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The Maximum Temperatures (T_{max}) Distribution on the Body Surface of Sport Horses

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Abstract: The objective of the study was to determine the usefulness of measuring maximum temperatures in designated regions of a healthy horse's body surface. Thermographic investigations (Thermovision®550, FLIR) were carried out on 35 horses from 6 to 16 years old participating in show jumping competitions. The rectal temperatures of the horses were in the range 37.5-38.2 ℃. The research was performed in a stable, the ambient temperature (T_{ab}) of which was 14 ℃ with a humidity (φ) of 60%. Thermograms of the left and right side of the horses were obtained. Each thermogram consisted of 36 body surface regions (before the competition) and 25 regions (immediately after the competition). The maximum temperature ranges at rest were 21.8 ℃-31.0 ℃ and symmetrical regions did not differ statistically ($P > 0.05$). The highest temperatures were on the head, neck and trunk, the lowest-on the limbs. The hind legs were warmer than the front legs in analogous areas, with the exception of the gaskin and forearm. The warmest body areas had the largest surface area, which is indicative of their crucial role in the thermoregulation of the equine organism. The research results may therefore be useful in veterinary diagnosis. The range of maximum temperatures after the competitions was 25.2 ℃-34.2 ℃. The highest increment was observed at the breast, elbow, forearm and gaskin, the lowest–at the head, pastern and hoof (fore- and hind limbs). Research regarding body surface temperature after exercise does not have diagnostic value for veterinarians because "warming-up" certain parts of body surface masks inflammation.

Key words: Horses, thermographic research, maximum temperatures, body surface.

1. Introduction

Horses are homeothermic animals whose daily and seasonal changes in body temperature do not exceed ±1.5 ℃. Rectal temperature constitutes an indirect indicator. Due to their tolerance to substantial changes in ambient temperature, horses are eurythermic, which means that the amount of heat their organism produces may vary within broad limits. Minimum amounts of heat are released during necessary, physiological, life-maintaining processes, whereas maximum amounts of heat are released during long-term strenuous physical effort. A horse's organism loses a majority of its heat through its skin by means of convection, radiation, evaporation and conduction as well as via the respiratory system as a result of evaporation [1]. The loss of heat gives rise to a change in the temperature at the body's surface. Thermovision technology allows its temperature to be monitored as a result of the transformation of infrared radiation into light emission. The colours seen on thermograms correspond to temperature ranges, depending on tissue vascularization [2].

It is apparent from the above that the temperature at the surface of the horse's body may constitute an indicator of changes in thermoregulation. It must be stressed that this is modified by the influence of micro-climatic conditions, primarily ambient temperature [3].

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Certain diseases may also give rise to changes in body temperature [4-6]. Research in this respect has been conducted by a large number of authors (since 1964), the majority of which are cited in the professor dissertation [7].

The objective of our study was to determine the usefulness of measuring maximum temperatures in designated regions of the body surface of a healthy horse in relation to the musculature of particular body parts and the determination of the warmest and the coldest regions.

2. Materials and Methods

Thermogram research was carried out on 35 horses from 6 to 16 years old participating in show jumping competitions. The body-surface temperature of each horse was registered from left and right sides. The measurements were made half an hour before the competition and immediately after its completion. A Thermovision®550 (FLIR) thermovisual camera was used to measure temperature variations from a distance of approx. 3 metres. The thermograms obtained were analysed in relation to specific regions of the body on the basis of equine anatomy. The maximum temperature was determined for each of the regions, and the warmest places were precisely identified. Temperatures in 36 regions of the horse's body were measured by thermovisual camera prior to the competition (Fig. 1).

Immediately after the competition, it was only possible to register temperatures in 25 regions of the body (due to the presence of a rider on the horse's back and pads on the limbs) (Fig. 2).

