Equine surface temperature before and after exercise using thermographic images

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***Abstract*— Infrared thermography is considered an accurate and non-invasive method to measure animals' body surface temperature accurately. Thus, this study evaluated changes in equine surface temperature before and after exercise using infrared thermography. A 2-year-old Mangalarga mare was used and exercised once a day. Thermographic images of the animal's left side were captured before and immediately after exercise for 6 days. Subsequently, the calculation of the animal's surface temperature (ST) before and after exercise was performed in the QGIS 3.20 software. The dry-bulb temperature (t_{db}) was monitored during the collection period. Infrared thermography allowed the identification of changes in the surface temperature of the equine skin at rest and after exercise. The averages of t_{db} remained considerably above the thermoneutrality zone (above 30 °C), indicating a heat stress situation. The evaluation of the monitored total mean ST after 30 minutes of exercise showed an increase of about 1 °C in about 39% of the animal's body region. It was also observed that ST varied as a function of air temperature. It is concluded that infrared thermography proved to be a promising tool for collecting data on heat production in the equine body.**

Keywords - thermal stress, horse, image analysis, physiological parameters, thermoregulation

I. INTRODUCTION

Equines are homeothermic animals with unique athletic performance, as their survival in nature is linked to the ability to provide explosive effort while fleeing potential predators [1]. The thermal balance between tissues and organs is imperfect for resting homeothermic species due to the continuous and widely variable metabolic heat production that occurs throughout the body [2]. Through a circadian pacemaker located in the suprachiasmatic nucleus (CNS) of the anterior hypothalamus, oscillations are generated that are modulated by environmental cycles of light and dark, food availability and ambient temperature [3,4].

Physiological adjustments are essential to maintain average body temperature and avoid heat stress [1]. Sweating prevents body temperature from rising during exercise, but when weather conditions are hot or humid, exercise-induced heat stress can occur as heat production exceeds heat dissipation [5]. In environments with milder temperatures, the primary way to dissipate heat is the sensible way (conduction convection and radiation), while under heat stress, latent heat loss (evaporation) is the most efficient [6]. In addition, the heat needs to be dissipated to prevent the temperature from rising too high, endangering the animal's life. Equines control this increase through sweating, vasodilation, and tachypnea [1]. In this sense, detecting the state of the equine after exercise is essential to maximize athletic performance [7]. One of the main characteristics of equine training is the significant influence of the thermal environment on sports performance, as they are outdoor activities, thus allowing direct exposure to climatic variables [8]. Research has demonstrated how surface temperature varies with environmental conditions, body temperature and skin conditions, structures beneath the skin, and in different regions of the body [2, 9].

Infrared temperature can detect changes in peripheral blood flow and can be a useful tool to assess animal stress [10]. The use of infrared thermography (IT) is considered an accurate and non-invasive method that measures heat emission from the surface of the body of animals [11, 12]. The thermographic camera detects surface heat emitted as infrared radiation and produces an image that maps temperature differences across the target [13,14]. A standard distance between the equine's surface and the camera should be maintained for all images taken, and equines should be given time to get used to the procedure [8].

However, research relating the surface temperature of equines with the thermal environment and exercise is still scarce in the literature. This research was carried out to evaluate changes in equine surface temperature before and after exercise using infrared thermography.

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II. MATERIALS AND METHODS

A. *Description of the location, animals and management*

The animal research and ethics committee of the Federal University of Lavras (UFLA) approved all the procedures adopted in this experiment (under protocol CEUA/UFLA nº 084/16), following the ethical principle of animal experimentation.

The study was conducted at the Federal University of Lavras (UFLA), Lavras - MG, Brazil, in April 2017 (autumn), for three weeks, accounting for 6 non-consecutive days of collection (data collection days: 04/03, 04/05, 04/10, 04/12, 04/14 e 04/17). The location is at the geographic coordinates - latitude 21° 1' 43" S and longitude 44° 59' 59", an altitude of 919 meters.

For the experiment, a 2-year-old female Mangalarga equine was evaluated according to the adapted methodology [10]. The animal had dark brown fur and a body mass of ± 300 kg. The equine had never been subjected to exercise, had no visible lameness and had no signs or symptoms compatible with musculoskeletal injuries. The equine's hair was considered adequate, being fine and short.

