U.S. Army Research Institute of Environmental Medicine

Natick, Massachusetts

TECHNICAL REPORT NO. T20-14
DATE July 2020

PLANNING WORK/REST CYCLES FOR MILITARY WORKING DOGS IN HOT ENVIRONMENTS USING A CANINE THERMAL MODEL

United States Army
Medical Research & Development Command

DISCLAIMERS

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*: 07-30-20

2. REPORT TYPE: Technical Report

3. DATES COVERED *(From - To)*: 2019-2020

4. TITLE AND SUBTITLE

PLANNING WORK/REST CYCLES FOR MILITARY WORKING DOGS IN HOT ENVIRONMENTS USING A CANINE THERMAL MODEL

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)

Catherine O’Brien

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Thermal and Mountain Medicine Division
U.S. Army Research Institute of Environmental Medicine
Building 42 - 10 General Greene Ave
Natick, MA 01760

8. PERFORMING ORGANIZATION REPORT NUMBER

T20-14

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Medical Research and Development Command
504 Scott Street
Fort Detrick , MD 21702-5012

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The U.S. Army Research Institute of Environmental Medicine (USARIEM) Canine Thermal Model (CTM) was used to construct work/rest cycles for Military Working Dogs (MWDs) in hot environments. The CTM predicted Tc response to exercise and recovery of an average sized MWD (30 kg body mass, 100 cm length) in various environmental conditions (24°C to 30°C air temperature, 45% to 85% relative humidity, 0 to 40°C mean radiant temperature, low wind speed). Exercise intensity was estimated as metabolic equivalent of task (MET level). During recovery, MWDs were assumed to be at rest (1 MET) in the shade. Work time to reach a Tc of 41°C was 16 to 17 min at 7 METs and 20 to 23 min at 5.5 METs. Rest time to return to a Tc of 39.2°C was 46 to 72 min. Work/rest cycles constructed using the CTM can improve guidance for mitigation of heat strain in MWDs. Predicting recovery is a critical aspect of risk management when evaluating environmental heat stress and implementing control measures. A mobile application of the CTM is currently being developed by the U.S. Army Medical Materiel Development Activity (USAMMDA)

15. SUBJECT TERMS

core temperature, exercise, recovery, hyperthermia, heat injury, thermoregulation, work/rest, guidance, risk assessment, limits, exposure, MWD, heat stress, heat strain, training

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	Unclassified	24	Catherine O'Brien
					19b. TELEPHONE NUMBER *(Include area code)*: 508-206-2350

Reset

USARIEM TECHNICAL REPORT T20-14

PLANNING WORK/REST CYCLES FOR MILITARY WORKING DOGS IN HOT ENVIRONMENTS USING A CANINE THERMAL MODEL

Catherine O'Brien

Thermal and Mountain Medicine Division

July 2020

U.S. Army Research Institute of Environmental Medicine

Natick, MA 01760-5007

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

BS	Building Search
CA	Controlled Aggression
CTM	Canine Thermal Model
GF	Gunfire
KW	Exercise walk at the kennel area
MET	Metabolic equivalent of task
MRT	Mean radiant temperature
MWD	Military working dog
OB	Obedience
OC	Obstacle Course
Ta	Air temperature
Tc	Core temperature, measured in the gastrointestinal tract for this study
Tw	Water temperature
RH	Relative humidity
SC	Scouting
USARIEM	United States Army Research Institute of Environmental Medicine
USAMMDA	United States Army Medical Materiel Development Activity
VS	Vehicle Search
WBGT	Wet bulb globe temperature
WS	Wind speed

INTERNATIONAL SYSTEM OF UNITS

This report uses the international system of units. The following conversions are presented as reference for key core temperature values:

°C	°F
38.3	100.9
39.2	102.6
40.5	104.9
41.0	105.9

ACKNOWLEDGMENTS

The participation of the Military Working Dogs (MWDs) and handlers, and the support of the 341st Training Squadron and the Department of Defense MWD Veterinary Service were critical to the success of this project and are sincerely appreciated. The Canine Thermal Model (CTM) was developed by Dr. Larry Berglund. His enthusiasm and depth of knowledge of canine physiology ensured success. This development and the validation of the CTM would not have been possible without the vision of Dr. Reed Hoyt, the data collection contributions of William Tharion, Anthony Karis, and Heather Sullivan, and the funding provided by the Defense Health Program Joint Program Committee 5.

EXECUTIVE SUMMARY

Introduction: Effective planning for duration of work and rest is important for limiting the increase in core temperature (Tc) and ensuring adequate recovery to mitigate risk of overheating. This report describes the application of the U.S. Army Research Institute of Environmental Medicine (USARIEM) Canine Thermal Model (CTM) for constructing work/rest cycles for Military Working Dogs (MWDs) training in hot environments. **Methods:** The CTM was used to predict Tc response to exercise and recovery of an average sized MWD (30 kg body mass, 100 cm length) in various environmental conditions (air temperature, relative humidity, mean radiant temperature, wind speed). Exercise intensity was based on estimated metabolic equivalent of task (MET level): 7 METs for a training session and 5.5 METs for an exercise walk. During recovery, MWDs were assumed to be at rest (1 MET) in the shade. Environmental conditions spanned temperatures from 24°C to 30°C and humidity from 45% to 85% RH, and solar radiation varied with time of day. Work duration was determined by the time for predicted Tc to reach 41°C, a typical value reached by MWDs during training. Recovery duration was determined by the time for predicted Tc to return to 39.2°C, the upper end of the range of resting Tc. **Results:** Work durations ranged from 16 to 17 min at 7 METs, 20 to 23 min at 5.5 METs. Recovery durations ranged from 46 to 72 min. During work, the largest contributor to the increase in Tc is metabolic heat production from exercise; therefore, work duration depends more on exercise intensity than the environmental conditions. However, during rest, rate of recovery of Tc is more directly related to environmental conditions. The CTM simulations were evaluated against measured Tc of MWDs exercising in similar environmental conditions, providing a way to assess the suitability of the CTM for constructing work/rest guidance for this population. **Summary:** Work/rest cycles constructed using the CTM can improve guidance for mitigation of heat strain in MWDs by identifying limits for maximum work duration and minimum recovery time. Adequate recovery time ensures the dog begins the next session near resting Tc. Prolonged recovery duration can have a significant impact on the total time required for training when multiple sessions are planned, reflecting the magnitude of environmental heat stress. Predicting recovery time is a critical aspect of risk management that is often overlooked when evaluating environmental heat stress and implementing measures for heat strain mitigation. **Future:** A mobile application of the CTM is currently being developed by the U.S. Army Medical Materiel Development Activity (USAMMDA).

INTRODUCTION

The U.S. Army Research Institute of Environmental Medicine (USARIEM) developed a biophysical model (Canine Thermal Model, CTM) to predict core temperature (Tc) of military working dogs (MWDs) (Berglund and others, 2011). The model determines heat storage by calculating heat produced from metabolism and heat transfer between the dog and the environment through convective, radiative, and evaporative heat flow. The model includes thermoregulatory responses, such as adjustments in blood flow distribution and panting, which affect the rate of heat storage. The CTM provides a method to predict Tc of MWDs during work and rest.

