Comparison of Postexercise Cooling Methods in Working Dogs

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ABSTRACT

Background: Overheating is a common form of injury in working dogs. The purpose of this study was to evaluate the relative efficacy of three postexercise cooling methods in dogs with exercise-induced heat stress. **Methods:** Nine athletically conditioned dogs were exercised at 10kph for 15 minutes on a treadmill in a hot environmental chamber (30°C) three times on separate days. After exercise, the dogs were cooled using one of three methods: natural cooling, cooling on a 4°C cooling mat, and partial immersion in a 30°C water bath for 5 minutes. **Results:** Time-weighted heat stress was lower for immersion cooling compared with the cooling mat and the control. The mean time required to lower gastrointestinal temperature to 39°C was 16 minutes for immersion cooling, 36 minutes for the cooling mat, and 48 minutes for control cooling. **Conclusion:** Water immersion decreased postexercise, time-weighted heat stress in dogs and provided the most rapid cooling of the three methods evaluated, even with the water being as warm as the ambient conditions. The cooling mat was superior to cooling using only fans, but not as effective as immersion. The placement of simple water troughs in working-dog training areas, along with specific protocols for their use, is recommended to reduce the occurrence of heat injury in dogs and improve the treatment of overheated dogs.

Keywords: *canines; hyperthermia; heat injury*

Introduction

Dogs are capable of very high rates of oxygen consumption,[1–3] and thus the generation of large amounts of mass-specific metabolic heat during exercise. However, they lack the robust heat dissipation processes of other athletic mammals such as humans and horses.[4] This mismatch of heat generation and dissipation makes dogs particularly prone to overheating and heat-related injuries during exercise. The implications of heat-related injury are substantial, with a mortality rate of up to 50% of dogs that have central nervous system signs related to overheating.[5] Professional working dogs, such as dogs used in law enforcement or military applications, appear to be particularly at risk because of the substantial amount of metabolic heat generated during short-term strenuous exercise and the hot environments in which this exercise takes place. Heat-related injury is at least as common as ballistic injury.[6] and, in some cases, more common, in law enforcement dogs. The key treatment for addressing overheating in human athletes is rapidly removing the excess heat through immediate and aggressive cooling.[7,8] Similar techniques have not been tested in dogs in a field situation where the greatest benefit can be realized. Therefore, the purpose of this study was to compare the relative benefits of two methods used to cool dogs with exercise-induced hyperthermia: a transportable refrigerated mat and 5 minutes of immersion in 30°C water. We predicted cooling with the refrigerated mat would be more rapid than cooling after immersion.

Methods

Experimental Design

All procedures used in this study were approved by the Oklahoma State University Institutional Animal Care and Use Committee. Nine healthy Labrador retrievers (*n* = 4 intact male dogs; *n* = 5 spayed female dogs) were used in this study. Their mean (standard deviation [SD]) age was 3.1 (0.8) years and mean body weight (SD) was 28.6 (3.5) kg. Dogs had completed a 5-week endurance conditioning program to prepare them for up to 9 h/d of intermittent off-leash exercise under warm environmental conditions.[9]

The study design consisted of testing of three different cooling techniques (i.e., control, cooling pad, and immersion) on three different days in a randomized, complete-block design. For each cooling technique, a radiotelemetric temperature sensor (CorTemp; HQInc, http://www.hqinc.net/) was administered to the dogs approximately 30 minutes before they performed a standardized treadmill exercise (10kph on a 2% incline for 15 minutes) in a warm environmental chamber (30°C). Whereas ambient air temperature was positively controlled through a high-capacity heating, ventilation, and air conditioning system, water vapor content of the air in the environmental chamber was not specifically controlled. As a result, relative humidity increased throughout each day of the study due to the presence of dogs and personnel in the chamber, beginning each day at approximately 40% and increasing to approximately 80% by the end of the day, resulting in ambient enthalpy range of 57–84kJ/kg. To avoid the confounding effect of different enthalpy gradients on the effectiveness of cooling techniques, dogs were exercised in the same order each day so that for each dog, the exercise and postexercise ambient conditions were approximately the same.