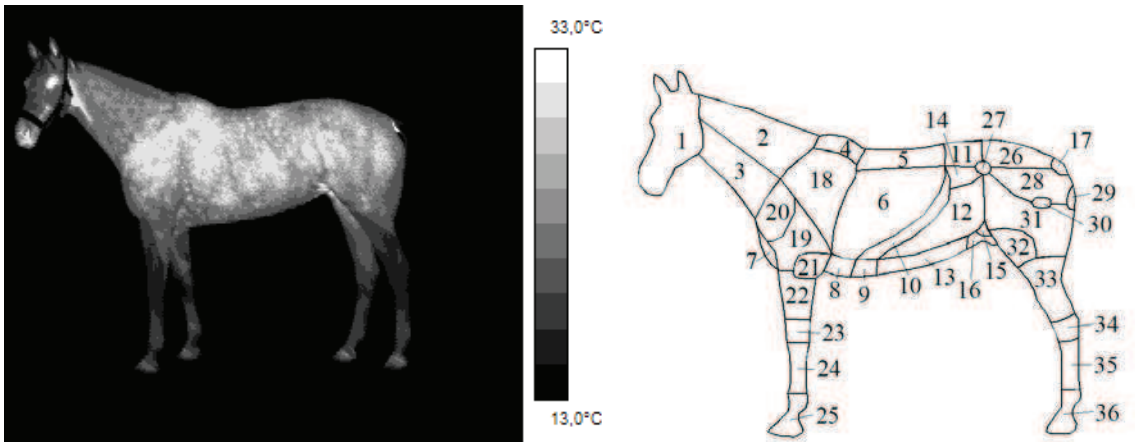

Fig. 1 Thermogram and regions of horse conformation before competition (explanation in Table 1).

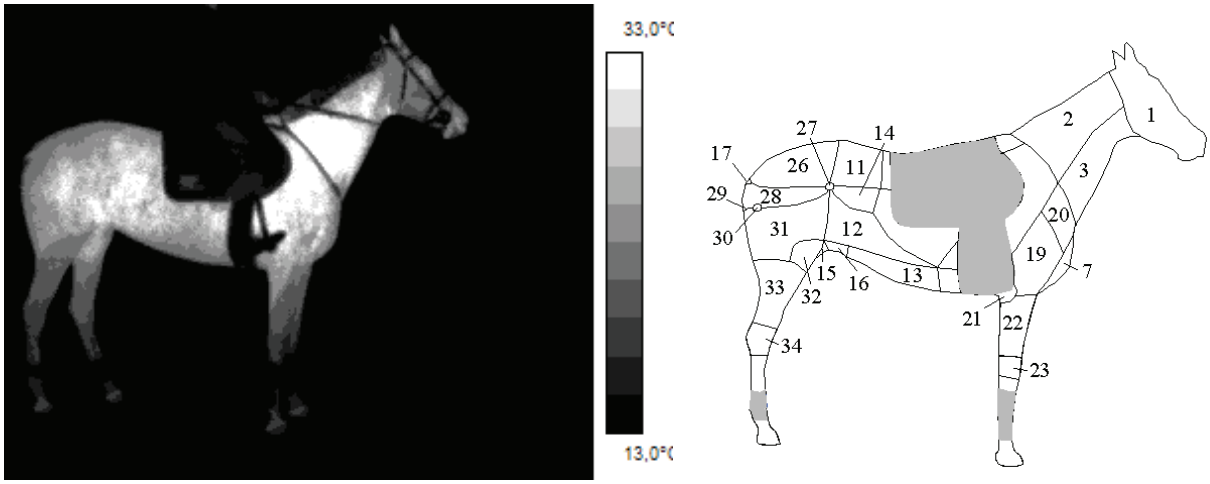

Fig. 2 The thermogram and regions of horse conformation after the competition (explanation in Table 2).

The rectal temperature of all horses fell within the boundaries of 37.5-38.2 ℃. The research was conducted in stables with an ambient temperature of T_{ab} = 14 ℃ and a relative humidity of φ = 60%.

The results of the research were analysed statistically, determining the maximum temperature and standard deviation, applying a Shapiro-Wilks normality test and a student's t-distribution test using Statistica 9.0 software of StatSoft Company (Poland) [8].

3. Results and Discussion

The maximum temperature of the horses' body surface at rest was from 21.8 ℃ to 31.0 ℃ (Table 1).

The lowest temperatures were observed in the case

Table 1 Maximum body surface temperature of horses before competition.