The CTM was validated by individual comparisons of CTM predicted Tc to measured Tc of MWDs in training at Lackland Air Force Base, San Antonio, TX (O'Brien and others, 2017). After 30 min of recovery from exertional heat strain, predicted Tc was within 0.5°C of measured Tc for 92% of comparisons (O'Brien and Berglund, 2018). During exercise, the CTM-predicted Tc was within 0.5°C of measured Tc at the end of a training session for 85% of comparisons (O'Brien and others, 2020). This high level of agreement supports the use of the CTM as a mission planning tool to mitigate heat strain of MWDs working in hot environments. By managing duration of work and providing adequate recovery time between exercise bouts, dogs can more safely work in a wide range of environmental conditions, including those of high heat and humidity.

The CTM allows specific scenarios to be simulated, as defined by the user. Inputs include the physical characteristics of the dog (body mass and length); environmental conditions of air temperature (Ta), relative humidity (RH), mean radiant temperature (MRT, an index of solar radiation), and wind speed (WS); and the work intensity of the dog, expressed as the metabolic equivalent of task (MET level), a multiple of resting metabolic rate. The model simulates changes in Tc over time based on thermoregulatory responses to changing conditions. Work/rest cycles can be derived from these predictions when used in conjunction with pre-determined Tc thresholds. For example, the CTM can be used to predict the time to reach a Tc of 41°C during exercise, and the time to return to a Tc of 39.2°C during rest. This provides quantitative guidance for handlers that can improve efficiency of training sessions or missions plans that may require rotation of MWD teams to avoid excessive heat strain.

Evaluation of the CTM method for work/rest cycle guidance was conducted by comparing CTM predictions to measured Tc of MWDs during exercise and recovery. These comparisons demonstrate how work/rest cycles can be constructed to allow training to take place in hot environments while proactively mitigating risk of heat injury. Evaluation of both work (exercise) and rest (recovery) are important, as it is not only the Tc achieved during work, but also the rate of change in Tc upon recovery that provides insight into the relative risk of heat injury. Recovery prediction also ensures the dog begins the next session near resting Tc value.

METHODS

Work duration, recovery duration, and work/rest cycles were created for conditions encountered in a previous study (O'Brien and others, 2017). That study provided data for CTM inputs, including mean body mass and length of the MWDs, environmental conditions (Ta, RH, MRT, and WS), and estimated work intensity expressed as a MET level. By using representative environmental conditions from that study, CTM predicted Tc for an average sized MWD (mean body mass 30 kg and length 100 cm) could be evaluated against the measured Tc of individual MWDs in similar conditions (O'Brien and others, 2017).

Two types of exercise were used in the current CTM simulations. One involves training sessions for MWDs learning patrol and detection activities, and the other is a standard exercise walk around the kennels (O'Brien and others, 2017). The MWDs in training are exercised daily, typically completing 2 to 3 sessions each time. The population of dogs being walked on the kennel grounds consists of dogs that have completed training and are awaiting assignment, dogs that were recently procured and have not yet begun training, dogs in the breeding program, and dogs that are not currently in training for some other reason. These dogs are exercised less frequently, twice a week, rather than five times a week, and the exercise consists of a single leashed walk about 800 m long. The dog is walked from the kennel to a climate controlled building (26.7°C, 59% RH) where the dog stands while being groomed, then is walked back to the kennel.

Environmental Conditions

Environmental conditions where several MWDs were exercising at a similar Ta (± 1°C) and RH were identified for comparisons (O'Brien and others, 2017). The means ± standard deviations of the actual conditions are shown in Table 1, along with the number of dogs with available Tc data in each environment. To simulate training sessions, the corresponding conditions used for the CTM were at Ta and RH combinations: of 24°C, 50%; 26°C, 45%; 28°C, 60%; and 30°C, 55%, with a MRT of 40°C, equivalent to late morning sun, and low wind speed of 0.2 m/s. To simulate exercise walks, corresponding conditions for the CTM were at 24°C, 85%; 25°C 82%; and 30°C, 70%, with MRT varying between 0 to 40°C according to the time of day of the walk (dawn to late morning), and low wind speed (0.2 m/s). For recovery from training, two conditions were simulated: 26°C, 45%; and 30°C, 55%, assuming dogs in the shade (MRT = 0) with low wind speed. Recovery data were only available from MWDs in training who completed multiple sessions.

Table 1. Summary of actual environmental conditions measured for individual MWDs which were used for comparisons with CTM simulations. * indicates that 6 MWDs were training for Building Search indoors (MRT = 0).

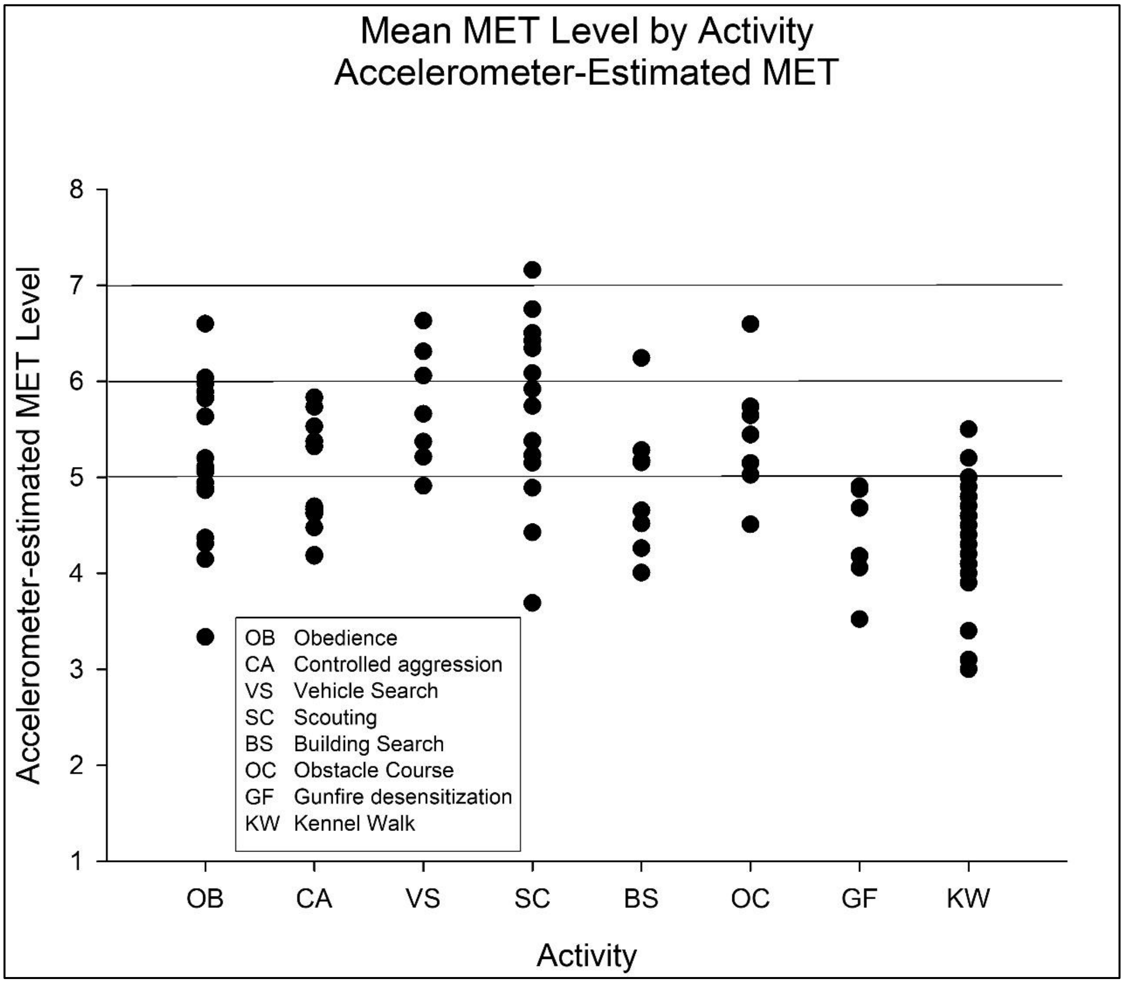
Activity	Ta, °C	RH, %	MRT, °C	WS, m/s	# MWDs
Training	24.1 ± 0.6	51.0 ± 3.0	26.4 ± 4.0	1.3 ± 0.4	8
	24.1 ± 0.5	76.4 ± 4.5	3.5 ± 2.3	0.2 ± 0.1	8
Training	25.9 ± 0.5	44.8 ± 1.9	34.2 ± 5.7*	1.5 ± 0.6*	16
Training	28.4 ± 0.3	62.4 ± 3.2	19.5 ± 5.7	1.1 ± 0.6	10
Training	29.9 ± 0.5	55.4 ± 3.5	28.2 ± 4.2	1.4 ± 0.5	14
Walk	24.2 ± 0.3	84.4 ± 1.1	1.5 ± 2.5	0.8 ± 0.1	7
Walk	25.3 ± 0.1	80.9 ± 1.4	3.5 ± 5.0	1.8 ± 0.3	9
Walk	28.0 ± 0.4	64.1 ± 4.4	28.5 ± 7.6	2.6 ± 0.6	8
Recovery	26.2 ± 0.6	43.9 ± 2.0	Shade	0.2	15
Recovery	29.7 ± 0.6	58.0 ± 5.8	Shade	0.2	4

