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Original article

Application of thermography in the assessment of physical effort on body surface temperature distribution in racehorses

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Abstract

The aim of this study was to evaluate the efficacy of thermography in assessing the impact of regular physical effort on changes in the body surface temperature of the upper body parts of young racehorses. The study involved monitoring 33 racehorses aged 3 years in 3 imaging sessions over a period of 3 months. Temperature measurements of the neck and upper part of the forelimbs and hindlimbs from both sides were taken just before and after training. Three regions of interest (ROIs) located at the base of the neck, elbow and quarter on both sides of the body were analysed. Before physical effort, the average temperatures in all ROIs did not differ significantly between the right and left side of the body. After physical effort average surface temperatures of the left side of the elbow and quarter were significantly higher compared to the opposite side and the temperature at the base of the neck was higher on the right side in comparison to the left side ($p<0.001$). Body surface temperatures of all ROIs after physical effort significantly ($p\leq0.001$) increased, with the greatest increase observed in the elbow (4.7°C) and the lowest in the base of the neck (3ºC). All regions demonstrated a positive correlation between average surface temperatures on the left and right side of the body, before and after training. There was a strong positive correlation between the average temperatures in the analyzed ROIs after physical effort with the strongest correlation between the elbow and quarter ($r=0.773$) and the weakest between the quarter and base of the neck ($r=0.474$). In conclusion, our study revealed that thermography remains a feasible diagnostic modality for identifying changes in upper parts of the body in response to physical effort and can therefore provide valuable insights into the assimilation of training regimes by the equine physiology.

Keywords: body surface temperature, horses, physical effort, thermography, upper part of the body

Introduction

Thermography is a non-radiating and contact-free imaging tool to monitor physiological functions related to body surface temperature (Kastberger and Stachl 2003). It is based on the registration and measurement of emitted infrared radiation (heat) from body surface providing qualitative and quantitative information on real-time changes in the surface temperature of the targeted tissues (Howell et al. 2020). Body surface temperature is influenced by fluctuations in peripheral blood flow beneath the skin, tissue metabolism density, extent of subcutaneous and muscle tissue, and coat characteristics. Therefore its distribution varies for each individual horse (Redaelli et al. 2014). In previous studies body surface temperature has been described in different environmental conditions (Kold and Chappell 1998, Tunley and Hanson 2004, Soroko et al. 2017a,b). It has been indicated that upper body areas with a rich vascular network, muscle tissue (e.g. neck, upper forelimb and hindlimbs) have a higher body surface temperature compared to the less muscular areas (e.g. around the forearm and gaskin) or areas with no muscle (e.g. the distal part of limbs: the carpal/tarsal joint to the hoof) (Čebulj-Kadunc et al. 2022).

Thermography serves as a valuable auxiliary tool in the identification and localization of temperature abnormalities characterized by increases in the case of an inflammatory process or decreases in the case of thrombosis, swelling or dense scar tissue in body surface temperature (Yanmaz et al. 2007, Čebulj Kadunc et al. 2020, Zielińska et al. 2020, Soroko-Dubrovina and Davis Morel 2023). Consequently, it has found successful application in the field of veterinary medicine in detecting inflammatory processes occurring in distal parts of limb regions including: laminitis (Turner 1991), tendinopathy, buck shines (Soroko et al. 2013) and inflammation of the stifle (Purohit et al. 2006), carpal and tarsal joints (Turner 2001). Other studies have indicated the usefulness of thermography in the detection of upper body injuries including spinous process inflammation (Turner et al. 1996), upper limb muscle strain, muscle inflammation, croup and caudal thigh myopathy (Turner 1996). It was found that temperature differences of more than 1°C over 25% of the compared body area in horses is considered to be abnormal (Turner et al. 1983, Soroko et al. 2013).