No.	Region of interest (ROI)	Maximum temperature ($\overline{T}_{max} \pm S_T$ (℃))		Test L v. R *P* value	Surface	
		Left side	Right side		cm^2	%
1	Head	30.8 ± 1.8	31.0 ± 1.7	0.687	1,338	8.3
2	Dorsal s. of neck	29.2 ± 2.0	29.8 ± 1.6	0.155	1,313	8.1
3	Ventral s. of neck	29.7 ± 2.4	29.6 ± 1.9	0.809	901	5.6
4	Withers	28.9 ± 2.3	29.4 ± 2.3	0.348	228	1.4
5	Back	29.1 ± 1.6	29.0 ± 1.3	0.823	487	3.0
6	Ribs	30.1 ± 1.3	30.3 ± 1.5	0.606	1,925	11.9
7	Breast	26.3 ± 2.1	25.6 ± 2.2	0.162	82	0.5
8	Fore flank	27.9 ± 2.2	28.0 ± 1.7	0.848	141	0.9
9	Costal cartilage	28.1 ± 2.1	28.0 ± 1.9	0.859	114	0.7
10	Subribs region	29.4 ± 1.8	29.6 ± 2.1	0.670	392	2.4
11	Loin	28.3 ± 1.9	28.9 ± 2.4	0.276	258	1.6
12	Hind flank	29.5 ± 1.5	30.0 ± 1.3	0.114	923	5.7
13	Abdomen	28.0 ± 1.2	28.1 ± 1.1	0.586	381	2.4
14	Coupling	29.6 ± 1.2	29.5 ± 1.0	0.588	160	1.0
15	Sheath	28.8 ± 2.6	28.0 ± 2.8	0.205	34	0.2
16	Groin	29.1 ± 3.1	29.2 ± 3.9	0.940	77	0.5
17	Dock	30.7 ± 3.2	29.4 ± 4.4	0.166	50	0.3
18	Shoulder	30.5 ± 4.2	30.9 ± 3.0	0.580	1,154	7.1
19	Arm	29.1 ± 4.1	29.7 ± 3.6	0.528	565	3.5
20	Point of shoulder	29.0 ± 4.3	29.9 ± 2.8	0.320	448	2.8
21	Elbow	27.7 ± 3.6	27.1 ± 3.8	0.467	220	1.4
22	Forearm	27.3 ± 5.0	27.2 ± 4.0	0.890	399	2.5
23	Knee	24.9 ± 4.2	24.6 ± 4.2	0.409	162	1.0
24	Cannon	21.8 ± 4.6	22.2 ± 4.0	0.625	255	1.6
25	Digit (phalanx)	26.9 ± 5.1	25.0 ± 4.0	0.082	261	1.6
26	Croup	29.1 ± 2.5	29.1 ± 2.0	0.966	453	2.8
27	Point of hip	28.5 ± 2.4	29.5 ± 2.1	0.060	45	0.3
28	Haunch	29.4 ± 2.7	29.9 ± 2.8	0.513	601	3.7
29	Point of buttock	29.8 ± 2.6	30.0 ± 2.3	0.728	42	0.3
30	Trochanter	28.7 ± 3.1	29.6 ± 2.7	0.243	48	0.3
31	Thigh	30.2 ± 3.7	30.5 ± 3.1	0.650	1,135	7.0
32	Stifle joint	28.0 ± 3.1	28.5 ± 3.4	0.569	326	2.0
33	Gaskin	26.4 ± 3.4	25.8 ± 3.4	0.517	601	3.7
34	Hock	25.1 ± 3.4	24.9 ± 5.0	0.377	160	1.0
35	Cannon	22.8 ± 5.5	23.1 ± 4.3	0.687	250	1.5
36	Digit (phalanx)	26.6 ± 4.6	27.1 ± 4.5	0.652	254	1.6
Total					16,183	100.0

of cannons, knee, hock and, breast and gaskin. The lower parts of the rear limbs were generally slightly warmer than the analogous parts of the front limbs, with the exception of the gaskin and forearm [9]. The areas around the digits were warmer than the areas around the cannons. Intermediate temperatures were recorded in the case of fore flank, costal cartilage, loin, stifle sheath and digits. The highest temperatures were identified in 20 places at the surface of the head, neck, trunk and upper parts of the limbs.