Metabolic Equivalent of Task (MET level)

The CTM input for work intensity is in the form of a MET level, a multiple of resting metabolic rate where rest = 1 MET. Although considerable human research has been done to relate MET levels to a wide range of activities (Ainsworth and others, 2000), the only data on dogs are from a previous study to validate the CTM during activity (O'Brien and others, 2017). The high level of agreement between predicted and measured Tc in that study suggests the MET estimates were appropriate, although the method used, an equation to relate accelerometer data to MET level, has not yet been validated against a gold standard measurement. The MET levels estimated in that study (O'Brien and others, 2020) are shown on Figure 1 for training activities, including Obedience (OB), Controlled Aggression (CA), Vehicle Search (VS), Scouting (SC), Building Search (BS), Obstacle Course (OC), and Gunfire (GF), as well as for an exercise walk at the kennel area (KW).

For CTM simulations, the lower and upper ends of the range of estimated MET levels (4 and 7 METs, respectively) were used to predict Tc for training sessions. For exercise walks, a single level of 5.5 METs was used, representing the upper end of the range for that population. Using the upper level of expected MET level produces conservative guidance that would protect most dogs.

Figure 1. Estimated work intensity (MET levels) of MWDs during various activities. Abbreviations are described in the text.



Recovery Simulations

To simulate recovery, dogs were assumed to be at rest (1 MET) and in the shade (MRT = 0), with a low wind speed (0.2 m/s). When the CTM was validated for predicting recovery from exercise (O'Brien and Berglund, 2018), the initial Tc was matched to the measured peak Tc post-exercise for each dog. While the mean peak Tc was 40.1°C for those dogs, in 15% of cases the peak Tc was 41°C or higher. Therefore, for predicting recovery time, an initial Tc of 41°C was used for CTM simulations to create a more conservative (longer) recovery duration.

RESULTS

Recommendations for work and rest durations are based on the time to reach a pre-determined Tc, which can be selected by the user. Typical values were chosen here for the purpose of describing the development of work/rest cycles. For exercise conditions, four reference lines are drawn on the graphs presented below. Two represent resting values: 38.3°C, the average resting Tc for MWDs and the default value used by the CTM; and 39.2°C, the upper end of the range of resting Tc for MWDs (Vogelsang, 2007). Most dogs begin training sessions at a Tc between these values, although some dogs may have a lower than average resting Tc. A dog beginning a training session at Tc that is above 39.2°C is likely either not at rest (e.g., barking or spinning), or did not have sufficient time for complete recovery from previous exercise. Two additional reference lines are drawn at values observed during exercise in previous studies. A Tc of 40.5°C is a typical value for work, with some dogs reaching a Tc over 41°C (Carter and Hall, 2018; O'Brien and others, 2017; Robbins and others, 2017; Steiss and Wright, 2008). For the purposes of this report, a limit of 41°C is used for work duration.

