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# Effort and Recovery in Nellore Oxen during Vaquejada Assessed with Ocular and Tail Infrared Thermography Superficial Temperature

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## Abstract

Infrared thermography (IRT) has emerged for evaluation of animal welfare. To test the hypothesis that cattle subjected to vaquejada increased temperature in the eye (CLO) and tail due to physical effort, a research was developed that aimed to measure maximum surface temperature in the CLO and base of tail using IRT. Eighty Nellore cattle were used, which were subjected to physical effort in three periods (morning, afternoon and night). IRT was performed at CLO and base of tail, in rest pen/corral (control) and during the vaquejada (pre- and post-run). Tails' analysis was divided in 3 points (E1, E2 and E3). ANOVA and Tukey's test ($p < 0.001$) were used for analysis. Temperatures were higher in morning and afternoon and different from those at night on control ($p < 0.001$). During vaquejada with one run, CLO was higher in pre-run, followed by a slight reduction in post-run ($p < 0.001$). Analyzing temperatures variations at tail, higher temperatures were observed in the morning, followed by the evening and night ($p < 0.001$), but without differences within the pre- and post-run periods. Temperatures at tail's points were higher in morning period in cattle with two runs ($p < 0.001$). Finally, it was concluded that there were no increases in CLO or at tail's points after vaquejada races. The IRT method was efficient in determining surface temperatures in CLO and tail points in cattle under the same conditions and may be a good

noninvasive method for clinical and welfare assessments.

## Keywords

Thermogram, Bovine, Welfare, Diagnosis, Exercise

## 1. Introduction

In recent years, different methods for the evaluation of signs and indicators of animal welfare have been used. However, currently, the objective is to use non-invasive methods of an objective nature that can be combined with others, aiming to provide more accurate assessment systems and thus assist in making more accurate decisions for assessing animal welfare [1] [2] [3] [4]. In this sense, the use of infrared thermography (IRT) has emerged as a practical and simple possibility that can be used in various conditions. It presents good precision in its results and is accepted in the scientific community as an effective methodology in the evaluation of animal welfare [5] [6] [7].

Different articles cite the use of IRT as a noninvasive diagnostic method of various processes of different species. In dairy cattle, this technique was used to diagnose hoof and legs diseases [4], to characterize negative or positive responses to farm management practices [5] and to evaluate the effects of environmental temperature conditions in tropical conditions [6]. It also demonstrated its efficiency and importance in the diagnosis of stress during management practices under extensive rearing [8].

These different uses and approaches to IRT are able to identify the problems, or at least, help in the evaluation of the inflammatory processes of the animals, showing themselves as another tool of analysis to the adaptive, physiological or pathological processes, and thus contributing to the accurate diagnosis of animal welfare under different situations. However, the IRT method has been greatly influenced by the types of facilities, management and environmental conditions. Thus, during the use of the IRT, the annotations of the local temperature and the relative humidity of the air should be performed to make the evaluation more accurate, minimizing possible interference in the results between the experiments under different environmental conditions.

To test the hypothesis that Nellore cattle raised extensively and subjected to vaquejada race exhibit elevated surface temperature in the eye and tail due to physical effort, a study was conducted that aimed to: 1) the maximum surface temperature in the ocular caruncle (CLO) and at the base of the tail in Nellore cattle before the runs at different times of the day (morning, afternoon and night) or control group; 2) to determine these parameters immediately before and after the cattle races in vaquejada with tail protection harness at different times of the day (morning, afternoon and night) in one or two races in the same period or exercised group. The results obtained may contribute to the evaluation

of management practices during wading and the effects of physical effort during runs on the welfare of animals.

## 2. Materials and Methods

This study was approved by the Ethics Committee on Animal Use of the Centro Universitário Cesmac (CEUA/CESMAC) under protocol number 03A/2021. It is important to note that the test was performed in a real vaquejada race test environment, respecting the legal, regulatory and regulatory provisions and precepts in Brazil [9] [10] [11] [12].

### 2.1. Animals

Eighty Nelore cattle were used, which were housed on a farm in the municipality of Garanhuns, state of Pernambuco (8˚53'25"S; 36˚29'31"W), provided with pasture of Brachiaria grass (Brachiaria decumbens) and supplemented daily with Campimaçu grass silage (Pannisetum purpureum Schum, cultivar RNC 33503). The animals had free access to mineralized salt and water, regularly receiving parasite control and vaccination to prevent rabies, foot-and-mouth disease and clostridia. With an average age of 30 months and average weight of 540 kgPV, they were kept in homogeneous lots composed of 40 animals, which were identified by marking with a green marker stick and another in yellow (Raidl-Maxi, RAIDEX GmbH, Dettingen/Erms, Germany).