The above breakdown of areas at the surface of the horse's body at rest may be of diagnostic relevance. Their interrelations in respect of temperature are typical and any change in the above relations may be indicative of disease. It is important to compare the temperature of the given region with another region (temperature gradient) rather than the absolute numerical value of one of them. The surface area of each region and its percentage share of the entire surface area of the horse's side were calculated. Attention was paid to the fact that the largest clusters of maximum temperatures occurred over surfaces anatomically determined to be the largest, i.e. head, neck, shoulder, ribs and thigh. This indicated that they had a substantial share in the thermoregulation functions of the horse's organism.

After the show jumping competition, the range of the horses' body-surface temperatures was from 25.2 ℃ to 34.2 ℃ (Table 2). The lowest temperatures occurred at the knee and hock. The intermediate temperatures were

Table 2 Maximum body surface temperature of horses after competition.

No.	Region of interest (ROI)	Maximum temperature ($\overline{T}_{max} \pm S_T$ (℃))		Test L v. R *P* value
		Left side	Right side	
1	Head	30.9 ± 1.0	30.9 ± 1.2	0.829
2	Dorsal s. of neck	33.9 ± 1.2	33.3 ± 1.2	0.069
3	Ventral s. of neck	34.2 ± 1.5	33.8 ± 1.5	0.311
7	Breast	31.0 ± 1.2	31.0 ± 1.1	0.831
11	Loin	32.4 ± 1.5	32.1 ± 1.9	0.524
12	Hind flank	32.3 ± 1.7	33.1 ± 1.7	0.112
13	Abdomen	30.7 ± 1.9	31.1 ± 1.8	0.530
14	Coupling	32.0 ± 1.4	32.6 ± 1.3	0.066
15	Sheath	32.4 ± 1.0	32.3 ± 1.2	0.765
16	Groin	31.7 ± 1.8	31.6 ± 1.9	0.827
17	Dock	31.2 ± 1.6	31.6 ± 1.3	0.239
19	Arm	33.1 ± 0.6	33.1 ± 0.6	0.608
20	Point of shoulder	33.2 ± 1.7	32.9 ± 1.8	0.475
21	Elbow	32.4 ± 1.6	32.6 ± 1.7	0.627
22	Forearm	31.6 ± 1.3	31.7 ± 1.3	0.858
23	Knee	25.8 ± 1.7	25.2 ± 1.7	0.164
26	Croup	32.4 ± 1.7	31.5 ± 2.1	0.074
27	Point of hip	32.3 ± 2.2	31.9 ± 1.8	0.447
28	Haunch	32.9 ± 1.8	32.3 ± 1.9	0.272
29	Point of buttock	33.2 ± 1.3	33.1 ± 1.6	0.802
30	Trochanter	31.6 ± 1.4	31.7 ± 1.4	0.773
31	Thigh	33.1 ± 1.3	32.8 ± 1.8	0.580
32	Stifle joint	33.0 ± 1.8	32.6 ± 1.2	0.296
33	Gaskin	31.1 ± 1.8	31.3 ± 1.5	0.602
34	Hock	25.7 ± 1.0	25.9 ± 0.8	0.515

observed in the case of head, breast, abdomen, groin, forearm and gaskin, while the highest temperatures were recorded at the neck, arm, point of shoulder and thigh and another ten places. Similarly like before the competition, no statistically significant asymmetry in temperature between the right and left sides of the horses was found after the exercise [10, 11].

The greatest increase in maximum temperature following the competition was observed in the case of ventral s. of the neck, point of shoulder, elbow, croup, hip, haunch, stifle joint, gaskin (Table 3). This indicated that these regions played the greatest role in heat releasing from the horse's organism during an extreme work. However, no impact of effort on the increase in temperature was observed in the regions of the dock, knee and hock. On the other hand, the surface temperature of the head following the horse's exercise was slightly lower than before the competition. This could be explained by the functioning of the thermoregulatory centre in the hypothalamus, which controled the balance between heat-generating processes in the organism and its dissipation into its surroundings, on the basis of information sent by thermoreceptors.

The results presented in Table 3 may be interesting for horse riders and trainers in relation to the intensity of work of chosen regions of the body, in particular well-muscled regions. The following muscles had an

Table 3 Differences of body surface temperature * of horses, before and after competition.