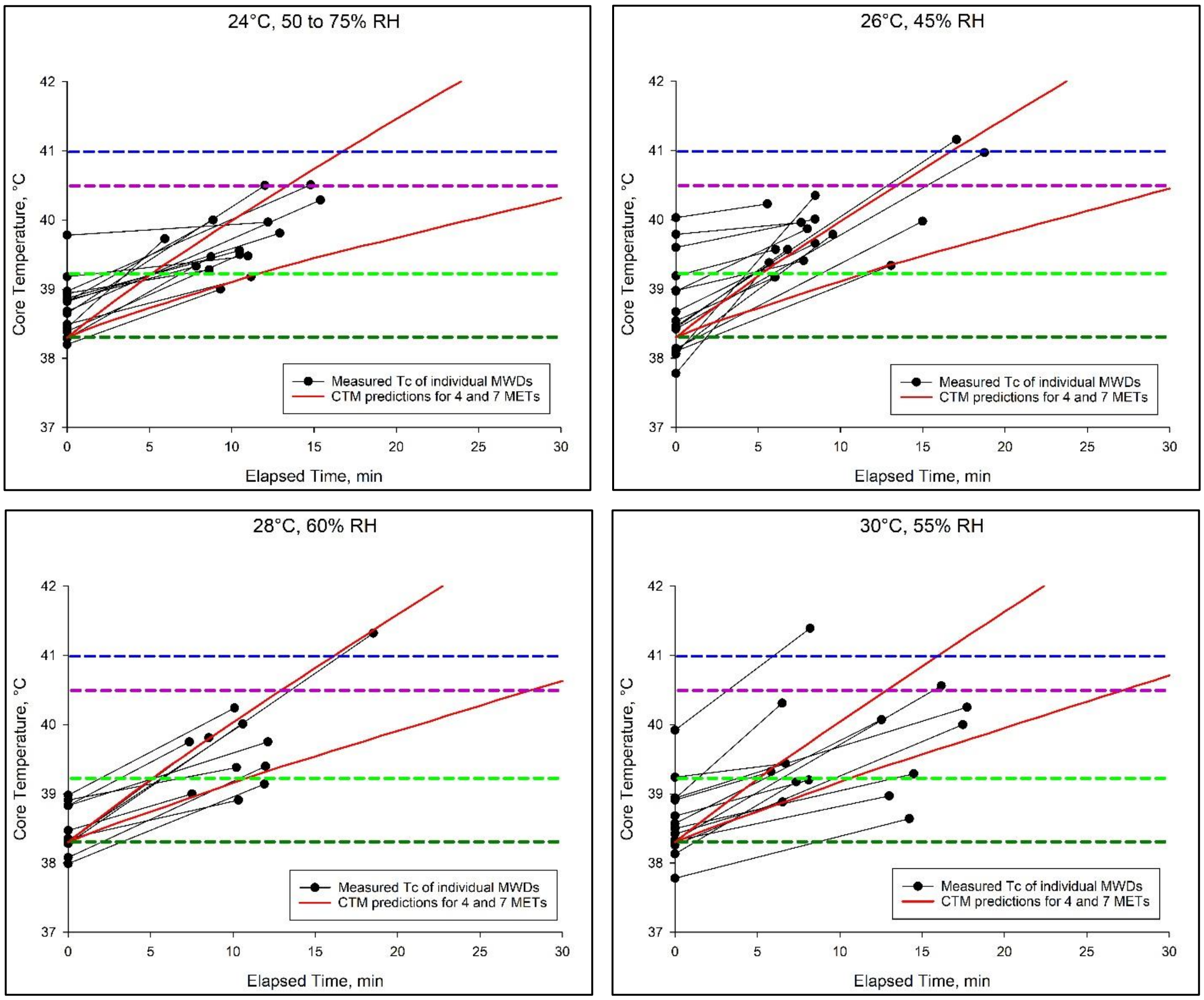
Work Duration for Training

Figure 2 presents graphs for each of the four environmental conditions of MWDs in training, with measured Tc of individual MWDs (O'Brien and others, 2017) shown with the CTM simulations at 4 and 7 METs. For all conditions, when working at 7 METs the CTM prediction indicates a work duration of 13 to 14 min to reach a Tc of 40.5°C, and 16 to 17 min to reach a Tc of 41°C. These work duration limits appear to be appropriate when compared to the measured Tc of individual MWDs.

The Tc of two dogs increased faster than the CTM prediction, as indicated by the higher slope. Both of these occurred during scouting, which can be higher than 7 METs if the dog locates the decoy very soon after beginning the search and the sprint and apprehension comprise most of the short session. Sprinting is one of the most metabolically demanding activities, but typically is not sustained for a long duration.

The distribution of initial Tc of individual MWDs can be seen on the graphs in Figure 2. Most are within the range of normal resting Tc; however, one dog began a training session at an elevated Tc and consequently exceeded a Tc of 41°C as Tc continued to increase during work. The higher initial Tc was due to inadequate time for recovery from the previous activity. This underscores the importance of planning recovery duration as well as work duration.

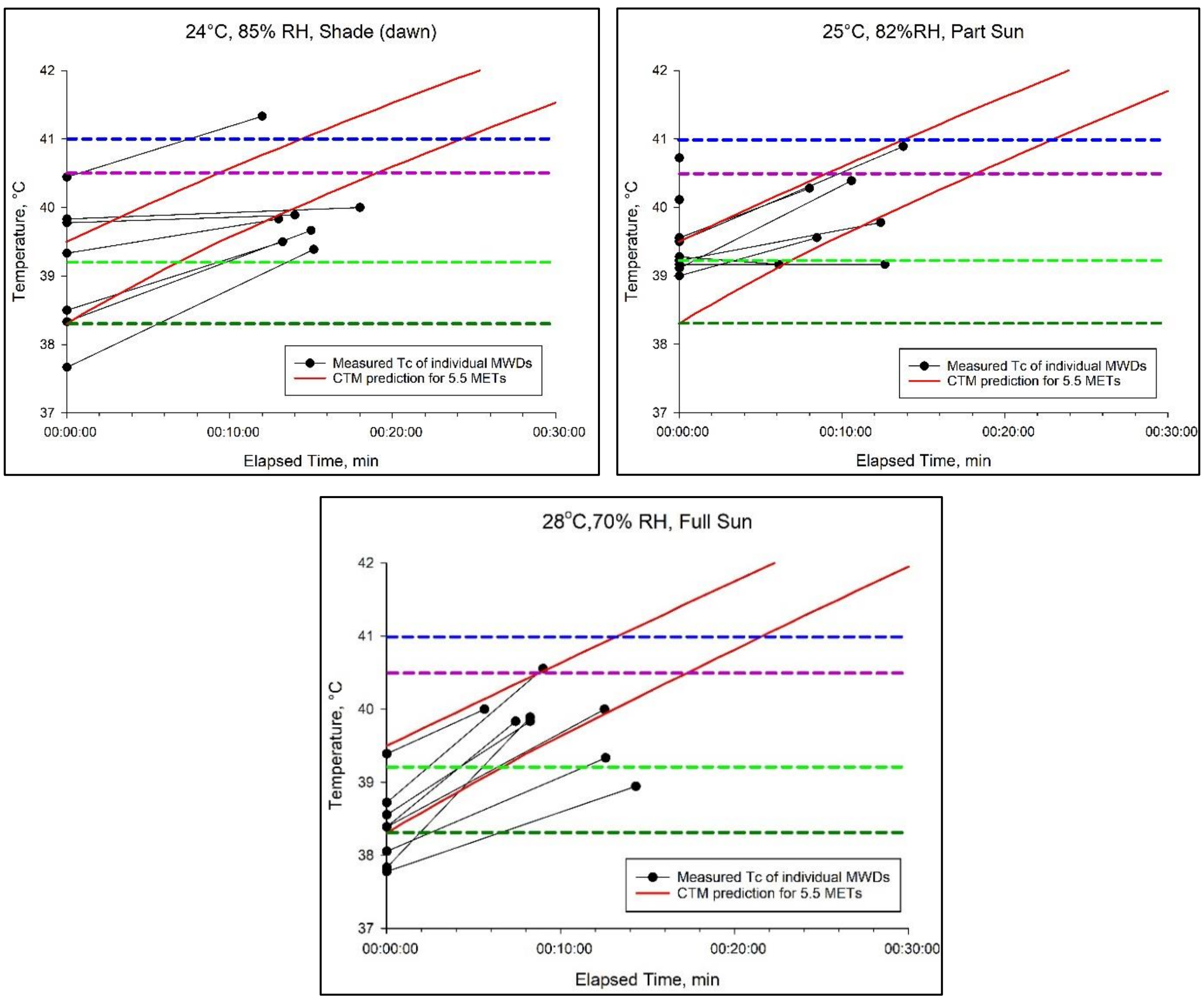
Figure 2. Measured Tc of MWDs during training in four environments, with CTM simulations for work intensities of 4 and 7 METs. Horizontal reference lines are drawn at typical Tc for rest (38.3°C), a target for recovery (39.2°C), typical final Tc for work (40.5°C), and a proposed limit for work (41°C).



Work Duration for Exercise Walks

The CTM simulation at 5.5 METs and measured Tc of individual dogs (O'Brien and others, 2017) for the three environmental conditions of exercise walks are presented on Figure 3. For simplicity, the CTM simulation and data presented are for just the first continuous walk from kennel to grooming building. A number of these dogs began the walk at an elevated initial Tc, which may be in part due to excitement and excess activity in the kennel before the walk begins (spinning, leaping). Therefore, along with the CTM simulations beginning from a neutral Tc (38.3°C), a second simulation was performed using an elevated initial Tc of 39.5°C, and both of these are presented on the graphs. When beginning the walk at a neutral Tc, the CTM predicts a work duration of 17 to 19 min to reach a Tc of 40.5°C, and 22 to 24 min to reach a Tc of 41°C. If initial Tc is elevated to 39.5°C, these work durations are reduced by 8 to 10 min, with a work duration of 13 to 14 min to reach 41°C.

Figure 3. Measured Tc of MWDs on an exercise walk in three environments, with CTM simulations for a work intensity of 5.5 METs beginning at a neutral Tc of 38.3°C and an elevated Tc of 39.5°C. Horizontal reference lines are drawn at typical Tc for rest (38.3°C), a target for recovery (39.2°C), typical final Tc for work (40.5°C), and a proposed limit for work (41°C).

