Influence of exercise on thermographically determined surface temperatures of thoracic and pelvic limbs in horses

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Objective—To determine the amount of time required for surface temperatures of thoracic and pelvic limbs in horses to return to pre-exercise temperatures after high-speed treadmill exercise, as detected via infrared thermographic imaging.

Design—Prospective study.

Animals—6 Thoroughbreds.

Procedures—All horses had been trained on and conditioned to use of a high-speed treadmill. Baseline thermographic images were obtained 3 days prior to exercise (baseline). Horses were exercised on a treadmill at a walk for 5 minutes, a slow trot (3 m/s) for 5 minutes, a trot (5 to 6 m/s) for 5 minutes, and a slow gallop (6 to 8 m/s) for 5 minutes, then back to a trot for 3 minutes, a slow trot for 3 minutes, and a walk for 3 minutes prior to stopping. Thermal images were obtained immediately after stopping exercise (0 minutes) and 5, 15, 45, and 60 minutes and 6 hours after stopping exercise. Ambient temperature surrounding each horse was recorded.

Results—In all regions, significant differences in surface temperatures were detected between thermograms obtained before exercise and those obtained immediately after, 5 minutes after, and 15 minutes after exercise was stopped. There were no significant differences in surface temperatures between thermograms obtained before exercise and those obtained ≥ 45 minutes after exercise was stopped.

Conclusions and Clinical Relevance—In horses, images generated via infrared thermography are not influenced by exercise-generated heat ≥ 45 minutes after exercise is stopped. (J Am Vet Med Assoc 2006;229:1940–1944)

Thermography measures the amount of heat emitted from an object. Infrared thermographic imaging is noninvasive and has the potential to produce real-time assessments of regional inflammation that may subsequently cause clinical disease.1 Thermography can identify areas of inflammation and blood flow alterations by detecting changes in surface heat emitted from injured tissue.2 Infrared thermographic imaging can detect temperature changes before such changes can be detected by palpation.3 This sensitivity to emitted heat is beneficial for diagnosis of lesions, with potential to induce lameness in horses.4 Early detection of inflammation with thermographic imaging at flexor tendon sites and joints has been associated with positive prediction of clinical lameness.5,61 Influential tissue changes may be detected as much as 2 weeks before the onset of other clinical signs.6 Determining this information has the obvious benefit of helping avoid more serious injury. Limitations of thermography include a lack of sensitivity to deep lesions and chronic processes as well as a lack of specificity.6 Visual thermal images are generated with an infrared camera and computerized data manipulation. All objects with temperatures greater than absolute zero emit infrared energy as photons into the atmosphere.6,30 An infrared camera receives these photons on the lens surface, where photons are displaced and the current flow is measured to determine the amount of radiant energy emitted from the object.39 Modern infrared imaging instrumentation is approximately 10 times as sensitive to changes in surface temperature as that of the human hand.7

Thermal images should be obtained under standardized conditions. Controllable variables include motion, room temperature, and airflow. Ideally, thermography should be performed in a room with a temperature range of 20° to 23°C (68° to 77°F); however, thermography can be performed in temperatures < 30°C (86°F).6,14 Thermographically determined surface temperature patterns in horses have a high degree of bilateral symmetry between the thoracic limbs distal to the carpus and the pelvic limbs distal to the tarsus.10,12 The contralateral limb is typically imaged for symmetry and comparison.

Physical exercise results in net heat production, as only 20% to 25% of energy used by muscle is converted to mechanical energy.13 Thermoregulation is the maintenance of internal body temperature within a thermoneutral zone. Horses maintain body temperature within a thermoneutral zone of 37° to 40°C (98.6° to 104°F), which is evidence of active thermoregulatory capability.14 Heat loss through evaporation and convective...
Horses use these methods of thermoregulation during exercise and in a hot environment. In addition to sweating (heat loss through evaporation), horses can lose as much as 30% of heat generated during maximal exercise through respirations. Exercise intensity is the primary determinant of the rate of heat production. During exercise, metabolic heat production increases as exercise intensity increases.

High-speed treadmill trials have been routinely used to model exercise in horses. A working understanding of exercise and the influence of exercise on thermographic images of clinically normal horses is important to appropriately use thermography. The purpose of the study reported here was to determine the amount of time required for surface temperatures of thoracic and pelvic limbs in horses to return to pre-exercise temperatures after high-speed treadmill exercise, as detected via infrared thermographic imaging.