No.	Region of interest (ROI)	T_{max} (℃) mean (min to max)		Mean (℃) difference	Two-tailed probability
		before competition	after competition		
1	Head	30.9 (30.5 to 31.7)	30.9 (30.6 to 31.2)	-0.02	$P = 0.6972$
2	Dorsal s. of neck	29.6 (29.1 to 30.4)	33.6 (33.3 to 33.9)	4.03	$P < 0.0001$
3	Ventral s. of neck	29.6 (28.9 to 29.9)	34.1 (33.8 to 34.5)	4.49	$P < 0.0001$
7	Breast	26.1 (25.5 to 27.9)	31.0 (30.7 to 31.3)	4.39	$P < 0.0001$
11	Loin	28.5 (28.1 to 29.6)	32.2 (31.8 to 32.7)	3.66	$P < 0.0001$
12	Hind flank	29.8 (28.9 to 30.2)	32.7 (32.3 to 33.2)	2.94	$P < 0.0001$
13	Abdomen	28.1 (27.4 to 29.3)	30.9 (30.4 to 31.4)	2.75	$P < 0.0001$
14	Coupling	29.5 (28.6 to 29.9)	32.3 (31.9 to 32.7)	2.81	$P < 0.0001$
15	Sheath	28.5 (28.1 to 29.3)	32.3 (32.0 to 32.6)	3.81	$P < 0.0001$
16	Groin	29.1 (28.6 to 29.1)	31.6 (31.1 to 32.1)	2.46	$P < 0.0001$
17	Dock	30.0 (29.2 to 30.9)	31.4 (31.0 to 31.8)	1.39	$P = 0.0026$
19	Arm	29.4 (28.8 to 30.9)	33.1 (32.9 to 33.3)	3.65	$P < 0.0001$
20	Point of shoulder	29.3 (28.0 to 30.2)	33.0 (32.6 to 33.5)	3.72	$P < 0.0001$
21	Elbow	27.4 (27.1 to 29.2)	32.5 (32.1 to 33.0)	4.96	$P < 0.0001$
22	Forearm	27.2 (25.9 to 28.3)	31.7 (31.3 to 32.0)	4.52	$P < 0.0001$
23	Knee	24.7 (23.4 to 26.0)	25.5 (25.1 to 26.0)	0.81	$P = 0.2722$
26	Croup	29.1 (28.4 to 30.4)	31.9 (31.4 to 32.4)	2.82	$P < 0.0001$
27	Point of hip	28.8 (28.3 to 29.4)	32.1 (31.5 to 32.6)	3.32	$P < 0.0001$
28	Haunch	29.6 (28.4 to 29.9)	32.6 (32.1 to 33.1)	3.04	$P < 0.0001$
29	Point of buttock	29.9 (29.3 to 30.7)	33.2 (32.8 to 33.6)	3.29	$P < 0.0001$
30	Point of hip	29.1 (28.4 to 29.8)	31.7 (31.3 to 32.0)	2.57	$P < 0.0001$
31	Thigh	30.4 (29.2 to 30.9)	33.0 (32.5 to 33.4)	2.60	$P < 0.0001$
32	Stifle joint	28.2 (27.2 to 30.1)	32.8 (32.4 to 33.2)	4.56	$P < 0.0001$
33	Gaskin	26.1 (25.3 to 28.2)	31.2 (30.8 to 31.6)	5.10	$P < 0.0001$
34	Hock	25.0 (23.9 to 26.9)	25.8 (25.4 to 26.1)	0.84	$P = 0.0747$

*arithmetic means and 95% confidence interval for the means.

influence on body-surface temperature above the knee: *Common digital extensor*, *Extensor carpi radialis* and *Ulnaris lateralis*, and above the hock: *Long digital extensor* and *Lateral digital extensor*. The surface temperature of the neck and trunk depends on the position of the following muscles: *Trapezius, Deltoideus, Long head, Lateral head, Cleidobrachialis, Subclavius, Latissimus dorsi, Extensor intercostal muscles, Extensor abdominal oblique* and *Internal intrecostal* [12].

The research regarding body surface temperature following an exercise were of no diagnostic value for veterinarians. It was proven in previous studies that "warming-up" certain parts of body surface masked an inflammation processes [13].