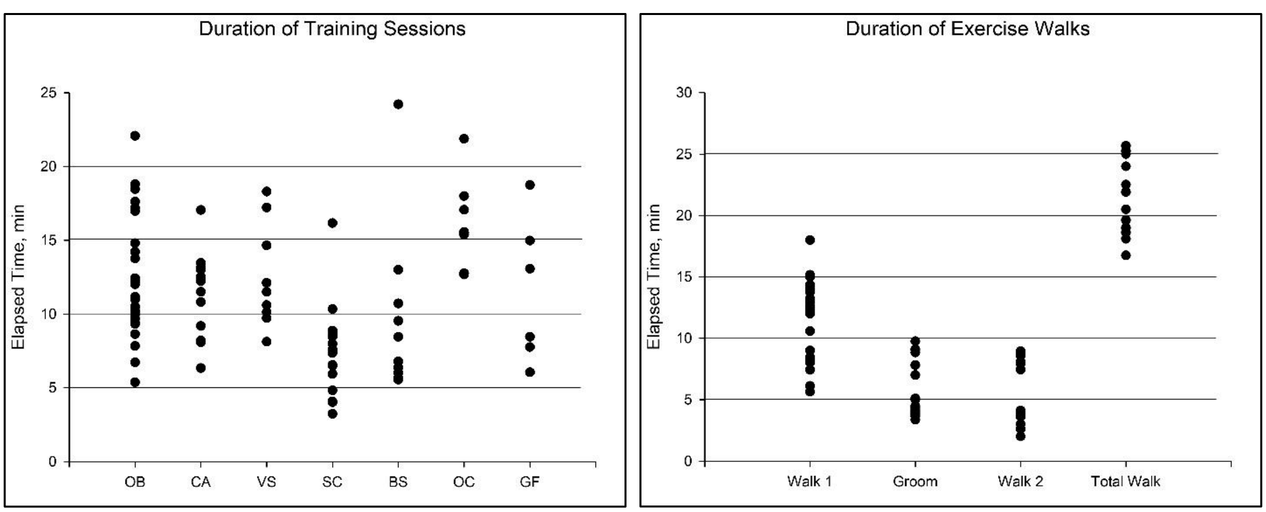


The individual Tc data suggest these time limits would be appropriate for most dogs. There were a few outliers of dogs that began the walk at an elevated Tc or the increase in Tc was much faster than for the other dogs (O'Brien and others, 2017). One dog that began the walk with a Tc within normal resting range, but reached a Tc of 40.5°C in only 9 min, a faster increase in Tc than predicted by the CTM. Further investigation revealed that this dog had a documented prior heat injury. Three dogs began the walk at an initial Tc above 40°C. All of these dogs were taken to the veterinary clinic based on handler observation of heavy panting (two before reaching the grooming area). One was also found to have a history of prior heat injury. This underscores the importance of physical assessments and monitoring signs and symptoms of overheating, even when guidance for work/rest cycles is available.

Minimum Work Duration Required

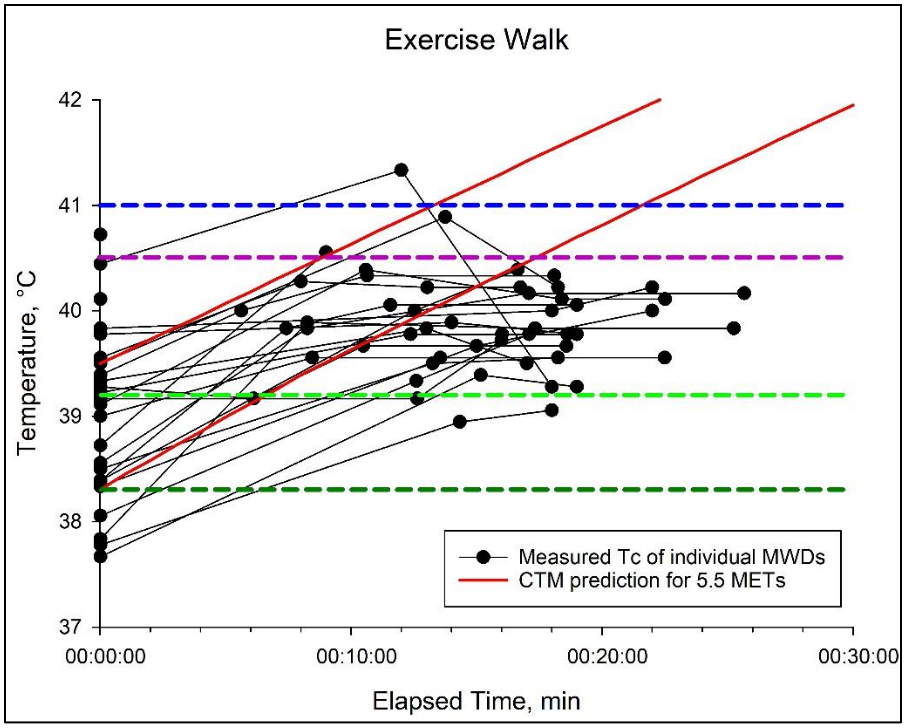
Managing risk of heat strain by limiting work duration can be effective, as long as there is sufficient time to complete the task. Duration of training sessions and exercise walks measured in a previous study (O'Brien and others, 2017) are shown in Figure 4. The majority of training sessions lasted between 5 and 15 min; therefore a work limit of 10 min would likely provide time to meet training objectives if handlers plan accordingly. For kennel walks, the initial walk from kennel to grooming building (Walk 1) can be accomplished within 15 min for most dogs. The proximity of the dog’s kennel to the grooming building affects the walk time, and for some dogs a time restriction to 10 min may require a “shortcut” in the path for the dogs kenneled farthest away. The dogs remained in the climate controlled (26.7°C, 59% RH) grooming building for 5.3 ± 2 min (range 3.4 to 9.8 min), then walked back to their kennel. Walk 2 is the measured time to the kennel after grooming.

Figure 4. Measured duration of 24 MWDs during training sessions (left graph) and 24 MWDs on an exercise walk (right graph).



For the kennel dogs on an exercise walk, the biggest increase in Tc occurred during the initial walk to the grooming building. For most dogs, Tc did not continue to increase after the break for grooming, which may be in part due to the partial rest and recovery in a cooler, dryer environment, and in part due to a lowered energy or excitement level on Walk 2 compared to Walk 1. The Tc measurements of all dogs during the complete exercise walk are shown in Figure 5 (O'Brien and others, 2017). These data suggest that guidance in terms of a duration limit for Walk 1 may be sufficient for the entire walk.

Figure 5. Measured Tc of 24 MWDs at the start, upon reaching the grooming building, and upon return to the kennel. The CTM prediction at 5.5 METs for the late morning conditions (28°C, 70% RH, Sun) is shown, both starting from a neutral Tc of 38.3°C and from an elevated Tc of 39.5°C.



