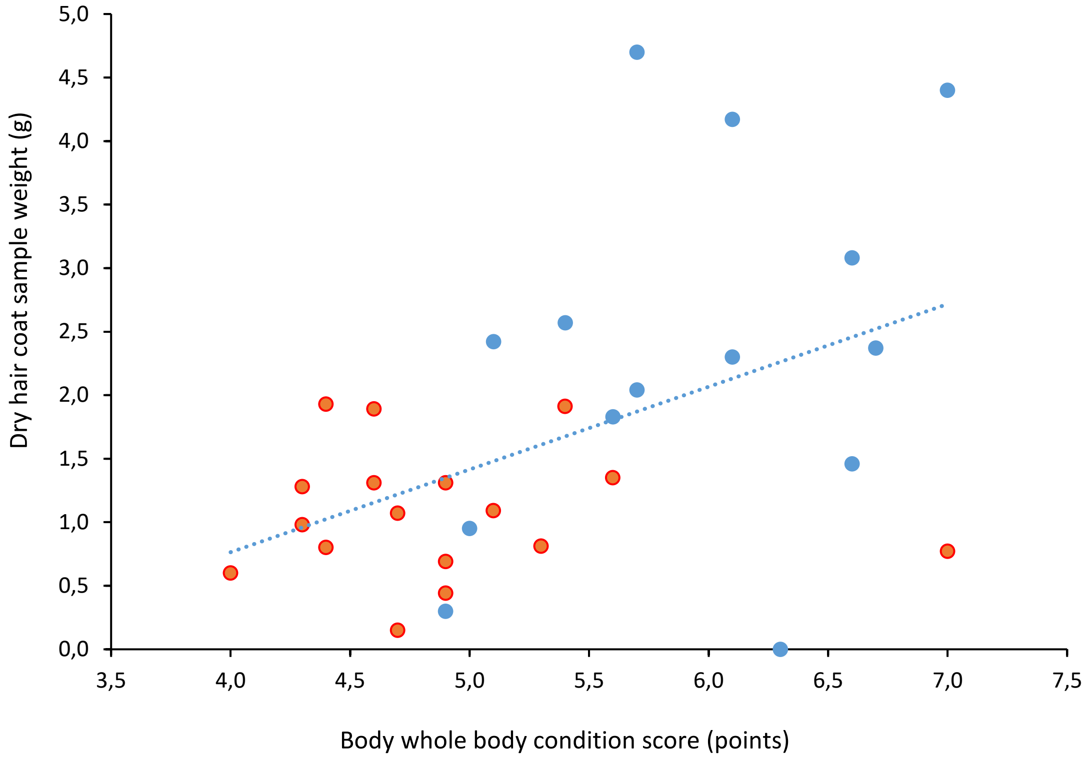


Figure 3. Relationship between 31 measurements of body condition score and hair coat sample weight in a total of 21 horses (r=0.46; *P*=0.008; y=0.6511x – 1.84; $R^2$=0.21. Blue dots indicate CB horses and red dots WB horses.

Figure 4.

