MILITARY MEDICINE, 178, 10:1141, 2013

Thermal-Work Strain During Marine Rifle Squad Operations in Afghanistan

Alexander P. Welles, BA; Mark J. Buller, MS*; CPT Lee Margolis, MS USA*;
CDR Demetri Economos, MSC USN†; Reed W. Hoyt, PhD*; MAJ Mark W. Richter, USMC (Ret.)†*

ABSTRACT The physiological burden created by heat strain and physical exercise, also called thermal-work strain, was quantified for 10 male Marines (age 21.9 ± 2.3 years, height 180.3 ± 5.2 cm, and weight 85.2 ± 10.8 kg) during three dismounted missions in Helmand Province, Afghanistan. Heart rate (HR) and core body temperature (T_{core}) were recorded every 15 seconds (Equivital EQ-01; Hidalgo, Cambridge, United Kingdom) during periods of light, moderate, and heavy work and used to estimate metabolic rate. Meteorological measures, clothing characteristics, anthropometrics, and estimated metabolic rates were used to predict T_{core} for the same missions during March (spring) and July (summer) conditions. Thermal-work strain was quantified from HR and T_{core} values using the Physiological Strain Index (PSI) developed by Moran et al. July PSI and T_{core} values were predicted and not observed due to lack of access to in-theater warfighters at that time. Our methods quantify and compare the predicted and observed thermal-work strain resulting from environment and worn or carried equipment and illustrate that a small increase in ambient temperature and solar load might result in increased thermal-work strain.

INTRODUCTION

Military operations requiring rigorous physical activity and occurring in extremes of climate and terrain can induce severe thermal-work strain in dismounted warfighters.[1] Given demanding mission activities and operational conditions, commanders must balance "the physical ability of soldiers against the risks of not carrying items of clothing, equipment, food, water, or munitions."[2] Included in this balance are considerations for the effects of macroenvironmental factors (e.g., solar load, ambient temperature), microenvironmental factors (protective clothing and equipment), and physical activity (metabolic heat production and increased work intensity). In this context, heat stress generally refers to conditions that increase body temperature, whereas heat strain refers to the physiological responses associated with the increase in body temperature. Thermal-work strain refers to the physiological burden created by both heat strain and physical exercise.

Thermal-work strain results from the rate of heat storage in body tissue—heat being generated either internally by metabolic mechanisms or absorbed from the external environment—exceeding the rate of dissipation. Physical exercise increases heat production as ~20% of the energy released during skeletal muscle contraction is used to perform mechanical work and the remaining ~80% is released into tissue as heat.[3] Dissipation of body heat is mediated by the evaporation of sweat from the surface of the skin and the nonevaporative transfer of heat from the body to the surrounding environment via convective, conductive, and radiative mechanisms.[4] Nonevaporative heat dissipation, however, requires a difference in temperature between the skin surface and the surrounding environment, whereas evaporative heat dissipation is dependent on the humidity of the micro and macroenvironments and greatly affected by the water vapor permeability of any worn clothing.

As an individual experiences more thermal-work strain, not only does the likelihood of thermal illness or injury increase but endurance performance decreases. Maximal oxygen uptake (VO_2 max)—a general indicator of aerobic performance capacity—decreases as the individual experiences increasing thermal-work strain.[3,5] The decrease in VO_2 max results in an increase in work intensity (%VO_2 max)[6] for a given absolute work rate which translates to increased effort to perform the task at hand, e.g., marching or sustained manual labor.[3] Clothing and individual equipment (CIE) can exacerbate thermal-work strain by impeding the evaporation of sweat[7,8] and increasing metabolic rate because of the cost of load carriage.[9]

Given the potential impact thermal-work strain can have, it is unsurprising that it has been studied under laboratory conditions and during military training exercises. However, little to no data exists examining the thermal-work strain experienced during actual in-theater missions, which may differ greatly from more controlled settings in terms of environment, activity, equipment, and subject motivation. Collecting the necessary physiological data to compare mission environments and activities has historically been hindered by lack of access to in-theater warfighters and difficulties associated

---

*Biophysics and Biomedical Modeling Division, U.S. Army Research Institute of Environmental Medicine, 44 Kansas Street, Building 42, Natick, MA 01760.

†Marine Expeditionary Rifle Squad, Marine Corps Systems Command, 2200 Lester Avenue, Quantico, VA 22134.

This work has been refined from a broader data set presented in U.S. Army Institute of Environmental Medicine (USARIEM) technical report T11-02, titled "Thermal-Work Strain During Marine Rifle Squad Operations in Afghanistan (March 2010)." However, this article improves on the previous work significantly by using ensemble permeability and insulation data collected from thermal manikin testing of the current U.S. Marine Corps field ensemble rather than estimating values (as done in T11-02).

doi: 10.7205/MILMED-D-12-00538

with collecting heart rate (HR) and T_{core} values in the field.[10–12] It is only with the recent development of compact, medical grade (U.S. Food and Drug Administration certified), and noninvasive physiological status monitoring (PSM) systems, that such data can be collected effectively during military missions.

Our article details the thermal-work strain experienced by a United States Marine Corps infantry company during March 2010 (spring) missions in Helmand Province, Afghanistan. The purpose of this study was (1) to characterize the thermal-work strain, activity profiles, and CIE of warfighters performing dismounted mission activities in Afghanistan during March and (2) to use the observed mission profiles to predict the effects of conducting the same missions during typical July (summer) weather conditions in the same location.

METHODS

Test Volunteers and Missions

The work detailed in this article was completed under the oversight of the Brook Army Medical Center Institutional Review Board and the Joint Combat Casualty Research Team (Afghanistan). At all volunteer recruitment briefings an ombudsman (either a chaplain or officer not related to the unit) was present to ensure no coercion occurred. The investigators have also adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 32 CFR Part 219.