Very early in the morning, the cattle were transported to the vaquejada park (8˚54'34"S; 36˚39'31"W), located in Paranatama-PE. The route was performed without stops, lasting approximately 40 minutes, in a truck suitable for the species, divided into sublots of 20 animals, without mixing between the different lots. The cattle were housed in two groups of 40 heads in rest pens, both with a capacity of 10 to 15 $m^2$/animal. The animals had free access to water and were supplemented with silage of Campimaçu (*Pannisetum purpureum* Schum, cultivate RNC 33503). The silage was the same farm and was provided in three daily meals through collective feeders ad libitum. The two rest pens had sand floors, with good drainage, and an area of artificial shading with 80% black screens, with more than 50 $m^2$.

The evaluation of the welfare level of the cattle ranged from leaving the farm to returning to the rest pen after the last run was being implemented throughout the event, the analysis technique referenced by the Concept of the Five Domains, considering the positive and negative conditions for the domains of ambience, nutrition, health, behavior and mental state [2] [13]. At the end of the event, the animals remained housed in the rest corrals, waiting for their sale.

### 2.2. Physical Effort and Vaquejada Races

The cattle were subjected to vaquejada races using protective harness (conical tail protector, MMC Protectors of Cauda LTDA, Teresina-PI, Brazil), according to oficial regulation [9] [10] [11] [12]. Each cow individually ran at a gallop (5 -

6 m/s), paired by two mounted horses (cowherds), being unbalanced and temporarily contained in a strip of soft sand, approximately 40 cm deep, which is approximately 80 meters from the point of departure. After standing up, the cattle were moved by walk or trot to the removal harness of the protection harness and then to the rest pen. The maximum permanence time of the cattle with protective harness on the tail was 8 minutes. The total length of the vaquejada track was 100 m, with soft sand throughout the course, where each cattle ran the race once or twice, with a minimum interval of 60 minutes between the first and second runs.

## 2.3. Physiological and Climate Annotations

Animals at rest in the control group: The animals that were at rest pens comprised the control group, which consisted of cattle that arrived at the vaquejada park but did not run. The evaluations were performed using the IRT technique using two calibrated and certified infrared thermograph equipment (Flir E4 Wi-fi, FLIR Systems AB, Sweden). Such evaluations were performed with the animals contained in holding corral, 12 hours before the beginning of the races, which were performed in the three periods of the day (morning, afternoon and night). The surface temperature was determined in the ocular caruncle (lacrimal caruncle) and in three points of the proximal portion of the tail, one near the insertion (E1), one median (E2), and one distal to the middle third, determined by a line that goes from the left ischium tip to the right (E3) (**Figure 1(A)** and **Figure 1(B)**). For the evaluation of well-being throughout the pre-race period, the system of the "5 Domains" was used throughout the period of cattle staging in the event.

The control group examination, that is, the capture of images through IRT in the control phase, was performed in a holding bretes, and the protective tail harness was immediately placed after the examination. Then, the cattle were released one by one and galloped to the end of the track, and at a walk or trot, they

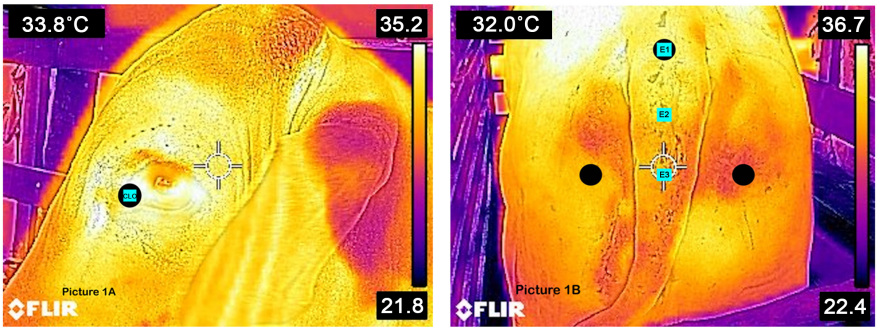


**Figure 1.** Indication of the points of surface temperature measurement by infrared thermography in Nellore cattle: ocular caruncle (CLO) (**Figure 1(A)**) and the measurement points in the medial third of the base of the tail (E1, E2 and E3) (**Figure 1(A)**). Observation: **Figure 1(B)**: The black spot in the eye indicates the target region, the ocular caruncle (CLO); **Figure 1(B)**: The black dots indicate the reference marking sites to obtain the measurements of the target areas E1, E2 and E3.

were re-accommodated in the holding pen with the other animals in their group. After the complete formation of the group, they returned to the step to the rest pen.