Materials and Methods

Horses—Six healthy adult Thoroughbreds (4 geldings and 2 mares) ranging in age from 7 to 12 years old and weighing from 463 to 542 kg (1,019 to 1,192 lb) were used in the study. Horses were owned by the Anatomy and Physiology Department, Kansas State University. The experimental protocol was approved by the Kansas State University Institutional Animal Care and Use Committee. Horses did not have clinical signs of lameness or musculoskeletal injury and were preconditioned to high-speed treadmill work. All horses were considered fit and routinely exercised on the treadmill while participating in ongoing studies. No physiologic parameters of fitness were determined during this study. Horses were housed in indoor 12 X 12-foot stalls. An indoor controlled environment was maintained before, during, and after the study. Coats of horses were considered normal and not excessively long. Surface temperatures of horses were adjusted for recorded ambient temperature. Ambient temperature was recorded by use of the infrared imaging camera, which was tested against a known heat source at 1.0 emissivity to ensure accuracy. Wind speed was considered to be zero because imaging was performed indoors. Images were obtained at a distance of 4 m perpendicular to the lateral and dorsal surfaces of the thoracic limbs and the lateral and caudal surfaces of the pelvic limbs (Figures 1 and 2). During imaging, horses were restrained with a halter and lead rope in a covered, environmentally controlled building. No sedation was administered at any time during the study. Horses were weight bearing on all 4 limbs during imaging.

Procedures—Thermal imaging equipment consisted of a high-resolution, short-wave (3- to 5-µm), radiometric infrared camera. The camera was equipped with a 16° field-of-view lens, with images displayed in a focal plane array arrangement. A certified technician using analytical software analyzed the images. Mean surface limb temperature was calculated from a 3,000-pixel image of each region imaged in each limb. Pixel intensity used in this study was chosen on the basis of equipment availability. Mean surface temperature of the proximal and distal portion of a limb by use of the carpal or tarsal region as the line of demarcation was determined. Calculations used the mean number of pixels com-

![Figure 1](image-url)

Figure 1—Lateral (A) and cranial (B) infrared thermographic images of the muscled regions (shoulder, pectoral, and antebrachial regions; black line) and MC3 regions (white line) of the forelimbs in a healthy horse. Color variants in the thermograms represent relative temperature transitions (gradients determined by camera sensitivity) and not absolute temperatures. These transitions are determined by the color spectrum differentials for each study. The real-time surface temperatures are also recorded by the receiving camera as numerical data such that these data are known for each study.
posing each image, with each pixel having a precision of 0.2°C. Mean temperature for each area was determined to compare changes in mean surface limb temperature or limb region as affected by time during the exercise protocol. Ambient temperatures were recorded and used to correct the daily mean surface limb temperature of horses by use of an adjustment factor of ±0.5 per degree > or < 20°C ambient temperature. Thermographic images were obtained 3 days prior to the beginning of the study as a baseline for all horses. Horses were exercised on the treadmill at a walk for 5 minutes, a slow trot (3 m/s) for 5 minutes, a trot (3 to 6 m/s) for 5 minutes, and a slow gallop (6 to 8 m/s) for 5 minutes, then back to a trot for 3 minutes, a slow trot for 3 minutes, and a walk for 3 minutes prior to stopping. Thermal images were collected before exercise (baseline); immediately after exercise was stopped (0 minutes); and at 5, 15, 45, and 60 minutes and 6 hours after exercise was stopped. Surface temperature was recorded for muscled regions (shoulder, pectoral, antebrachium, lumbar, rump, and crus and semimembranosus and semitendinosus muscles) and MC3 and MT3 regions. Exercise trials and infrared thermal imaging were performed 2 times/wk, and horses were continued in other exercise protocols between trials. Six exercise trials and image sets were completed for each horse.

Statistical analysis—Mean change in body surface temperature with time was compared by use of repeated-measures ANOVA for each region. All regions were analyzed individually. Each trial of each horse was compared, as were time intervals. All measurements were adjusted to account for variation in ambient temperature. For each region, the Kolmogorov-Smirnov normality lack-of-fit test was conducted on the residuals resulting from the associated repeated-measures ANOVA. In almost all regions, there were no significant deviations from normality (P > 0.05). In the 3 cases where the Kolmogorov-Smirnov test was significant, visual inspection of various probability plots indicated only minor deviations from normality; for example, P values resulting from the ANOVA were deemed valid. For all comparisons, a value of P ≤ 0.05 was considered significant. Paired t test comparisons of baseline and time intervals were performed to determine the statistical power by use of computer software. The power analysis was based on the maximum SD of differences among all muscled groups and MC3 and MT3 regions.