The non-invasive assessment of inflammatory changes underscores the role of thermography as an indispensable imaging modality for the analysis of alterations in body surface temperature following strenuous physical activity, with the capacity to evaluate specific anatomical regions within the context of sports and racing performance (Soroko et al. 2014, Soroko et al. 2017a,b, Soroko et al. 2022). An investigation conducted by Jodkowska (2005) described a model of horse body surface temperature before and after physical effort, ultimately concluding that body surface temperature patterns were correlated with exercise type and performance. As such, body surface temperature examination was helpful in assessing the quality of exercise and the preparation of the horse for training. Other studies highlighted the influence of treadmill exercises on body surface temperature changes in the forelimbs and hindlimbs as a measure of muscle activity (Simon et al. 2006, Yarnell et al. 2014). Remarkably, a substantial elevation in body surface temperature was observed in specific regions, including the neck, shoulder, elbow, gluteus and quarter regions, subsequent to treadmill work (Soroko et al. 2019a). However, the above studies were based on a small group sample and on data based on single thermographic evaluations. In addition, little objective work has been published on the thermographic reproducibility and reliability of upper body surface temperature changes within groups of horses in response to regular training. Consequently, the present study was aimed at evaluating the efficiency of thermography in assessing the impact of regular physical effort on changes in the body surface temperature of the upper body parts of young racehorses.

Materials and Methods

All horses included in this study underwent established, non-invasive protocols that ensured their well-being and physical comfort. As a consequence, this study did not necessitate approval from the Local Ethical Commission for Animal Experiments in accordance with the European directive EU/2010/63.

Animals and data collection

Measurements were collected from a cohort comprising 33 clinically healthy racehorses including 14 Thoroughbreds and 19 Arabians, all of which were 3 years of age. All the horses were trained at Partynice Racing Track (Poland) and participated in flat races during the 2020 season. The horses were accommodated in individual stables measuring 3 x 4 meters and adhered to a standardized management and training regimen. Prior to the study, all horses underwent comprehensive clinical and orthopedic examinations following the guidelines outlined by Stashak (2002) to confirm their soundness.

Thermographic images of the neck, upper part of forelimb and hindlimb from both sides of the body were obtained before and just after physical effort in three

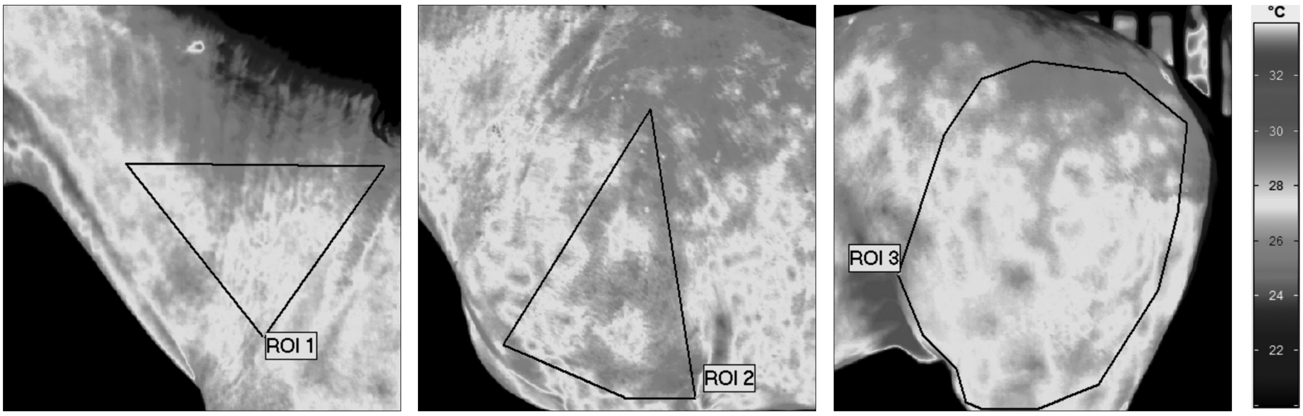

Fig. 1. Example of thermographic image of the left side of the horse neck, upper forelimb and upper hondlimb taken before physical effort with indicated regions of interst (ROI) including ROI 1 – base of the neck, ROI 2 – elbow and ROI3 – quarter indicated.

thermographic sessions taken every 4 weeks between April and June.

On each examination day, the horses underwent a training regimen that consisted of a 40-minute warm-up session within an automated horse walker, encompassing both walking and trotting in both directions. Following the warm up the horses had training under the saddle on the racetrack in walk for approximately 5 minutes, trot for 5 minutes with a distance of 1000 m and canter for 1 minute at a distance of 500 m in an inconsistent direction, and were cooled down in walk for 5 minutes. After training the horses returned to the stable. The horses were trained between 7.30 and 11.00 am at each session by a different rider from a team of four riders with similar riding experience and weight.