Animals subjected to running physical effort: Twenty-four hours after the tests in the control group, they were subjected to the physical effort of the vaquejada races in three periods (morning, afternoon and night), with a 18 hours of minimum interval between the periods of exercise. Thus, the surface temperature was measured through the IRT in the ocular caruncle (CLO) and in the three portions of the tail (E1, E2 and E3). The thermographic examination was performed before placing the tail protection harness (pre-race) and immediately after the race (post-race). In the post-race, thermographic images were obtained with the animals using the protective harness (with protector) and after the removal of the protector (without protector), with an average interval between the thermographic images (with and without protector) was less than 30 seconds. The thermographic images obtained when the animals still carried the tail protection harness were restricted to measurements in E1 and E2 because they were covered by the harness at the E3 imaging point.

For this study, an infrared thermograph (E4 Wifi, FLIR Systems AB, Sweden) was used, properly calibrated and trained. All thermographic photos were taken with the animals contained in a holding brete, without the use of ropes, harness or other devices, at an average distance of 100 cm from the body area studied. The room temperature and relative humidity were measured by a thermohygrometer (Thermo-Hygrometer #7666.02.0.00, Incoterm Indústria de Termometers LTDA, Brazil), with a resolution temperature of 0.1˚C and an accuracy of +1˚C from 0˚C to 50˚C, the relative air humidity had a resolution of 1% (accuracy + 5%) during all evaluations for calibration and obtaining the normalized results. The emissivity for the readings was set at 0.95 ε, as described in the literature for cattle [14]. The thermographic images were processed in a specific program (FLIR Tools, FLIR Systems AB, Sweden) to receive adjustments compatible with the ambient temperature and relative humidity at the time of collection, and then it was possible to determine the maximum temperatures in the regions evaluated in all experimental phases in the respective periods of the day, providing greater reliability in the data collected [14].

## 2.4. Statistical Analysis

The results were subjected to one-way ANOVA and Tukey's test, in both cases with $p < 0.001$. The results are expressed as the mean ± standard deviation. The SigmaPlot 13.0 application for Windows (Systat Software Inc., San Jose, California (USA)) was used in the analyses. The environmental temperature, relative air humidity and surface temperature in the CLO in the post-run phase were recorded immediately after removal of the tail protection harness (protector). The statistical evaluations for point E3, at the base of the tail, only used the measurements taken with the animals without the tail protector.

## 3. Results

None of the 80 animals participating in the experiment showed signs of illness, physical weakness, or functional, dietary and behavioral changes before, during and after the event.

The results of the control period indicated a variation in environmental temperature and humidity throughout the day ($p < 0.001$), with lower temperatures observed at night (~20.66˚C) (Table 1). They also showed that the surface temperatures (ocular and points at the base of the tail) were higher in the morning and afternoon periods and different from those measured at night ($p < 0.001$). The correlation values between the ambient temperature and the infrared images in the CLO were low ($R = 0.31$; $p < 0.001$), and in the three portions of the base of the tail was median ($r = ~0.66$; $p < 0.001$ (Table 2). Conversely, the points at the base of the tail (E1, E2 and E3) were high correlations ($r \geq 0.80$; $p < 0.001$). The correlations between the temperature in the CLO and the points at the base of the tail were median ($r \leq 0.55$; $p < 0.001$).