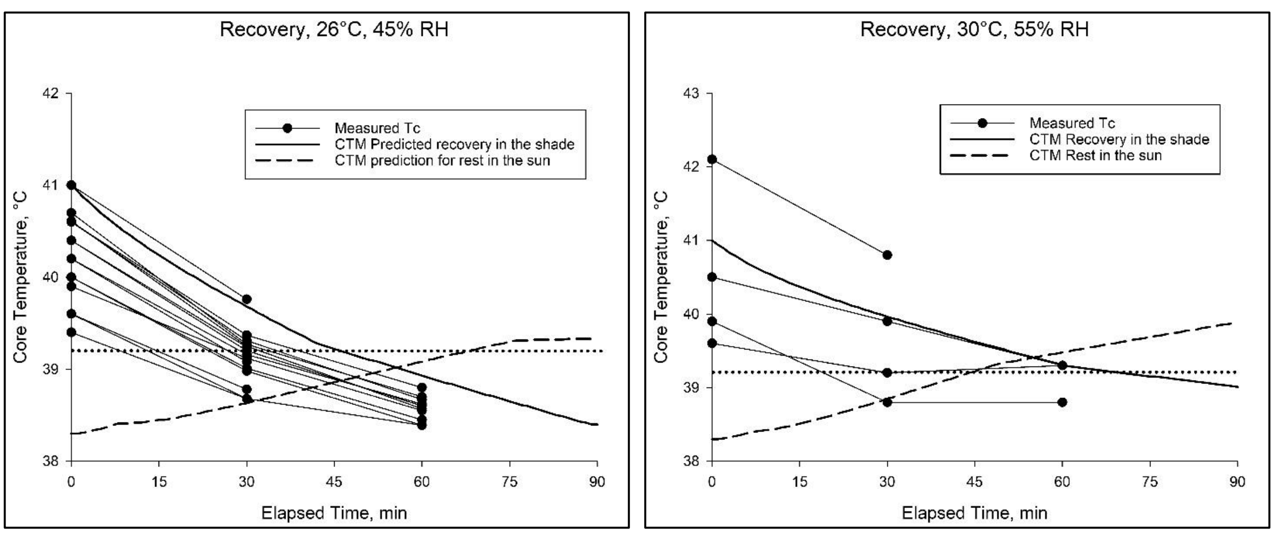
Recovery Duration

Providing sufficient recovery time for the dog's Tc to return to near baseline before the next work bout is an important aspect of heat strain mitigation when multiple training sessions are planned. Recovery predictions also provide a way to evaluate environmental heat stress across conditions, because the time to return to resting Tc is sensitive to small changes in Ta or RH, even when dogs are in the shade.

The CTM simulations for recovery were performed from an initial Tc of 41°C, the threshold used to limit work duration as described above. A Tc of 39.2°, the upper end of the range of resting temperature of MWDs (Vogelsang, 2007), was used as a target for recovery duration. This can be adjusted based on veterinary recommendations or mission planning. Recovery to a baseline Tc of 38.3°C would take longer, but the dog would begin the next training session at a lower Tc and subsequent work duration could be adjusted accordingly.

The CTM simulations for recovery and measured Tc of individual MWDs following a training session (O'Brien and others, 2017) are presented for two environmental conditions in Figure 6. At 26°C, 45%RH (Figure 6, left graph), data were available for 15 dogs after 30 min of recovery, and for 10 dogs after 60 min recovery. At 30°C, 55% RH (Figure 6, right graph), measured Tc from only four dogs were available, with data from two after 60 min recovery; however this condition is presented to illustrate the impact of the higher Ta and RH on predicted recovery duration. Dogs were housed in individual dog boxes on a trailer during recovery, which provided shade. Solar radiation becomes an important factor for heat storage when the dog is at rest and the contribution of MRT to heat gain becomes proportionately larger, compared to exercise when the biggest contributor to increased Tc is heat production from metabolism. To illustrate the influence of solar radiation (40°C MRT) on dogs at rest, CTM simulations are included on each graph in Figure 6 for a metabolic intensity of 1 MET beginning at an average resting Tc (38.3°C).

Figure 6. Measured Tc of MWDs during recovery from exercise and CTM prediction for recovery from a Tc of 41°C for a dog at rest (1 MET) in the shade. Also presented is the CTM prediction of Tc for a dog resting in the sun (40°C MRT). A horizontal reference line is drawn at 39.2°C, a proposed threshold for recovery.

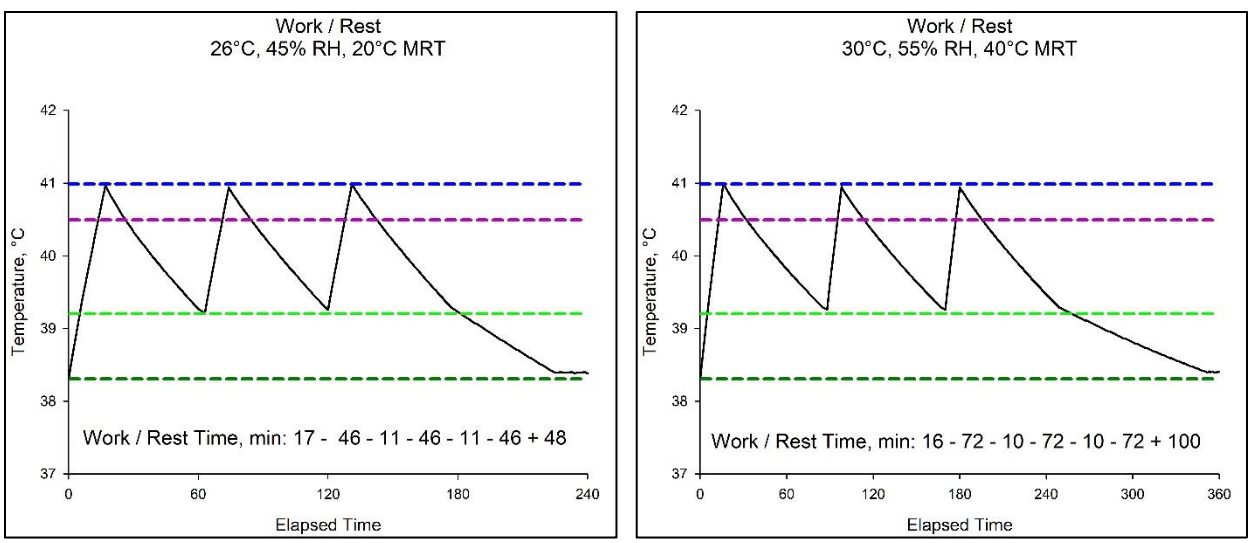


For the conditions presented in Figure 6, predicted recovery time from a Tc of 41°C to reach 39.2°C is 46 min at 26°C, 45% RH; and 68 min at 30°C, 55% RH. A dog resting in the sun was predicted to gain heat in these environments, with Tc increasing from 38.3°C to 39.2°C in 52 min at 26°C, 45%, and 44 min at 30°C, 55% RH. Onset of panting predicted by the CTM can be seen after ~10 min in each graph, where a change in the slope of increase in Tc occurs. For the first two conditions the Tc appears to plateau after reaching 39.2°C, due to the shift to deeper tidal volume panting predicted by the CTM. At 30°C, 55% RH this plateau did not occur, and despite deeper panting, Tc continued to increase, albeit at a lower rate. This underscores the importance of shade under these conditions whenever the dog is not working. While there is heat gain for a dog at rest in the sun under these conditions, the impact on recovery from an elevated Tc due to exertional heat strain would be to reduce the rate of heat loss and extend the recovery duration. Providing shade for recovery optimizes recovery time.