The equine's diet consisted of 2.5 kg/animal/day of concentrate with 18% crude protein (CP) and forage (Tifton hay or corn silage), divided into two treatments at 7:30 am and 4:30 pm. Water and mineral salt ad libitum, meeting the minimum nutritional recommendations [15].

The stable where the equine was housed was oriented in the southeast-northwest direction, 28.0 m long and 9.0 m wide, with a ceiling height of 2.80 m, eaves of 1.0 m. It had a sandwich-type roofing tile. The stable was divided into twelve stalls with 18.0 m² each (average size: 4.20 m wide x 4.20 m long), without a central corridor (Fig. 1). However, for the accomplishment of the experiment, only one of the 12 available stalls was used. The stalls have the following characteristics: side walls made of concrete blocks 2.0 m high, doors 1.10 m wide and 2.0 m high. The floor of the stalls is made of concrete and has walls of concrete blocks and a bed of sawdust. Each stall has a 0.165 m³ concrete drinker and a 0.6 m³ concrete feeder. Next to the stable was the round pen 15 m in diameter with sand floor where the horses performed the exercises (Fig. 2).

Fig. 1. Facility for accommodation of the animal

B. *Exercise routine according to property management*

The exercises were performed three days during the week; the horses were individually exercised for 30 minutes, from 1:00 pm to 2:00 pm in the round pen.

Fig. 2. Round pen for the practice of animal exercises

The exercise routine of the horses during the experiment was divided into two parts. An initial approach consisted of placing the crow and cervical flexion. In the second part of the exercise, the animal was placed on the round pen and clockwise they walked at a pace for an average time of 11 minutes, then the animal galloped, trotted, and again walked at a pace for about one minute in each gait. The cervical flexion exercise consisted of the recruitment of deep and superficial cervical flexor muscles [16]. Exercises consisting of dynamic mobilization have a mobilizing effect on the cervical and thoracolumbar spine, in addition to activating and promoting the strengthening of the epaxial and hypaxial musculature in the cervical, thoracic and lumbar regions [17].

Then the horses were placed in an anti-clockwise direction and again followed the sequence of gait, first step, followed by gallop, trotted gait and step, spending again about a minute for each gait; at the end, the trainer in question did an approach to stop the animals and cervical flexion. The animals were bathed on the spot using a hose and the animals' bodies were completely wet.

C. *Thermal environment*

To evaluate the thermal environment where the equine was inserted, the dry bulb temperature (t_{db}, °C) and relative humidity (RH) were measured daily at central points within the stall and round pen. The t_{db} data were measured and stored using sensors/recorders (Hobos Pro Series, Onset®) with an accuracy of ± 3%. t_{db} and RH collections were performed every 5 minutes, 24 hours a day, over six non-consecutive days.

The sensors used were protected and stored inside cages to prevent the animals from damaging them and kept at the height of 2.0 m from the floor to better characterize the microclimate in which they were exposed. A recording sensor was installed in the center of the round pen; another sensor was installed in the place where the animals were bathed with hoses.

Subsequently, the Temperature and Humidity Index (THI) was calculated from the model proposed by Thom [18], as described in equation 1. The THI was used as an estimate of the degree of discomfort experienced by horses.

$$THI = 0,8.t_{db} + \mathrm{RH}.\left(\frac{t_{bs} - 14.4}{100}\right) + 46.4 \quad (1)$$

D. *Surface temperature*

For the analysis of the surface temperature (ST) of the animal, a 320 x 240 pixels Fluke Ti55 thermographic camera was used, with an infrared spectrum range of 8 µm to 14 µm, an accuracy of ± 2 °C and an emissivity of 0.98 (Fig. 3). Images were obtained on non-consecutive days for 3 weeks by a trained examiner 1 m away from the animal, perpendicular to the animal's left side. The animal was evaluated for two days before the exercise, at 12:00, and immediately after the 30-minute exercise.