The environmental conditions during the vaquejada races showed significant differences, with the highest environmental temperature in the morning, followed by the afternoon and evening ($p < 0.001$). The relative humidity exhibited irregular variation ($p < 0.001$) (Table 3). Conversely, the temperature in the

Table 1. Results of the evaluations of the environmental conditions and surface temperature in the eyes and tail's points of Nellore cattle (n = 80) prior to the vaquejada races in the control group.

| *Period | Environmental conditions | | Average temperature by infrared thermography (˚C) | | | |
|---|---|---|---|---|---|---|
| | Ambient temperature, ˚C | Relative humidity, % | Eye caruncle | E1 | E2 | E3 |
| Morning | $25.10 \pm 0.76^{B}$ | $71.75 \pm 4.70^{B}$ | $37.27 \pm 0.74^{A}$ | $36.65 \pm 1.77^{A}$ | $36.45 \pm 1.60^{A}$ | $36.42 \pm 1.58^{A}$ |
| Afternoon | $26.24 \pm 0.62^{A}$ | $49.32 \pm 4.23^{C}$ | $37.37 \pm 1.23^{A}$ | $36.58 \pm 1.74^{A}$ | $36.15 \pm 1.46^{A}$ | $36.39 \pm 1.60^{A}$ |
| Night | $20.66 \pm 0.54^{C}$ | $89.54 \pm 1.34^{A}$ | $36.27 \pm 1.13^{B}$ | $27.20 \pm 2.27^{B}$ | $28.02 \pm 2.66^{A}$ | $29.02 \pm 2.72^{A}$ |

Note: different letters in the same column represent $p < 0.001$; E1: base of the tail; E2: midpoint between the base of the tail and a line between the two tips of the Ischium, E3: point on the line between the tips of the Ischium in the tail. *Periods: morning: evaluation performed between 9:00 am and 11:30 am; afternoon: evaluation performed between 14:30 h and 17:00 h; night: evaluation performed between 20:00 and 22:30.

Table 2. Spearman's correlations ($p < 0.001$) between the evaluations of environmental conditions and surface temperature in the eye and tail's points of Nellore cattle (n = 80) before vaquejada races in the control group.

| | **Ambient temperature** | **Relative humidity** | **Eye caruncle** | **E1** | **E2** | **E3** |
|---|---|---|---|---|---|---|
| Ambient temperature | ———— | −0.86 | 0.31 | 0.65 | 0.66 | 0.65 |
| Relative humidity | ———— | ———— | −0.40 | −0.70 | −0.70 | −0.71 |
| Eye caruncle | ———— | ———— | ———— | 0.54 | 0.52 | 0.50 |
| E1 | ———— | ———— | ———— | ———— | 0.90 | 0.86 |
| E2 | ———— | ———— | ———— | ———— | ———— | 0.91 |
| E3 | ———— | ———— | ———— | ———— | ———— | ———— |

Note: E1: base of the tail; E2: midpoint between the base of the tail and a line between the two tips of the Ischium; E3: point on the line between the tips of the Ischium in the tail.

**Table 3.** Results of the evaluations of the environmental conditions and surface temperature in the eye and tail's points of Nellore cattle (n = 80) with one run during vaquejada races.

| Period | Phase experimental | *Temperature environment, ˚C | *Relative humidity, % | **Ocular caruncle | E1 | E2 | ***E3 |
|---|---|---|---|---|---|---|---|
| Morning | Pre-race | 25.90 ± 1.25$^{A}$ | 65.1 ± 2.6$^{E}$ | 37.00 ± 1.10$^{A}$ | 37.30 ± 1.8$^{AB}$ | 37.05 ± 1.6$^{A}$ | 36.76 ± 1.3$^{A}$ |
| | Post-race CP | 25.99 ± 0.75$^{A}$ | 60.4 ± 1.9$^{F}$ | 36.10 ± 1.10$^{C}$ | 36.77 ± 1.5$^{AB}$ | 36.03 ± 1.6$^{BC}$ | ———— |
| | Post-race SP | | | | 37.46 ± 7.2$^{A}$ | 36.11 ± 1.7$^{B}$ | 34.78 ± 1.5$^{B}$ |
| Afternoon | Pre-race | 23.40 ± 0.39$^{B}$ | 82.7 ± 3.0$^{C}$ | 36.75 ± 1.50$^{AB}$ | 33.58 ± 1.5$^{C}$ | 33.93 ± 1.5$^{D}$ | 34.26 ± 1.8$^{B}$ |
| | Post-race CP | 23.18 ± 1.10$^{B}$ | 80.3 ± 3.6$^{D}$ | 34.67 ± 0.90$^{D}$ | 33.43 ± 1.2$^{CD}$ | 33.16 ± 1.3$^{DE}$ | ———— |
| | Post-race SP | | | | 33.25 ± 1.1$^{CDE}$ | 33.20 ± 1.1$^{DE}$ | 32.46 ± 1.1$^{D}$ |
| Night | Pre-race | 20.30 ± 0.32$^{C}$ | 89.8 ± 1.7$^{B}$ | 36.87 ± 1.20$^{AB}$ | 31.48 ± 1.5$^{F}$ | 32.21 ± 2.0$^{F}$ | 33.41 ± 2.0$^{C}$ |
| | Post-race CP | 19.11 ± 0.31$^{D}$ | 92.4 ± 1.9$^{A}$ | 35.73 ± 1.3$^{C}$ | 31.64 ± 1.6$^{F}$ | 32.28 ± 1.8$^{F}$ | ———— |
| | Post-race SP | | | | 31.93 ± 1.4$^{EF}$ | 32.25 ± 1.5$^{F}$ | 31.76 ± 1.4$^{D}$ |