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Control cooling involved placing dogs in a standard airline shipping kennel (91 × 63 × 68cm; volume, 390L) within the environmental chamber with a standard 40cm fan used to circulate air through the kennel. The cooling pad condition was similar to control cooling, with the addition of a mat on the bottom of the kennel that was continuously perfused with 4°C water. Immersion cooling involved placing the dog in a 400L water tank filled with ambient (30°C) water sufficient to cover the dog's back for 5 minutes immediately after completion of the treadmill exercise (Figure 1), then allowing the dog to remain in the environmental chamber in a standard airline kennel.

FIGURE 1 *Example of the immersion cooling technique using a standard livestock water trough.*

Gastrointestinal (GI) temperature was recorded from the ingested radiotelemetric sensor immediately before the exercise test and every 2 minutes after exercise for up to 120 minutes or until the GI temperature returned to the pre-exercise baseline (equal to or below the pre-exercise temperature for the individual dog on that day), whichever came first. In addition, rectal temperature was measured every 4 minutes after exercise on the first day of the study to compare rectal and GI temperatures for agreement and correlation.

Statistical Methods

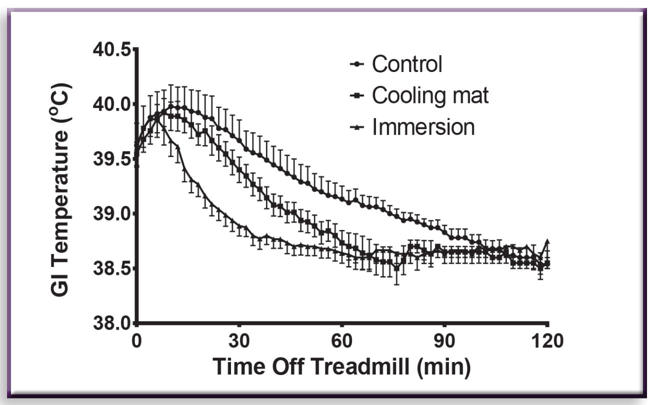
Several end points were calculated from the raw GI temperature data to assess cooling effectiveness. Peak postexercise temperature was the maximum GI temperature reading recorded for the dog after the exercise test. The 30-minute rate of cooling was the slope of the time versus temperature measurements for the first 30 minutes after the exercise test. The areas under the time versus temperature curve for 0 to 30 minutes (AUC30) and 0 to 60 minutes (AUC60) were calculated as the integration under the time versus temperature curve using the pre-exercise temperature as the baseline. Time to 39°C was the time after exercise required to record the first GI temperature reading that was at or below 39°C, and time to baseline was the time after exercise required to record the first GI temperature reading at or below the pre-exercise GI temperature. If the dog's temperature had not reached its pre-exercise value by 120 minutes, 120 minutes was recorded for the time to baseline for that dog and cooling technique.

Statistical analysis was performed using commercial statistical software (GraphPad, version 6.01; GraphPad Software, https://www.graphpad.com/). Analysis for an effect of cooling technique was performed using a repeated measures one-way analysis of variance with dog as the blocking variable and post hoc all-pairwise comparisons with correction for multiple comparisons. Rate of cooling in the first 30 minutes was analyzed using nonparametric techniques due to the extremely high variability and non-Gaussian distribution of the data. Bland-Altman analysis was performed on paired GI and rectal temperatures to assess the presence of bias. In all cases, $P < .05$ was considered statistically significant.

Results

All dogs completed the exercise test and subsequent cooling periods without evidence of heat-related injury. All dogs had resting temperatures that were appropriate for resting dogs before each exercise session, and there were no statistically significant differences (mean ± SD) in the GI temperatures of the dogs based on subsequent cooling technique before exercise (control, 38.49°C ± 0.35°C; cooling mat, 38.47°C ± 0.25°C; immersion, 38.53°C ± 0.27°C; $P = .88$) or immediately after exercise (control, 39.61°C ± 0.60°C; cooling mat, 39.54°C ± 0.33°C; immersion, 39.60°C ± 0.53°C; $P = .87$). GI temperature continued to rise for 10–15 minutes after completion of the exercise (Figure 2), resulting in a slightly higher peak after exercise, compared with immediately after exercise, that was not significantly different between cooling techniques ($P = .55$; Table 1).