Thermographic examination

During each of the three sessions, thermographic images were captured in the morning before training following a night's rest at the stable, between 6.00 and 7.00 am and immediately (2-3 minutes) after training and untucking the examined horse. Thermographic images taken before and just after training encompassed areas including the neck, and the upper part of the forelimb and hindlimb form both sides of the body. To prepare the horses for the thermographic examination, a 20-minute acclimatization period was observed in the stable with closed doors and windows, thereby preventing any air drafts and direct sunlight exposure. The horses were brushed 30 minutes before examination to ensure the transient heat generated by brushing had subsided before obtaining baseline measurements. Thermographic images before and after physical effort were always performed at the same place, outside the horse's box within an enclosed stable and closed windows (Soroko et al. 2019b, American Academy of Thermology 2023).

The camera was positioned at a consistent distance of 2.5 meters perpendicular to the lateral surfaces of the neck, upper forelimb, and hindlimb for all thermal image captures. It is worth noting that during imaging, the horses maintained weight-bearing positions on all four limbs. The emissivity (ε) for all measurements was set to a standard value of 1, following the guidelines outlined by Howell et al. (2021).

A calibrated VarioCam HR infrared camera (uncooled microbolometer focal plane array, Focal Plane Array sensor size of 640 x 480, spectral range 7.5-14 µm, noise equivalent temperature difference of <20mK at 30°C, using the normal lens with IFOV of 0.57mrad, measurement uncertainty of ±1% of the overall temperature range, InfraTec, Dresden, Germany) was used for thermographic examination. Throughout all three sessions the ambient temperature in the stable was around 20°C with a humidity level of 50% (without major fluctuations). The outside temperature was on average 14°C. Temperature readings were obtained using a TES 1314 thermometer (TES, Taipei, Taiwan).

The temperature was calculated manually using IRBIS 3 Professional software (InfraTec, Dresden, Germany), by a single individual (M.S.D.). For each thermographic image capturing the neck and the upper part of the forelimb and hindlimb, a specific region of interest (ROI) was defined on the basis of major muscle groups and bony landmarks visible on the thermogram (Soroko et al. 2019a) including:

- the base of the neck (ROI1), encompassing the serratus ventralis
- the elbow (ROI2), encompassing the triceps brachii muscle
- the quarter (ROI3), encompassing the quarter muscle (Fig. 1).

Mean temperature (T average) was calculated for each ROI.

Table 1. Descriptive statistics of body surface temperature measurement results (°C) in horses in selected regions of interest with Pearson r correlation coefficient values on the left and right sides before and after physical effort.

	$T_{base\ of\ the\ neck}$		T_{elbow}		T_{quarte}r	
	Left side	Right side	Left side	Right side	Left side	Right side
Before physical effort						
Mean ±SD	29.9±1.1	30.0±1.1	29.0±0.9	29.0±0.9	28.6±1.1	28.7±1.2
Min-Max	26.5-31.5	26.7-31.6	26.2-29.9	26.2-30.1	25.0-30.3	24.7-30.4
Differencesleft *vs*. right	p=0.397		p=0.640		p=0.281	
Correlation left *vs*. right	r=0.900 p≤0.001		r=0.974 p≤0.001		r=0.962 p≤0.001	
After physical effort						
Mean ±SD	32.4±1.2	33.4±1.1	33.8±1.1	33.6±1.1	33.2±1.1	33.1±1.1
Min-Max	28.9-34.3	30.2-35.2	30.7-35.5	30.8-35.3	29.9-34.8	29.4-34.6
Differencesleft *vs*. right	p<0.001		p<0.001		p<0.001	
Correlation left *vs*. right	r=0.861 p ≤ 0.001		r=0.985 p ≤ 0.001		r=0.974 p ≤ 0.001	

p-value, t-test result for paired variables

Statistical analysis

The distribution of body surface temperatures did not exhibit statistically significant deviations from the normal distribution, which was verified by the Shapiro--Wilk test. In tables temperatures and their increments are presented as mean values and standard deviations. To assess the differences between temperatures recorded on the left and right sides of the body, as well as before and after physical effort, the t-test for dependent variables was used. The correlation between temperatures in different ROIs was checked by calculating Pearson's *r* correlation coefficients. The STATISTICA v. 13.3 program (TIBCO Software Inc., Palo Alto, CA, USA) was used for the statistical analysis of the measurement results.