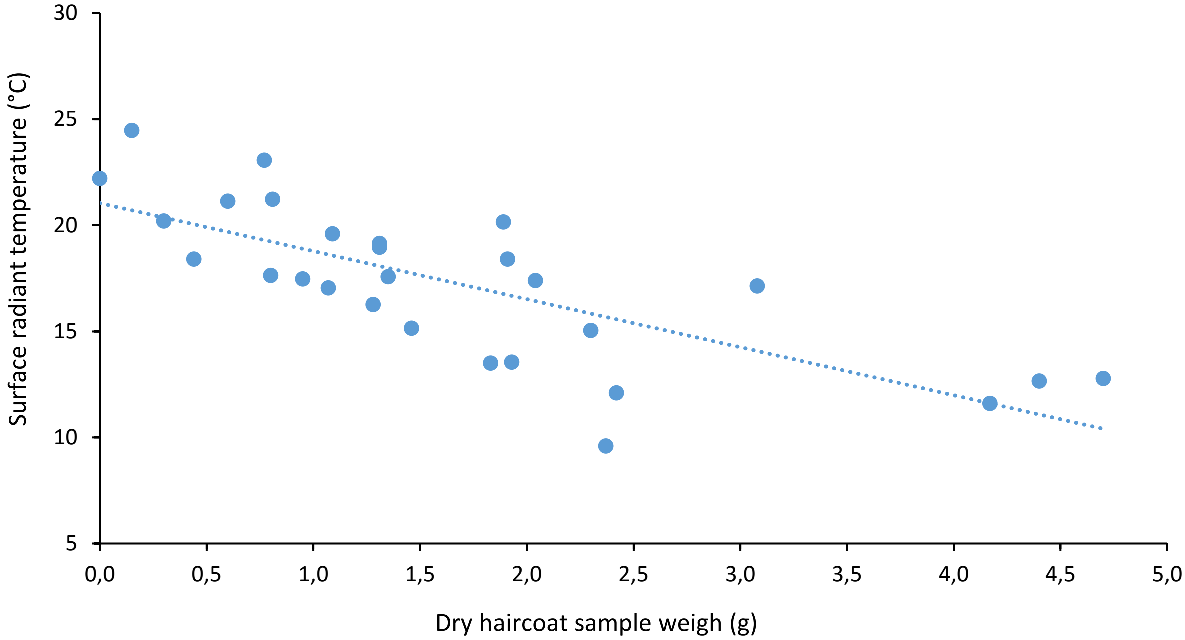

Figure 4. Relationship between 31 measurements of dry hair coat sample weight and surface radiant temperature from the side body of a total of 21 horses (r=-0.8; *P*<0.001; y=-2.2638x + 21.044; $R^2$=0.56).

Figure 5.

Figure 5.

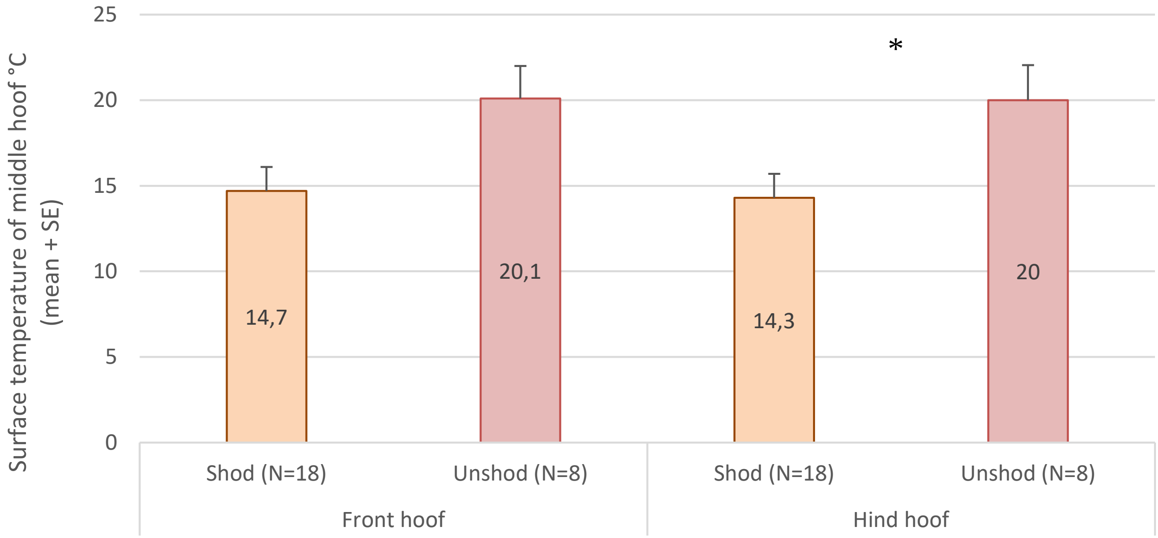


Figure 5. The difference between shod and unshod hooves in IR surface temperature. The difference between shod and unshod hind hooves was significant ($F_{2,4}$=9.4; $P$=0.03).