FIGURE 2 *Effect of cooling technique on gastrointestinal temperature of dogs after moderate exercise in thermally stressful environment.*



Data are expressed as mean ± standard error of the mean. Immersion positive error bars and control negative error bars have been omitted for visual clarity. GI, gastrointestinal.

Immersion in water at ambient temperature for the first 5 minutes after exercise resulted in faster reduction in GI temperature during the first 30 minutes after exercise than did the control cooling condition, but immersion was not significantly faster than cooling with the cooling mat ($P = .006$; Table 1). Five of the nine dogs had positive time versus temperature regression slopes during the first 30 minutes of the control cooling condition, whereas only two of the nine had positive slopes during the cooling mat condition and none of the dogs had positive 30-minute time versus temperature regression slopes during immersion cooling. The time-weighted heat stress for the first 30 minutes after exercise (i.e., AUC30) was significantly lower for immersion cooling compared with both the control and cooling mat conditions ($P = .01$; Table 1).

All cooling techniques differed from each other in time required to reduce GI temperature to 39°C ($P = .002$), with immersion requiring less than one-half the time required using the cooling

TABLE 1 *Postexercise Cooling Using Three Different Methods for Nine Dogs*

End Point	Control	Cooling Mat	Immersion
Peak postexercise temperature, °C	40.03 ± 0.60	39.94 ± 0.39	39.88 ± 0.49
30-minute rate of cooling, °C/h	4.86 (−3.65 to 18.86)[a]	−5.15 (−9.39 to 0.11)[a]	−7.32 (−11.49 to −5.98)[a]
AUC30,[b] °C × 30 minutes	40.99 ± 14.88[a]	37.56 ± 14.02[a]	26.02 ± 14.95[a]
AUC60,[b] °C × 60 minutes	66.66 ± 28.89[a]	53.69 ± 24.30[a]	40.10 ± 29.96[a]
Time to 39°C, minutes	51.33 ± 20.22[a]	38.00 ± 11.49[a]	20.22 ± 7.44[a]
Time to baseline, minutes	102.40 ± 22.20	77.11 ± 27.93	73.11 ± 46.09

Data are given as mean ± standard deviation except for 30-minute rate of cooling, which is reported as median (25%–75%), due to non-normal distribution. AUC30, area under the time versus temperature curve for 0 to 30 minutes; AUC60, area under the time versus temperature curve for 0 to 60 minutes.
[a]$P < .05$.
[b]Area under the curve of the temperature × time curve, representing a measure of cumulative heat stress.

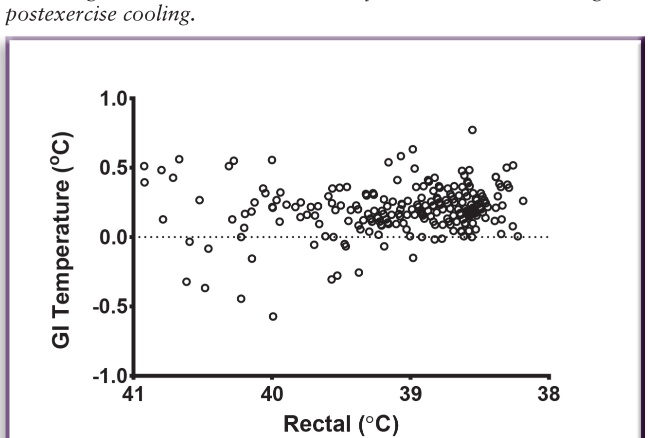
mat and one-third the time required by control cooling. Immersion resulted in lower time-weighted heat stress for 60 minutes after exercise compared with control cooling (i.e., AUC60; $P = .02$), but there was no statistically significant difference between use of the cooling mat and control cooling. Despite the more rapid initial cooling using the immersion technique, we did not measure a statistically significant effect of cooling technique on time required to return to baseline temperature ($P = .18$).