Results

Prior to physical effort, the average temperatures in all ROIs did not differ significantly between the right and left side of the body for both breeds. However, following physical effort, it was observed that the average surface temperatures on the left side of the elbow and quarter were higher in comparison to the right side. The surface temperature of the base of the neck was higher on the right side in contrast to the opposite site. These distinctions were found to be statistically significant at a significance level of p<0.001, as indicated in Table 1.

Body surface temperatures of all ROIs immediately after physical effort significantly (p≤0.001) increased, compared to ROIs at rest. The most substantial increase in body surface temperature was observed in the elbow (ΔT_{elbow} = 4.7°C), while the smallest increase occurred at the base of the neck ($\Delta T_{base\ of\ the\ neck}$ = 3.0°C). In all three ROIs there was a strong positive correlation between average surface temperatures on the left and right side of the body, both before (from 0.900 on the base of the neck to 0.962 on the quarter) and after physical effort (from 0.861 on the base of the neck to 0.985 on the elbow). All correlation coefficient values reached values at p<0.001 (Table 1).

In the analysis of interdependence between the temperatures of the three ROIs, the average temperature increases measured on the left and right side of the body were taken into account. There was a strong positive correlation between the average temperatures in the analyzed ROIs before and physical effort (from a value of 0.937 between the quarter and elbow to 0.785 between the elbow and the base of the neck). The most significant correlation was observed in the context of the increase in body surface temperature between the elbow and the quarter (r=0.773), while the weakest correlation was noted between the quarter and base of the neck (r=0.474) (Table 2).

Discussion

Our findings underscore the practicality of employing thermography as a valuable tool in assessing the impact of physical effort on body surface temperatures in the upper body regions. Thermography stands out as a reliable, user-friendly, and secure equipment option for fast and accurate quantitative analysis of upper body surface temperature changes in response to physical exertion.

Table 2. Values of correlation coefficients between temperatures in regions of interest (ROI) before and after physical effort.

	ROI	ROI		
		Elbow	Quarter	Base of the neck
Before physical effort	Elbow	×	0.937 (p<0.001)	0.877 (p<0.001)
	Quarter		×	0.810 (p=0.001)
	Base of the neck			×
After physical effort	Elbow	×	0.890 (p<0.001)	0.863 (p<0.001)
	Quarter		×	0.785 (p=0.001)
	Base of the neck			×
Temperature increase	Elbow	×	0.773 (p<0.001)	0.756 (p<0.001)
	Quarter		×	0.474 (p=0.005)
	Base of the neck			×

Several studies on performance horses have documented changes in body surface temperatures across various body regions before and after physical effort confirming increment of body surface temperature following physical exertion (Jodkowska et al. 2011, Soroko et al 2019a, Soroko et al. 2022). During physical effort, the constriction of skin blood vessels directs blood primarily to the working muscles (Merla et al. 2010), concurrently restricting blood flow to other tissues (Charkoudia 2010). In this context, the core body temperature rises, approaching approximately 38°C, which triggers vasodilation as a thermoregulatory response. Subsequently, thermoregulatory mechanisms come into play, resulting in a linear increase in peripheral skin blood flow (Simmons et al. 2011). This increase is critical for dissipating excess body heat and is especially evident in active muscles (Hodgson et al. 1994). Previous studies conducted on clinically healthy horses confirmed that physical effort contributed to bilateral symmetry increment of body surface temperatures (Simon et al. 2006, Jodkowska et al. 2011, Čebulj-Kadunc et al. 2022). However, in the current study, it was observed that the increment in body surface temperature within all three ROIs was asymmetric following physical effort. Specifically, the left side of the elbow and quarter exhibited higher body surface temperatures compared to the right side, while the base of the neck displayed higher body surface temperatures on the right side.

The above results can be associated with the limitations of the study. Asymmetrical distribution of body surface temperature after physical effort could potentially be attributed to several factors, including training in varying directions or type of exercises performed. Nonetheless, previous studies based on horses working in a straight line on treadmill and in a circle during lunging indicated a high degree of bilateral symmetry in the upper parts of the body after physical effort (Simon et al. 2006, Čebulj-Kadunc et al. 2019, Čebulj-Kadunc et al. 2022). It is possible that environmental factors, such as variations in ambient temperature, wind speed, and sunlight exposure during outdoor training, contributed to the observed asymmetry between the left and right sides of the body. It has been reported in many studies that environmental factors have the most significant influence on body surface temperature distribution (Soroko et al. 2017a,b).