The animal's ST calculation before and after the exercise was performed in the QGIS 3.20 software. For this, a 4-step workflow was performed. In the first step, the images were exported from the standard SmartView Classic 4.4 camera software to QGIS. In the second step, vectors of the contour of the animal were created and used to cut the images and remove the influence of the image background in the calculation of the ST of the animal (Fig. 4). In the third step, the ST values of the pixels present in each of the cropped images were extracted. In the fourth and last step, the pixel values were quantified in pre-defined class intervals to obtain the area of the animal with different ST. The animal ST ranges were defined in 6 classes: 35 to 36 °C; 36.01 at 37 °C; 37.01 at 38°C; 38.01 at 39°C; 39.01 at 40 °C and 40.01 at 41 °C.

Fig. 3. Examiner capturing images 1 m away from the animal, perpendicular to the animal's left side

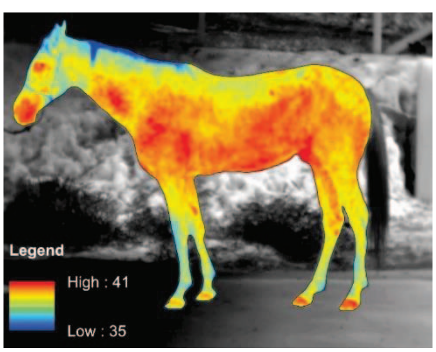

Fig. 4. Thermographic image of the outline of the animal after exercise

III. RESULTS AND DISCUSSION

Fig. 5 shows the percentage of the area of the animal (%) in the classes of average surface temperature (°C); and dry bulb temperature variation (t_{db}, °C) before and after exercise, in autumn.

It is observed that during the evaluated days 04/03, 04/05, 04/12, 04/14 and 04/17 the t_{db} maintained mean values close to 30 °C and 35 °C, before and after the exercises, respectively. On the third day evaluated (04/10), higher mean values of t_{db} were observed near 32 °C and 42 °C before and after the exercises, respectively. After the exercise, t_{db} was measured on the external side (round pen), the place with the greatest exposure to solar radiation. The averages of t_{db} remained considerably above the thermoneutrality zone, above the range between 5 and 25 ºC cited Morgan [19] and Lewis [20] as being comfortable for equines. It was also possible to verify that the ambient temperature, regardless of the period analyzed, exceeded the thermoneutrality zone of the animal, being subjected to levels of heat stress.

Fig. 6 shows the Temperature-Humidity Index (THI) observed during six days in autumn, before and after the exercise. THI values up to 70 indicate a non-stressful environment, between 71 and 78 critical, between 79 and 83 dangerous and above 83, an emergency condition [21]. It is observed that during the evaluated days 04/03, 04/05, 04/12, 04/14 and 04/17 the THI maintained values above thermoneutrality (in the range of values considered as critical). Similar to t_{db}, the highest THI values were found on the third day (04/10) of evaluation, higher mean values of t_{db} were observed near 76 and 87 before and after the exercises, respectively.

Graciano [22] mentions that heat is one of the main limiting factors in the production of animals in the tropics since there are significant changes in the biological functions of the animal. According to the same author, due to heat stress, there is an increase in rectal temperature, skin and hair, sweating and respiratory and heart rates, as well as a reduction in water loss in feces and urine. Dysfunctions in protein, energy and mineral metabolism, as well as disturbances in enzymatic reactions and hormone secretion. In addition, the expenditure of energy to eliminate the animal's body heat is verified. Heat loss occurs mainly by evaporation associated with the loss of water vapor from the surface of the body and the respiratory system [23].

Concerning the moment of rest, the mean total ST monitored after 30 minutes of exercise, showed an increase of about 1°C for 39% of the animal's body region. Among the quantification of the highest ST values, at rest, it was possible to observe that 51% of the animal's body region presented a ST variation from 36.01 to 37 °C; and 28% of the animal's body region showed a ST variation from 37.01 to 38 °C. After exercise, 39% of the animal's body region showed a ST variation from 36.01 to 37 °C; and 32% of the animal's body region showed a ST variation from 38.01 to 39 °C.