Observations: Different letters in the same column indicate that $p < 0.001$. *The measurements of environmental temperature and relative humidity were measured only once at the time of the evaluations at post-race. **The surface temperature in the ocular caruncle was the mean, measured immediately after removal of the tail protector. ***E3 only used the measurements taken without the tail protector for the correlations. CP: with tail protector; SP: without tail protector.

CLO was higher at the beginning of the periods, followed by a slight reduction in post-run ($p < 0.001$). Analyzing the variations at the base of the tail, higher surface temperatures were observed in the morning, followed by the evening and night ($p < 0.001$). In the pre- and post-run phases, there were few variations within the same period. Additionally, in this group of animals with one run, the correlations with environmental temperature were very low with CLO ($r = 0.07$) and high (E1) with the median (E3) with the base of the tail (Table 4). The correlations between CLO and the points at the base of the tail were low at the three points ($r \leq 0.40$; $p < 0.001$). The correlations between the points on the tail were median to high ($r \geq 0.66$ - $0.76$; $p < 0.001$).

Finally, in the results obtained in the group that ran twice, it was determined that the environmental temperature was higher in the morning and lower at night ($p < 0.001$) (Table 5). The relative humidity of the air followed an inverse pattern ($p < 0.001$) to that observed for the ambient temperature. The temperatures at points E1, E2 and E3 were higher in the morning ($p < 0.001$). The temperatures in the evening and night periods in E1, E2 and E3 were similar. By analyzing the correlations, it was observed that the ambient temperature had a low correlation with the CLO ($r = 0.18$; $p < 0.001$) and an average correlation with the three points of the tail base ($r \geq 0.65$; $p < 0.001$), all of which were significant (Table 6). The correlations between CLO and the three points of the tail were low ($r = \sim 0.32$; $p < 0.001$. Conversely, between the three points of the tail was low between E1 and E2 ($r = 0.33$; $p < 0.001$), and the median was low between E1 and E3 ($r \leq 0.70$; $p < 0.001$).

**Table 4.** Spearman's correlations ($p < 0.001$) between environmental conditions and surface temperature in the eye and tail's points of Nellore cattle (n = 80) with one run during vaquejada races.

| | Ambient temperature | Relative humidity | Caruncle Ocular | E1 | E2 | *E3 |
|---|---|---|---|---|---|---|
| Ambient temperature | ———— | −0.95 | 0.07 | 0.86 | 0.71 | 0.58 |
| Relative humidity | ———— | ———— | −0.04 | −0.79 | −0.67 | −0.52 |
| Eye caruncle | ———— | ———— | ———— | 0.22 | 0.28 | 0.36 |
| E1 | ———— | ———— | ———— | ———— | 0.86 | 0.66 |
| E2 | ———— | ———— | ———— | ———— | ———— | 0.76 |
| E3 | ———— | ———— | ———— | ———— | ———— | ———— |

Note: E1: base of the tail; E2: midpoint between the base of the tail and a line between the two tips of the Ischium; E3: point on the line between the tips of the Ischium in the tail. *E3 only the measurements taken without the tail protector were used for the correlations.