Thermographic images taken while the horses were at rest in a controlled environment presented bilateral symmetry between both sides of the body. These results are consistent with findings from previous studies on performance horses, where the distribution of temperature between symmetric sides of the body typically demonstrated a high degree of symmetry (Soroko et al. 2017a, Čebulj-Kadunc et al. 2019). It has been well documented that, in healthy horses, the pattern of skin surface temperature in the same body area on contralateral sides of the body is very similar (Palmer 1983, Tunley and Henson 2004). A number of studies have reported repeatable body surface temperature distribution in different horses (Purohit and McCoy 1980, Palmer 1981). This may also explain the positive correlation between ROI temperatures on both sides of the body indicated in the current study.

This study has also confirmed the substantial impact of physical effort on body surface temperature increase in all ROIs. The regions with the highest increase in body surface temperature were noted in the elbow area. A similar result was obtained in a previous study where the area of the shoulder manifested the highest increment in body surface temperature after a jumping competition (Jodkowska et al. 2011) and in routinely ridden horses (Soroko et al. 2019a). Differences in average surface temperature between the elbow and quarter after physical effort indicate the different muscle work of these regions, with the forelimbs carrying a greater load in supporting the body than the hindlimbs. During physical effort, the body weight of the horse is distributed between the forelimbs and hindlimbs with a ratio of 57:43 (Dutto et al. 2004, Witte et al. 2004). Consequently, the increased physical demand on the forelimbs accelerates the metabolic rate and oxygen demand, leading to elevated muscle perfusion and, ultimately, increased skin perfusion. This heightened skin perfusion enhances the dissipation of excess heat into the environment (Hinchcliff et al. 2008). Similar findings have been reported in other studies where it was indicated that a significant increase in body surface temperature was considerably higher in the forelimbs compared to the hindlimbs after physical effort (Jodkowska et al. 2001, Čebulj-Kadunc et al. 2022). Furthermore, a strong correlation was identified between the temperature increase of the triceps brachii and quadriceps femoris after training. Both of these limbs play a crucial role in movement, encompassing functions related to shock absorption and weight-bearing. A weaker correlation was noted between the neck and quadriceps.

We found that the lowest increase in body surface temperature after physical effort was in the neck area. Contrasting results were presented by Jodkowska et al. (2011), Soroko et al. (2019a) and Čebulj-Kadunc et al. (2022), where the neck was one of the warmest part of the body after training and at rest. However, in a prior study we conducted using dynamic infrared thermography to evaluate heat loss from body surface temperature during exercise on a treadmill, we found that the neck area actually cooled more compared to the shoulder and croup area after physical effort (Soroko et al. 2018). The fact that the neck area experienced the lowest increments in body surface temperature may reflect a slower increase in thermoregulation in the muscles of this area. Another explanation could be associated with the sweating effect, which allows heat dissipation via evaporation. It has been confirmed that the sweating rate in the neck was higher compared to the other areas of the body (Matsui et al. 2002). Moreover, it has been indicated that the neck area, as one of the warmest regions in terms of body surface temperature, exhibits a significant positive correlation between skin temperature and sweat production (Marlin et al. 1999). It is possible that localized sweating may account for these temperature differences; however, the specific influence of sweat was not assessed in our study.

In conclusion, our study has demonstrated that thermography remains a viable diagnostic modality to identify changes in the upper part of the body in response to physical effort. It offers valuable insights into how the body responds to training. We found that physical effort contributed to asymmetric body surface temperature distribution between both sides of the body and there was a significant increase in body surface temperature in all ROIs, with the highest increase in the elbow and the lowest in the base of the neck. The strongest correlation in body surface temperature increase was between the elbow and quarter, the weakest between the quarter and neck. Importantly, positive correlations were noted in the body surface temperatures of all ROIs on both sides of the body, both before and after physical effort. It is worth noting that thermography technology continues to advance, thereby increasing the sensitivity of the detectors and allowing for further definition and refinement of its existing uses. Further evaluation is warranted to explore the potential of this strategy for controlling the training load of high-performance athletes.

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