A total of 239 pairs of GI and rectal temperatures were available for Bland-Altman analysis, which found a bias for GI temperature to be 0.20°C ± 0.17°C higher than rectal temperature for all measurements. The bias was not uniformly distributed across all observations (Figure 3); rather, the bias was smaller (but the variability greater) when GI temperature was higher than approximately 39°C (0.14°C ± 0.21°C; $P = .022$; $n = 90$ observations) compared with when the GI temperature was equal to or lower than 39°C (0.24°C ± 0.13°C, $P = .011$; $n = 149$ observations; $P < .0001$).

Discussion

Heat-related injury is a relatively common occurrence in exercising dogs.[10] A commonly cited threshold for the diagnosis of heat stroke in dogs is a core temperature of 40°C,[11] but this and many other studies[9,12–15] have reported higher core or rectal temperatures in dogs that did not appear to suffer from

FIGURE 3 *Bland-Altman residual distribution for difference between gastrointestinal and rectal temperatures obtained during postexercise cooling.*



The horizontal dotted line is a reference point for zero bias, with most of the data points above the zero reference line, illustrating that rectal temperature underestimated core temperature in this group of dogs.

heat-related injury. Rectal temperature is the more commonly used measurement to assess body temperature in dogs, but the agreement between rectal temperature and the temperature of the GI tract is difficult to predict because of regional differences in tissue temperature and lag time in CorTemp capsules,[16] particularly in dogs exercising in thermally stressful environments where a steady state may not be achieved. Tissue damage resulting from heat stress is the product of temperature intensity and duration. Although any excess in temperature carries a risk of heat-related tissue injury, very high temperatures cause tissue damage much more rapidly than do high temperatures.[17] Although the exact threshold may be subject to debate, clinical signs of organ system dysfunction, particularly the central nervous system, mandate rapid minimization of heat production and prompt removal of excess heat. Current recommendations cite heat removal as the primary initial goal of therapy.[11,18] Water immersion is the gold standard treatment in human exertional heat stroke.[19] Based on the results of the current study, immersion demonstrated clear superiority over other methods in reducing postexertional heat load in dogs, as well.

Removal of excess metabolic heat from a dog is a two-step serial process: Transport the heat to a surface of the dog that is in direct contact with the environment, and passively dissipate the heat from that surface into the environment using one or more heat-transfer processes. Heat transport to the surface of the dog is accomplished through blood flow through the source of the metabolic heat (i.e., muscle) and then to the vasculature within the heat dissipating tissues.[15]

The importance of cardiovascular performance in thermoregulation is well established: Decreased cardiovascular performance leads to impaired thermoregulation.[14] Skin is by far the most abundant surface directly in contact with the environment surrounding a dog. Canine skin is poorly suited for heat transfer compared with human skin. Canine skin lacks an extensive network of superficial papillary capillaries[20,21] (exceptions being the footpads and the nasal planum) and the vestigial sweat glands of canine skin are not under central control,[22] resulting in a lack of activation during whole-body hyperthermia. In addition, the thick fur coat of the typical canine athlete insulates the skin from the environment (evidenced by a gradient between skin surface temperature and the temperature of the outer fur[3]), slowing the rate of heat transfer by conduction or convection. As a result, there is minimal heat loss through the skin until the rectal temperature is above 40°C.[3,23]

At rectal temperatures below 40°C, thermoregulation is mostly through the respiratory tract by the combined processes of warming and humidifying inhaled air (with likely some contribution through nonglabrous areas such as the footpads). At 24°C and 53% relative humidity (total ambient enthalpy, approximately 47 kJ/kg), maximal rate of respiratory evaporative cooling in a 26kg dog is about 1.8 kcal/min,[4] but this rate would be expected to be lower in the conditions of our study (57–84 kJ/kg).

Assuming that the peak postexercise GI temperature represents an approximate mean temperature of the entire dog and 0.83kcal/kg/°C as the specific heat of mammalian tissue,[3] the dogs in our study had approximately 30kcal of excess metabolic heat stored after the exercise challenge and thus would require at least 16 minutes, using only evaporative cooling, to return to baseline temperature. Faster exercise for a longer duration can result in a greater amount of stored metabolic heat even in the presence of a cooler environment more favorable for heat dissipation.[13] That the actual time required was much longer highlights not only the fact that the maximum rate of evaporative cooling was lower in the more thermally stressful conditions of our study but also the possibility that the dogs either elected not to use maximal evaporative cooling or were unable to do so.