**Table 5.** Results of the evaluations of the environmental conditions and surface temperature in the eyes and tail's points of Nellore cattle (n = 80) with two runs during vaquejada races.

| Period | Experimental phase | *Temperature environment, ˚C | *Relative humidity, % | **Ocular caruncle | E1 | E2 | ***E3 |
|---|---|---|---|---|---|---|---|
| Morning | Pre-race | $27.56 \pm 0.64^{A}$ | $57.58 \pm 1.6^{E}$ | $37.24 \pm 0.88^{A}$ | $37.19 \pm 1.60^{AB}$ | $37.42 \pm 1.40^{A}$ | $37.12 \pm 1.29^{A}$ |
| | Post-race CP | $26.94 \pm 0.67^{B}$ | $57.36 \pm 1.7^{E}$ | $36.75 \pm 0.89^{B}$ | $37.47 \pm 1.46^{A}$ | $37.00 \pm 1.18^{AB}$ | ———— |
| | Post-race SP | | | | $36.72 \pm 1.72^{AB}$ | $36.51 \pm 1.20^{AB}$ | $35.60 \pm 1.10^{B}$ |
| Afternoon | Pre-race | $23.00 \pm 0.09^{C}$ | $84.37 \pm 0.8^{D}$ | $37.17 \pm 1.41^{A}$ | $33.01 \pm 1.54^{C}$ | $33.97 \pm 1.75^{C}$ | $34.40 \pm 1.72^{BC}$ |
| | Post-race CP | $21.70 \pm 0.12^{D}$ | $86.06 \pm 0.2^{C}$ | $35.14 \pm 1.26^{C}$ | $32.88 \pm 1.30^{C}$ | $32.92 \pm 1.36^{C}$ | ———— |
| | Post-race SP | | | | $33.22 \pm 1.62^{C}$ | $33.02 \pm 1.33^{C}$ | $32.36 \pm 2.29^{C}$ |
| Night | Pre-race | $20.41 \pm 0.18^{E}$ | $90.40 \pm 0.5^{B}$ | $37.94 \pm 0.94^{A}$ | $32.15 \pm 1.47^{C}$ | $33.25 \pm 1.55^{CD}$ | $33.98 \pm 1.70^{CD}$ |
| | Post-race CP | $19.84 \pm 0.09^{F}$ | $95.27 \pm 0.2^{A}$ | $36.12 \pm 1.35^{BC}$ | $32.54 \pm 1.72^{C}$ | $32.33 \pm 2.29^{D}$ | ———— |
| | Post-race SP | | | | $33.18 \pm 1.58^{C}$ | $33.02 \pm 1.30^{C}$ | $32.37 \pm 2.29^{D}$ |

Observations: Different letters in the same column indicate that $p < 0.001$. *The environmental temperature and relative humidity were measured only once at the time of the evaluations at post-race. **The surface temperature in the ocular caruncle was measured immediately after removal of the protector. ***E3 only the measurements taken without the tail protector were used for the correlations. CP: with tail protector; SP: without tail protector.

**Table 6.** Spearman's correlations ($p < 0.010$) between environmental conditions and surface temperature in the eye and tail's points of Nellore cattle (n = 80) with two runs during vaquejada races.

| | Ambient temperature | Relative humidity | Eye caruncle | E1 | E2 | *E3 |
|---|---|---|---|---|---|---|
| Ambient temperature | ———— | −0.92 | 0.18 | 0.72 | 0.76 | 0.63 |
| Relative humidity | ———— | ———— | −0.10 | −0.70 | −0.73 | −0.61 |
| Eye caruncle | ———— | ———— | ———— | 0.30 | 0.33 | 0.31 |
| E1 | ———— | ———— | ———— | ———— | 0.89 | 0.70 |
| E2 | ———— | ———— | ———— | ———— | ———— | 0.83 |
| E3 | ———— | ———— | ———— | ———— | ———— | ———— |

Note: E1: base of the tail; E2: midpoint between the base of the tail and a line between the two tips of the Ischium; E3: point on the line between the tips of the Ischium in the tail. *E3: only measurements taken without the tail protector were used for correlations.

## 4. Discussion

This research was the first to use the IRT during the vaquejada race and demonstrated that the use of IRT in cattle during the races is an efficient, practical and objective non-invasive method to evaluate some aspects of the cattle welfare during this equine sport. In the current research, the IRT identified minimal and accurate changes in the temperature of the surface of the eye and the base of the tail. Also, this non-invasive method demonstrated that the studied points vary according to the period of the day and according to the phase of physical effort, reinforcing the importance of assessments at different times of the day and with serial assessments. When it is performed during the vaquejada races, the IRT can be a good tool for evaluating the general clinical conditions of the animals used in this sport, mainly because it allows evaluation at the base of the tail at the event site and with immediate results. Finally, temperatures at CLO had lower correlations with ambient temperature, as opposed to correlations with points E1, E2 and E3 at the base of the tail, indicating that measurements at CLO can be more efficient and less related to changes in temperature environment and relative humidity, and thus more accurately assess the physiological or pathological stress. The surface temperature at the base of the tail can be important to assess the occurrence or absence of injuries in this region during the vaquejada races. The use of IRT for the assessment of inflammatory lesions has already been suggested under similar conditions by different researchers [5] [14] [15] [16].