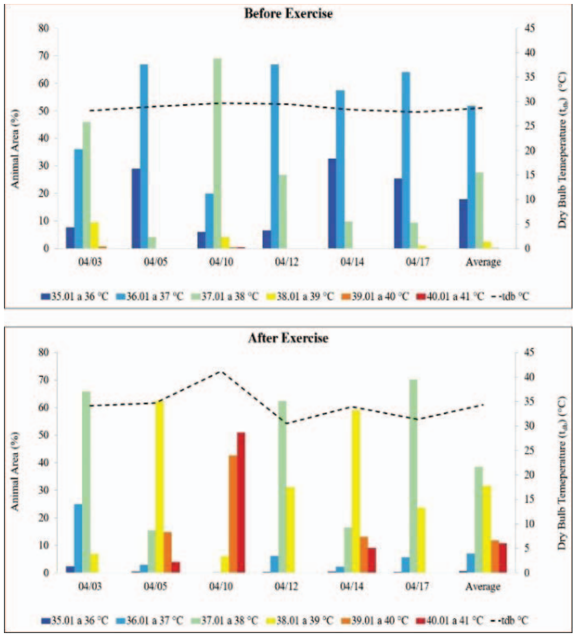

Fig. 5. Percentage of the animal's area (%) in the average surface temperature classes (°C); and variation of the dry bulb temperature (t_{db}, °C), for six days in autumn, before and after the exercise.

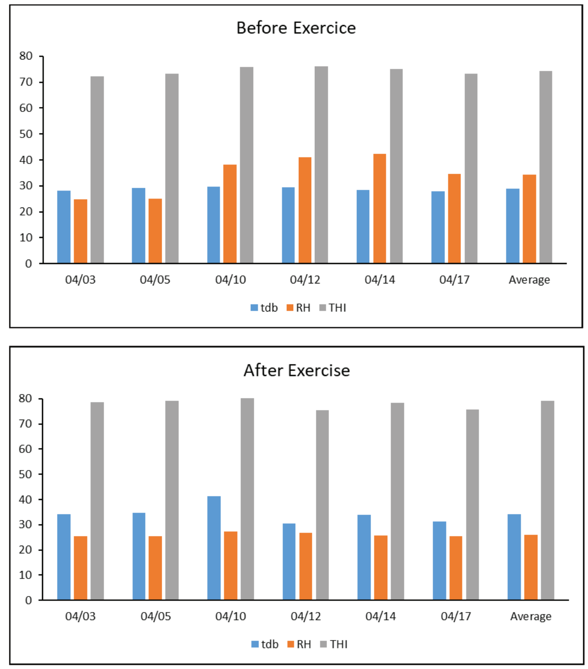

Fig. 6. Dry bulb temperature (t_{db}, °C), Relative Humidity (RH, %) and Temperature-Humidity Index (THI) observed during six days in autumn, before and after the exercise

Simultaneously, it was possible to observe (Fig. 5) that for all the days evaluated, after the performance of the exercises, the equine presented higher values of ST when compared to the moment of rest. Similar behavior was observed in research carried out Moura *et al*., [10]; the authors evaluated the use of infrared thermography in equine thermoregulation after the exercise condition. It was concluded that exercise increased the equine's body heat production.

It was also possible to observe that the ST had a higher value on the third day, probably due to the higher t_{db} value found for that day; that is, it demonstrated an increase in ST as the t_{db} increased. These results confirm the direct relationship between body and environmental temperature, highlighting the strong effect of the thermal environment on equines, which can modify their physiological response in a given situation.

When animals are exercised, oxygen consumption and carbon dioxide production increase, and respiratory rate increases to keep up with changes. Consequently, during moderate exercise with satisfactory preconditioning, little difference is noted in PaO_2 (partial pressure of O_2 in arterial blood), $PaCO_2$ (partial pressure of carbon dioxide), and arterial pH [22]. When exercise takes place in environments where the temperature and/or humidity are high, the competitive demands of evaporative cooling and energy production can limit performance and, depending on the case, result in severe disturbances associated with high temperatures [24].

IV. CONCLUSIONS

Individual surface temperature assessment using infrared thermography proved to be a promising tool for collecting data on equine body heat production. This tool made it possible to identify changes in skin temperature at rest and after exercise. The evaluation of the total mean surface temperature monitored after 30 minutes of exercise showed an increase of about 1°C for 39% of the animal's body region. It was also observed that the surface temperature varied as a function of the air temperature. However, further studies should be carried out on a more significant number of horses and during competitions to ascertain our preliminary findings. The averages of t_{db} and THI remained considerably above the thermoneutrality zone, indicating a heat stress situation.

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