Work/rest Cycles

By combining predictions for work duration and recovery duration, work/rest cycles can be constructed for risk mitigation of heat strain when multiple sessions are planned. Using data presented above, two examples of 4 hour work/rest cycles were developed for a series of three training sessions in the following environmental conditions: 26°C, 45% RH, Part Sun, and 30°C, 55% RH, Sun. Because recovery predictions were for the time to return to a Tc of 39.2°C, rather than to baseline Tc of 38.3°C which was used to predict work duration of the first session, subsequent sessions begin at a higher Tc and work duration was correspondingly shorter.

Figure 7. Work/rest cycles for 26°C, 45% RH, 20°C MRT and 30°C, 55% RH, 40°C MRT simulated by the CTM for work at 7 METs and rest at 1 MET in the shade.



Work/rest cycles for a dog exercising at 7 METs and resting at 1 MET in the shade, are presented in Figure 7 for environments of 26°C, 45% RH, 20°C MRT (left graph) and 30°C, 55% RH, 40°C MRT (right graph). At 26°C, 45% RH, the CTM predicts a dog could train during the first session for up to 17 min before reaching a Tc of 41°C, with two additional sessions at up to 11 min each. Recovery from a Tc of 41°C was predicted to take 46 min. After the last session, an additional 48 min of rest in the shade was required for predicted Tc to return to a baseline of 38.3°C. At 30°C, 55% RH, the CTM predicts a dog could train during the first session for up to 16 min, with two additional sessions at up to 10 min each. Recovery from a Tc of 41°C to reach 39.2°C was predicted to take 72 min, with an additional 100 min after the last session to return to baseline Tc of 38.3°C. Note that for the same work intensity (MET level) there was little difference in work duration between the conditions in Figures 7; however, recovery time was much longer in the hotter environment.

Table 2. Sample work/rest cycles according to environmental conditions and work intensity (MET level). Bold (**32.2**°C) indicates Ta or WBGT conditions where exercise may be limited by some organizations.

Temperature Humidity Solar Wind	Estimated WBGT	Work or Rest Cycle	Duration at 5.5 METs	Duration at 7 METs
32.2°C 50% RH 40°C MRT 0.2 m/s	34.4°C	1st session	20 min	16 min
		2nd session	13 min	10 min
		Recovery to 39.2°C	90 min	
		Recovery to 38.3°C	>240 min	
30°C 55% RH 40°C MRT 0.7 m/s	**32.2°C**	1st session	21 min	16 min
		2nd session	14 min	10 min
		Recovery to 39.2°C	72 min	
		Recovery to 38.3°C	202 min	
26°C 45% RH 20°C MRT 0.2 m/s	18.3°C	1st session	23 min	17 min
		2nd session	15 min	11 min
		Recovery to 39.2°C	46 min	
		Recovery to 38.3°C	94 min	

Another way to portray this type of guidance is shown in Table 1. Work and rest durations are presented for the examples above, as well as for 32.2°C, 50% RH, 40°C MRT. Work durations are presented for both the first session, assuming the dog began the session at a resting Tc of 38.3°C, and second session, assume a starting Tc of 39.2°C, the threshold Tc used for recovery. As environmental heat stress increases, recovery duration becomes longer, making it less practical to conduct multiple training sessions. Recovery duration could be reduced if exercise duration were shortened to the time predicted to reach a lower Tc limit. This is a balance that should be considered for risk mitigation.

The environmental conditions currently used to limit training at Lackland are noted on Table 1 in bold font: 90°F (32.2°C) WBGT for MWDs in training, and for exercise walks an air temperature alone of 90°F (32.2°C). The Wet Bulb Globe Temperature (WBGT) is a single index of environmental heat stress that combines influences of Ta, RH, MRT and WS. It was originally developed for military basic training to mitigate heat strain in humans, and it is a relevant index for comparing environmental conditions (Budd, 2008), even for dogs when the primary mechanism for heat loss is panting rather than sweating. Since the WBGT includes solar radiation, moving into the shade lowers the effective WBGT.

DISCUSSION

This report illustrates how the CTM can be used to construct work/rest cycles for MWDs in hot environments. Predicted Tc during work and recovery were presented with previously measured Tc of individual MWDs (O'Brien and others, 2017). This illustrates how the choices of work intensity (MET level) and Tc thresholds for work and recovery affect the duration of work and recovery phases of each cycle. Examples for guidance were presented, including graphic display of 4-hour work/rest cycles and a table of maximum work and minimum recovery times.

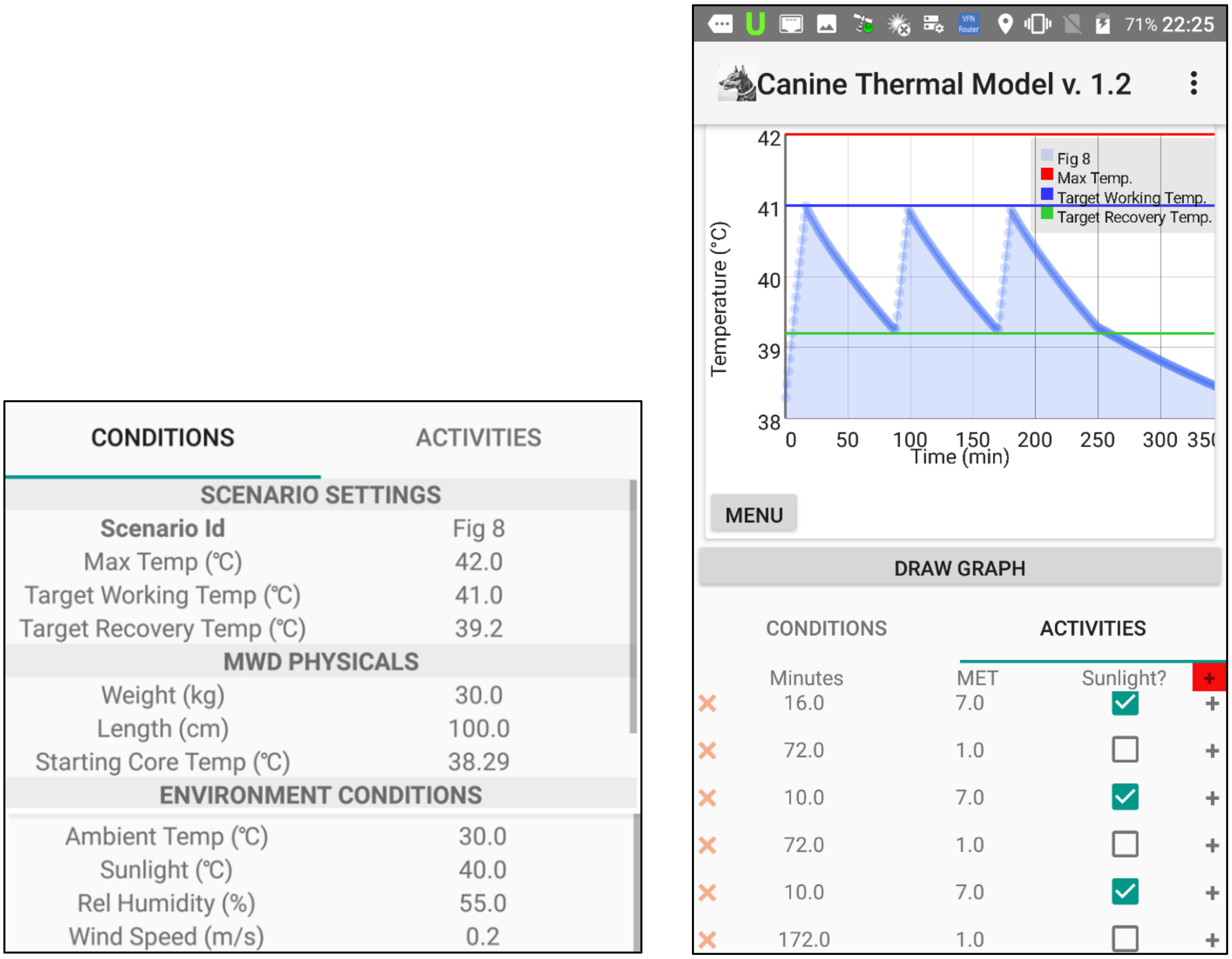
Guidance is typically constructed conservatively, so that the most vulnerable individuals are protected. The CTM simulations presented here for work were performed using the upper end of the range of MET levels estimated for this population of dogs (O'Brien and others, 2020). Exercise duration is primarily influenced by metabolic heat production related to work intensity, with the CTM prediction to reach a Tc limit of 41°C for work at 7 METs occurring at a similar elapsed time (16-17 min) among the different environmental conditions presented here. In contrast, recovery duration is more closely related to environmental heat stress, with predicted time to return to a Tc of 39.2°C from a peak Tc of 41°C ranging from 46 to 72 min. Prediction of recovery is important to ensure that subsequent work cycles begin at an appropriate Tc, but also provides an objective assessment of the impact of environmental heat stress on the thermoregulation of the dog.