It must be emphasised that the horses being studied were taking part in competitions of varying difficulty levels (length of route, height and width of obstacles), hence their physical ability levels were not identical. Despite this fact, the differences in maximum temperature at the body-surface of individual horses before and after the competition were minor, as indicated by the standard variation levels, particularly around the region of the neck and trunk, which was indicative of the thermostability of these regions proven earlier [14].

However, the maximum temperatures of the limbs were characterised by a greater standard variation, which pointed to the thermolability of these regions. As an example, the temperatures of the surface before competition were thermolabile on the knee (ROIb 23) (Fig. 3) and thermostabile on the point of buttock (ROIb 29) (Fig. 4). After the show jumping, competition the temperature of point of buttock rose significantly, in comparison to knee. The knee lability decreased. Earlier publications proved the thermo-stability and thermo-instability of regions of the body in relation to variable micro-climatic conditions [14]. In this study, this was demonstrated in relation to horses subject to a workload.

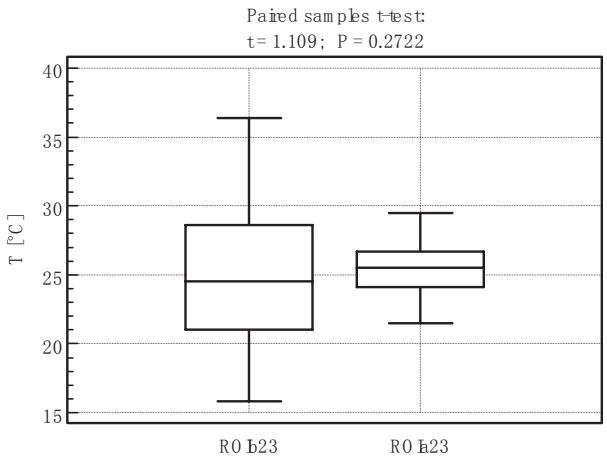

Fig. 3 Graphical characteristics of the surface temperature of knee (23) before (ROIb) and after (ROIa) exercise and the result of the student's t-distribution test (difference in temperature 0.8 ℃ statistically insignificant at a level of $P > 0.05$).

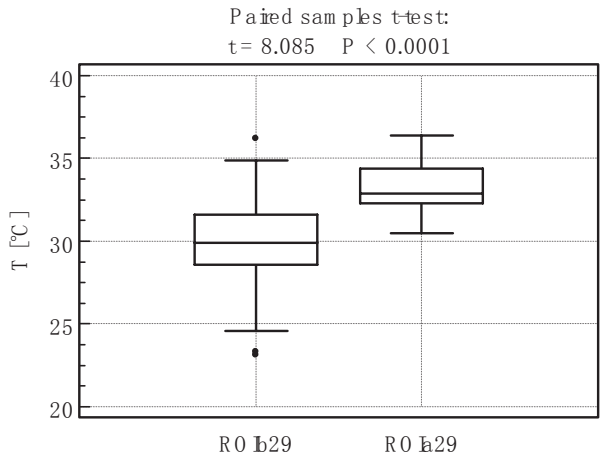

Fig. 4 Graphical characteristics of the surface temperature of point of buttock (29) before (ROIb) and after (ROIa) exercise and the result of the student's t-distribution test (difference in temperature 3.2 ℃ statistically significant at a level of $P < 0.0001$).

4. Conclusions

The study demonstrated the changes in body surface temperatures resulting from the exercise in particular body regions in horses. The choice of maximum temperatures is useful for characterising the distribution of temperatures for diagnostic purposes and for assessing the functioning of particular parts of the body during exercise. It is worth to emphasize that the interdependence of regions with maximum temperatures is significant in relation to the

musculature of particular areas. Horses are symmetrical as regards body-surface temperature measured from both sides, what means that any asymmetry discovered in this regard should be examined by a veterinarian. However the temperature level (℃) varies depending on individual characteristics and the environmental impact, the graphical distribution of body-surface temperatures is characteristic for all healthy horses regardless of their level of training. The knowledge of the body surface temperatures of horses in relation to the musculature of particular areas may be a useful tool in sports training planning.

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