Results Each horse successfully completed the exercise protocols and recovery period without complications. In all horses, surface temperature changes were bilaterally similar on the basis of visual inspection and results of a paired t test. Surface temperatures of all muscled regions recorded in all horses immediately after, 5 minutes after, and 15 minutes after exercise were significantly (P ≤ 0.001 for all regions in all horses) increased, compared with surface temperatures recorded before exercise (baseline). Similarly, surface temperatures of all MC3 and MT3 regions recorded in all horses immediately after, 5 minutes after, and 15 minutes after exercise were significantly (P ≤ 0.001 for all regions in all horses) increased, compared with surface temperatures recorded before exercise (baseline). Similarly, surface temperatures of all MC3 and MT3 regions recorded in all horses immediately after (P ≤ 0.001), 5 minutes after (P ≤ 0.001), and 15 minutes after (MC3 left limb and MT3 right limb, P = 0.003; MC3 right limb, P = 0.010; and MT3 left limb, P = 0.002) exercise were significantly increased, compared with surface temperatures recorded before exercise. No significant differences were detected in surface temperatures between thermograms obtained before exercise and those obtained 45 minutes after exercise across all regions.

In all horses, a similar increase and decrease in emitted surface temperature were detected with time in muscled regions. Mean surface temperatures of all muscled
regions of all horses returned to baseline values within 45 minutes after exercise (Figure 3). In 5 of 6 horses, emitted surface temperature remained increased, compared with baseline values, in the MC3 and MT3 regions 45 minutes after exercise, although this increase was not significant (Figure 4). At 60 minutes, and also 6 hours after exercise was stopped, there was no significant ($P > 0.05$) difference in emitted surface temperatures in muscled regions or in MC3 and MT3 regions from emitted surface temperatures before exercise. Results of the power analysis indicated that the sample size had 81% (MC3 and MT3 regions) to 82% (muscled regions) power to detect a 10% increase in surface temperature, compared with baseline values, 45 minutes after exercise was stopped.

**Discussion**

Thermography appears to be safe and easy to perform and was not associated with any complications. In our study, there were no significant differences in surface temperatures of muscled regions between thermograms obtained before exercise (baseline) and those obtained 45 minutes after exercise. All regions in all horses had a significant increase in surface temperature immediately after treadmill exercise, with temperatures returning to or near baseline values within 45 minutes after exercise. Compared with baseline values, emitted surface temperature remained increased in the MC3 and MT3 regions in 5 of 6 horses 45 minutes after exercise, although this increase was not significant. Surface temperatures in these horses had all returned to baseline values or were lower than baseline values 6 hours after exercise.

In all horses, surface temperature changes were bilaterally similar. The increase in emitted surface temperature was greatest immediately after and 5 and 15 minutes after high-speed treadmill exercise. Surface temperatures of horses in our study returned to baseline within 45 minutes after high-speed treadmill exercise, perhaps abbreviating recommendations from another study, which suggests waiting a minimum of 2 hours after exercise before performing thermography. In that study, the authors considered that images obtained earlier than 2 hours after exercise would be inaccurate because of heat production and the thermoregulatory mechanisms of horses, particularly evaporation from sweating. False-positive image interpretation leading to loss of training and performance was the primary concern.

Sweating, which allows heat dissipation via evaporation, does not appear to provide a significant amount of heat loss at high ambient temperatures with high humidity. Sweating also did not appear to influence the thermograms generated in the study reported here. Perhaps the apparent lack of sweat influence on the infrared images in our study was attributable to the fitness of horses as they were conditioned to high-speed treadmill exercise and to the fact that the ambient temperature and wind speed were controlled. Horses conditioned to intense exercise are considered more effective at thermoregulation, and loss of water and electrolytes from sweat production is comparatively less than for unconditioned horses. Differences in emitted surface temperatures among horses in our study may have been attributable to undetermined differences in fitness or conditioning.

In the study reported here, muscled regions appeared to cool more rapidly than nonmuscled regions. Muscled regions dissipated emitted heat more rapidly, possibly because more heat was generated in these areas during exercise, creating a higher emitted surface temperature after exercise than nonmuscled regions. Emitted temperatures from these regions could therefore decrease rapidly after exercise is stopped. The rapid cooling of muscled regions may also have been attributable in part to greater surface area, the associated soft tissue mass available to disperse heat, and greater vascular perfusion in muscled regions than in nonmuscled regions. Local sweating may explain these temperature differences; however, the specific influence of sweat was not evaluated in our study.

In the study reported here, an expected increase in emitted surface temperature of the thoracic and pelvic limbs of healthy horses and the time required after high-speed treadmill exercise to return skin-surface temperatures to baseline values was detected. This understanding can provide a sound timeline for expected return to baseline surface temperature after exercise, thus reducing the possibility of false-positive thermography results. Infrared thermographic imaging earlier than 45 minutes after exercise may produce false-positive results, leading to loss of training or performance time. Results of the study report-
ed here indicated that infrared thermographic imaging can be performed after at least 45 minutes have elapsed from the termination of high-speed treadmill exercise, without risk of artifactual change in limb surface temperature.

References