It should also be noted that all cattle ran once or twice a day for 3 consecutive days, with a minimum interval of 18 hours between days, being covered with tail protection harness, and no temperature increases were observed in the studied sites at the base of the tail, immediately after the runs and/or in the pre-runs of the following day, indicating the absence of inflation (acute) or chronic (>12 hours) injury in this region. Additionally, this absence of changes in the surface temperature in the tail in E1 and E2 in the post-run phase, with and without protective harness, indicates that the harness used produced little changed the local blood perfusion because when the surface temperature were similar. Before this research, nobody showed the significant improvement of the cattle welfare using this tail harness. In addition, the cattle showed no clinical signs of health loss and maintained the pattern of feeding/rumination/rest/interaction in the rest pen during the entire event, thus meeting the conditions described as good to excellent for the welfare of cattle within the vaquejada races, according to the literature [3] [13].

### 4.1. Temperature in the Ocular Caruncle

Studies on different species have shown that the analysis of surface temperature in CLO is the most reliable because it is associated with internal temperature and is less affected by environmental conditions [5] [14], like we showed here. In the current experiment, the CLO evaluations, both in the control group and in the animals subjected to physical effort, showed low correlations with the environ-

mental temperature, which was expected because this measurement has been shown to be accurate in the evaluations with the IRT in different species. The core temperature of cattle is between 38.0˚C and 39.3˚C [14], and it is expected that temperatures found in CLO do not exceed those values in normal health and wellness.

The temperature in the CLO may be influenced by diseases and/or physiological stress during management practices. The reduction in eye temperature may also be a response mediated by the sympathetic system, which produces a reduction in peripheral blood supply and consequently a reduction in surface temperature [5]. This is a physiological process that occurs in animals that exerts physical effort produces redistributing blood in muscle tissues, providing nutrients and oxygen to skeletal muscle tissue [17]. According to Idris *et al*. [14], the measurement of this parameter is quite efficient for determining variations in the behavior and metabolism of these animals because it is close to the hypothalamus, which is highly irrigated and has a fast and accurate response to the stressor. Under favorable conditions, when the stressor is removal, there is a rapid recovery of the normal CLO temperature. However Stubsjøen *et al.* [18] comments that the variations in temperature in CLO are little sensitive when compared to heart rate to assess stress, but at this research we did not measure the heart rate.

Studies on the reduction and increase in CLO temperature still present conflicting results. In a study by Stewart *et al.* [5], using equipment that causes stress in animals (electric rod, hose and plastic bags), there was a brief reduction in temperature in the CLO between 40 and 60 seconds, returning to normal after 120 seconds. However, other studies have shown an increase in eye temperature when evaluated by IRT. Cook *et al.* [19] showed that the surface temperature of the eye increases and facilitates the loss of heat by irradiation, as occurs during physical effort. Additionally, Stewart *et al.* [1] studied the possibility of using IRT to assess the well-being of dairy cows and demonstrated that the surface temperature in CLO increases under stress conditions and remains elevated for longer periods. These results indicate that the temperature in the CLO has a reduction/elevation/normalization cycle that should be better studied under the different management practices or utilization (sport) the bovines. Also, it is important remember that any methods for assessing well-being should have greater reliability and feasibility for their use to measure signs and indicators in clinical and well-being assessments [20]. More studies need to be done about the changes in CLO temperature and IRT in different breeds of bovines, principally in beef breeds.

In the current experiment, the CLO temperature of the animals subjected to physical effort showed a reduction between the pre- and post-race periods, which was expected due to the handling of the animal in the starting gate, plus the physical effort in the race and handling in the holding corral, where the tail harness was removed. This produces an adaptation to physical effort and con-

sequent activation of the sympathetic nervous system, favoring the redistribution of blood in tissues involved with exercise [17], such as muscles. Reductions in blood circulation were observed in organs that were not stimulated, such as the kidneys, but without reduction in the coat. However, in the current experiment, the evaluation of this parameter on the following day, the temperature in the CLO was normalized, and the animals were recovered. Here, it should be commented that the animals do not run more than twice in 24 hours and spent much of the time in the rest pen (>22 hours), with food, water and shadow, being able to interact with their group, favoring recovery.