The work/rest cycles derived from CTM simulations depend on the MET level used for work intensity and the thresholds for Tc for work and recovery. Consideration for choice of these values should be determined with input from a MWD veterinarian and could be modified for individual MWDs if susceptibility to overheating is known. The Tc limits for work presented in this report (40.5°C, 41°C) were based on measured Tc of MWDs during exercise and recovery (O'Brien and others, 2017), as well as reports for other dog populations (Angle and Gillette, 2011; Carter and Hall, 2018; Matwichuk and others, 1999; Steiss and Wright, 2008). These values could be adjusted, depending on the particular population of dogs and activities, and whether more conservative limits are desired. Although some dogs may routinely work at a higher Tc, a Tc above 41.0°C has been associated with heat injury, with heatstroke occurring at Tc > 43.0°C (Bruchim and others, 2006; Bynum and others, 1977; Taylor, 2008). How long a high Tc is maintained also influences risk of heat injury (Bruchim and others, 2006; Carithers and Seagrave, 1976). This underscores the importance of predicting recovery duration, since it reflects the rate at which Tc is likely to decrease after exercise ceases, a key component of risk mitigation.

Work/rest cycles may comprise one aspect of risk management. Other risk mitigation measures may be incorporated, such as conducting periodic physical assessments of the dogs. Handlers are trained to recognize signs and symptoms of excessive heat strain, but including Tc measurements at rest, during work, and during recovery will improve understanding of how CTM predictions apply to individual dogs. Despite designing exposures to protect all dogs, there may be outliers with higher than predicted Tc response to exercise. This could be due to inherent physiological differences, such as the dog's resting Tc, threshold for onset of panting, or capacity for panting heat loss; external influences, such as recent exercise or excitement; or factors influencing thermoregulatory responses, such as acclimatization status, physical fitness, or fatigue. Once identified, the duration of each phase could be adjusted for these dogs accordingly. Finally, access to cooling facilities such as an air conditioned building or vehicle may influence risk assessment.

Thermal models historically have been restricted to use by the modelers themselves, or provided in a format for limited use by specific personnel. Increasingly, thermal models are being made available as mobile applications, providing access to a broader audience, and allowing users to tailor the model inputs to a particular population or set of conditions. A mobile application of the CTM is currently being developed by the U.S. Army Medical Materiel Development Activity (USAMMDA) for use with MWDs. A basic understanding of how the model works will ensure that the model is used appropriately. Screenshots of the CTM mobile application are shown in Figure 8.

Figure 8. Screenshots of the CTM mobile application which is being developed by the U.S. Army Medical Materiel Development Activity (USAMMDA) for use by the Department of Defense (DoD) MWD community.



SUMMARY

This report presents examples of how the CTM can be used to create work/rest cycles for MWDs in hot environments. The CTM illustrates how training can be modified to mitigate heat strain according to environmental conditions, such as limiting work duration, extending recovery time, or restricting training to a single session. It can also be used as a teaching tool for new handlers to learn the influence of different environments on heat storage during work and recovery. The CTM can enhance mission planning, improve time management, and facilitate training effectiveness.

REFERENCES

Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, O'Brien WL, Bassett DR, Schmitz KH, Emplaincourt PO and others. 2000. Compendium of physical activites: an update of activity codes and MET intensities. Med Sci Sports Exerc 32(9):S498-S516.

Angle TC, Gillette RL. 2011. Telemetric measurement of body core temperature in exercising unconditioned Labrador retrievers. Can J Vet Res 75:157-159.

Berglund LG, Yokota M, Santee WR, Endrusick TL, Potter AW, Goldman SJ, Hoyt RW. 2011. Predicted thermal responses of military working dog (MWD) to chemical, biological, radiological, nuclear (CBRN) protective kennel enclosure. Natick, MA.

Bruchim Y, Klement E, Saragusty J, Finkeilstein E, Kass P, Aroch I. 2006. Heat stroke in dogs: a retrospective study of 54 cases (1999-2004) and analysis of risk factors for death. J Vet Intern Med 20:38-46.

Budd GM. 2008. Wet-bulb globe temperature (WBGT) - its history and its limitations. J Sci Med Sport 11:20-32.

Bynum G, Patton JF, Bowers W, Leav I, Wolfe D, Hamlet M, Marsili M. 1977. An anesthetized dog heatstroke model. J Appl Physiol 43(2):292-296.

Carithers RW, Seagrave RC. 1976. Canine hyperthermia with cerebral protection. J Appl Physiol 40(4):543-548.

Carter AJ, Hall EJ. 2018. Investigating factors affecting the body temperature of dogs competing in cross country (canicross) races in the UK. J Therm Biol 72:33-38.

Matwichuk CL, Taylor SM, Shmon CL, Kass PH, Shelton GD. 1999. Changes in rectal temperature and hematologic, biochemical, blood gas, and acid-base values in healthy Labrador Retrievers before and after strenuous exercise. Am J Vet Res 60:88-92.

O'Brien C, Berglund LG. 2018. Predicting recovery from exertional heat strain in Military Working Dogs. J Therm Biol 76:45-51.

O'Brien C, Karis AJ, Tharion WJ, Sullivan HM, Hoyt RW. 2017. Core temperature responses of military working dogs during training activities and exercise walks. AMEDD Journal October-December:71-78.

O'Brien C, Tharion WJ, Karis AJ, Sullivan HM. 2020. Predicting military working dog core temperature during exertional heat strain: Validation of a Canine Thermal Model. J Therm Biol 90.

Robbins PJ, Ramos MT, Zanghi BM, Otto CM. 2017. Environmental and physiological factors associated with stamina in dogs exercising in high ambient temperatures. Front Vet Sci 4:144.

Steiss JE, Wright JC. 2008. Respiratory alkalosis and primary hypocapnia in Labrador retrievers participating in field trials in high-ambient-temperature conditions. Am J Vet Res 69:1262-1267.

Taylor WM. 2008. Canine tactical field care Part 1: The physical examination and medical assessment. J Spec Oper Med 8(3):54-60.

Vogelsang R. 2007. Care of the military working dog by medical providers. J Spec Oper Med 7(2):33-47.