There were clear differences in the three approaches to postexercise cooling in this study, with the control technique of simply moving increased amounts of ambient air over the dog being the least effective and temporary immersion being the most effective. All dogs breathed air with similar water content (ranging from 12.5 to 25g/m^3) during the three different cooling techniques, so the contribution of respiratory evaporative cooling for each dog to the overall rate of heat dissipation was relatively constant. Though we did not measure the temperature of the air inside the kennel with the cooling mat, it is possible that the cooling mat cooled the air somewhat, resulting in slightly increased respiratory and cutaneous heat loss due to nonevaporative heat transfer. However, the volume of air in the kennel (approximately 362L, or 0.362m^3, after displacement of some volume by the dog itself) would only be able to absorb approximately 0.1kcal/°C due to the low specific heat capacity (0.2403kcal/kg/°C) and very low density (1.15kg/m^3). Thus, warming of the 30°C air in the kennel to the pre-exercise body temperature of the dog (38.5°C) would only remove 0.85kcal of stored metabolic heat, and even in the unlikely event that the air within the kennel completely equilibrated with the mat (4°C) and then was warmed by the dog's respiratory tract, only approximately 3.4kcal of stored heat would be removed.

More likely is that conduction between the dog's footpads and the cooling mat resulted in enhanced removal of stored metabolic heat, improving the cooling performance of this technique relative to simple air movement in the control approach. Although the dogs in this study did not reach body temperatures that would have allowed for significant transcutaneous heat transfer (as least with air as the environmental element receiving the heat), the vascular networks in the footpads were likely capable of transferring body heat from the dog to the environment, including the cooling pad. The dogs either stood, sat, or were recumbent on the pad, but in all postures, their footpads were consistently in contact with the cooling mat. Humans have similar vascular networks in the palms of the hands, and palmar cooling has been shown to be effective in rapidly removing metabolic heat from human athletes, in some cases resulting in improved performance.[24]

A similar phenomenon likely contributed to the more effective cooling with the cooling pad in this study, as well as to the even greater magnitude of cooling observed using the immersion technique. Although the water in the cooling mat was colder than the water in the immersion tank, the immersion tank allowed for a much greater cooling contact area across the footpads than the mat. In addition, by completely immersing the dog, the insulating properties of the fur were eliminated and the entire body surface of the dog was available for heat transfer. Despite the comparably lesser cutaneous perfusion in the dog relative to humans, blood flow nevertheless is present and thus is capable of delivering some excess metabolic heat to the skin to be dissipated, The combined differences in specific heat capacity and density between water and air means that it requires 0.0003 the volume of water to absorb the same amount of heat as does air. We believe that the combination of more water movement over the pads and greater overall surface area available for cooling resulted in the superior performance of the immersion cooling technique compared with the cooling pad or simple ambient air.

Recommendations

The conditions of our study were specifically constructed to replicate those typical of off-leash detection dogs under moderate environmental heat stress. The environmental temperatures and average moving speed were comparable to those measured in an experimental reenactment of a typical detection patrol for improvised explosive devices,[9] with the exception of the duration of the exercise, which was probably responsible for the slightly lower temperatures of the dogs compared with previous field exercises.[9,12] The parameters of postexercise cooling (specifically, leaving the dogs in the same environment in which they exercised and using water thermally equilibrated with ambient temperature) similarly were selected to replicate the relatively challenging and austere environment of forward-deployed patrols. The superiority of the immersion technique, despite the use of water that was the same temperature as the surrounding environment, highlights the potent capacity of water for absorbing heat, and the theoretical benefit of very cold water for rapid extraction of body heat down a large thermal gradient can be approximated with relatively large volumes of warmer water. A typical medium-sized livestock tank (such as was used in this study) contains up to 400L of water, which would provide the capacity to absorb more than 100 times the amount of excess heat in an overheated, average-sized dog even if the initial water temperature was 30°C. This approach is inexpensive and effective, and its prophylactic availability is recommended anywhere dogs are routinely exercising and incurring increased risk for heat-related injury.

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Disclosure
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