It is also noteworthy that cattle with previous experiences with inadequate management may recall that a particular activity produces discomfort and thus can anticipate the activity and the entire neuroendocrine system [5] [21]. Thus, some modifications in the IRT images could be associated with the anticipation of stress, *i.e.*, cognitive bias. In the current experiment, animals that had never been subjected to this type of physical effort were used; thus, it is observed that the temperature measurement in the CLO can be used to evaluate the stressor effects and how the animal reacts to it. Also, we did multiples IRT to evaluate the bovines welfare in vaquejada, because single or solitary evaluations may not provide reliability and viability when assessing the effects of stressors on well-being [5] [21]. Even with the temporary reduction of the CLO temperature in cattle with physical effort, they recovered because they were housed in their own environment, able to interact with each other and with good nutrition, favoring the full recovery of the exercise performed in the runs.

### 4.2. Temperature in the Tail

The method of unbalancing the cattle by the tail to count it has its cradle in the Iberian Peninsula and southern France, being introduced in Brazil by the Europeans, given the difficulty in restraining the animal with the use of the rope, due to the characteristics of the vegetation (caatinga) of northeastern Brazil, remaining present with the evolution of the sport of vaquejada [20]. In the current sport model, with regulations approved by different level of regulations [9] [10] [11] [12], participating cattle use a tail protection harness called a tail protector, which reduces the possibility of injury occurrence, working mechanically to uniformly distribute the pressure along the tail.

The detection of possible early injuries with the use of IRT can be considered one of the positive effects on well-being in management conditions and in sports that use cattle, producing important economic and social effects, favoring the obtainment of the social license to operate. The current project was developed to determine the surface temperature at the base of the tail, but it also presents itself as a way to evaluate the acute effects of using the tail to unbalance and temporarily contain cattle. Inflammation or acute and chronic lesions can modify the surface temperature and be easily detected with the use of IRT, especially in subclinical conditions. The IRT serves as an excellent indicator for clinical diag-

nosis and possible lesions in different regions, which will lead to loss of animal welfare [4] [5] [15].

In the current experiment, it was detected that the surface temperature at positions E1, E2 and E3 showed a reduction in the post-race period when compared to the pre-race, both in the animals that ran only once ($p < 0.001$) and in those that ran twice ($p < 0.001$). Erickson and Poole [17] observe that the circulation of blood in the coat does not change in horses during the maximum effort; however, horses and cattle run at speeds lower than 9.0 m/s during the physical effort of the cow [22], which does not characterize maximum effort and had different methods to dissipate the heating. In addition, the measurements at point E3 may reflect the use of the protective harness for up to 8 minutes, which can cause some degree of local sweating and thus reduce the surface temperature measured by the IRT. The small difference observed within the same phase during the day may be associated with a greater influence of the environmental temperature in these measurements, as it showed a median correlation with the surface temperature in E1, E2 and E3. The absence of acute (immediately after running) or chronic (in the evaluation of the following period) surface temperature at the base of the tail indicates the absence of local inflammatory process, resulting from injury or impairment of the structures used to unbalance and temporarily contain the cattle in the scoring range. However, because these three points has similar superficial temperature and showed same patterns of variation, in future we may need measure only one point, probably E1, which have a good clinical evaluation of the base of the tail after the race.

### 4.3. Environmental Conditions

Environmental conditions can interfere with the evaluations of the IRT as well as in the performance of horses and cattle during the running phase in vaquejada, but some automated systems already have algorithms that reduce the effects of the environmental conditions in this type of evaluation [8]. The measurements of the climatic conditions were performed in the areas of departure and arrival of the cattle and reflect these conditions, and it can also be stated that the climatic conditions were characteristically normal considering the seasonality and the state region where the vaquejada was occurring.

## 5. Conclusion

After the analysis of the results obtained in cattle that develop physical effort during vaquejada race, it was concluded that there were no elevations in the CLO or in the base of the tail at points E1, E2 and E3. The temperature in the CLO decreased physiologically due to running and activation of the sympathetic system but returned to normal values within 12 hours. The lack of elevations in the temperatures at the base of the tail, in all three points, indicates the absence of post-race injuries in this area throughout the vaquejada race. Thus, the IRT method was very efficient in determining the surface temperatures in cattle un-

der the conditions of the vaquejada race and can be a good noninvasive method for clinical and well-being evaluations in these situations, especially when combined with other methods such as "5 Domains".

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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