Physiological data (HR, T_{core}, and accelerometry counts) were collected during missions conducted by Fox Company, 2nd Battalion 2nd Marines under Regimental Combat Team Seven (RCT-7), which was stationed in Combat Outpost Sher, Helmand Province, Afghanistan. Ten males from RCT-7 (age 21.9 ± 2.3 years; self-report 3-mile run time 20.1 ± 1.6 minutes) (mean ± standard deviation) volunteered for this study after being briefed on the research procedures and risks. The cohort's mean percent body fat, height, weight, and waist circumference were 15.3% ± 3.4%, 180.3 ± 5.2 cm, 85.2 ± 10.8 kg, and 84.1 ± 5.9 cm, respectively. Volunteers carried total loads of 30.3 ± 4.0 kg (mean ± standard deviation). Contextual information including anthropometrics, clothing characteristics, individual equipment descriptions, meteorology, and mission profiles were documented and used as inputs for metabolic and thermoregulatory models used to estimate thermal-work strain during warmer summer weather. Mission profiles (e.g., vehicle movement, foot patrol, rest periods) were recorded by an in-theater investigator who accompanied the Marines on their mission.

The relatively small sample size of 10 subjects was due to the difficulties inherent in collecting physiological data in the field and the nature of in-theater operations. Data collection can be disrupted by premature passing of an ingested thermometer pill, vigorous movement or clothing and equipment disrupting sensor contact with the skin, or chance positioning of the pill in a subject's gastrointestinal tract leading to a blocked signal. Given in-theater safety and security considerations, it was often impossible to ensure or check whether or not an individual's PSM system was functioning properly much less whether or not valid data were being collected.

We were, however, able to collect data for three specific missions, each with a unique work profile: (A) heavy-to-moderate work separated by rest, (B) sustained heavy-to-moderate work, and (C) light work with bursts of intense very heavy work. Mission data were collected between 19 and 23 March, 2010 and activities included dismounted and mounted patrols and rifle range/squad rush training with Afghani police forces. Of the 10 volunteers, five participated in mission A, four in mission B, and three in mission C.

Physiological Measures

HR and T_{core} (beats per minute and °C) were recorded every 15 seconds from a chest-worn PSM (Equivital EQ-01; Hidalgo, Cambridge, United Kingdom) capable of recording data from an associated temperature pill. The Physiological Strain Index (PSI),[13] a 0-10 measure of thermal-work strain derived from HR and T_{core}, was calculated as an indicator of thermal-work strain.[13] PSI values are associated with the following levels of physiologically strain: 0 to 2, no/little; 3 to 4, low; 5 to 6, moderate; 7 to 8, high; and 9 to 10, very high. Metabolic rates $(\dot{M})$ were estimated using individual subjects' HR and ambient temperature (T_a)[14,15] (see biomedical modeling analysis below).

Anthropometric Measures

Height (self-report), body weight (seminude with shorts and t-shirt), and waist circumference at the navel (anthropometric tape measure) were used to estimate percent body fat.[16] Fighting weight (total weight with combat clothing and equipment) was also collected for use as model inputs.

Clothing and Individual Equipment Characterization

A typical CIE configuration for Fox Company 2nd Battalion 2nd Marines RCT-7 included the Flame Retardant Organizational Gear uniform; Scalable Plate Carrier with front, back, and side Enhanced Small Arms Protective Insert plates; and the Lightweight Helmet. Clothing insulation (clo) and vapor permeability (im) of the Marine ensemble were measured via thermal manikin by USARIEM personnel according to ASTM standards.[17,18] The permeability index, im, is a nondimensional index where 0 indicates a garment or ensemble is impermeable and permits no evaporative heat transfer. An im of 1 indicates the garment or ensemble allows the theoretical maximum of evaporative heat loss given by its insulation.[19] The ratio im/clo indicates the approximate "cooling power" of an ensemble. All values reported are given for a wind speed of 1.0 m/s.

Meteorological Measures

Meteorological data were collected at Kabul Airfield by the 14th Weather Squadron. Ambient air temperature (T_a), dew point, and black globe temperature (T_{bg}) were obtained for 19 to 23 March 2010 as well as for 17 to 25 July 2010. Relative humidity was calculated from air temperature and dew point using the National Weather Service's Meteorological Calculator.[20] The meteorological values recorded at the Kabul Airfield in July 2009 were averaged by hour to provide a composite 24 hour day that represented July weather (summer) in Kabul Afghanistan and the surrounding area. Wind speed was assumed to be 1 m/s for both the March and July modeling periods.

Procedures

Thermometer pills (Mini Mitter; Bend, OR) were orally administered to volunteers the evening before the initiation of data collection to avoid erroneous temperatures resulting from fluid ingestion.[12] The following morning volunteers donned the PSM chest belt system according to the manufacturer's instructions, and had waist circumferences and semi-nude weights measured before mission activities began.

Biomedical Modeling Analysis

The thermoregulatory model SCENARIO[21,22] was used to predict T_{core} (°C) and PSI values during meteorological conditions typical for July in Afghanistan. The SCENARIO model predicts T_{core} from: metabolic rate, meteorological parameters, clothing vapor permeability, clothing insulation, individual anthropometric measures (percent body fat, height, and weight), and heat acclimation state (all subjects were assumed to be heat acclimated as they had been in-theater for 5 months as of March 2012). Figure 1 depicts a schematic detailing the steps of our modeling efforts and the generation of mission profiles.

Metabolic Rate Estimation

Metabolic rate was calculated from resting HR, exercise HR, and T_a (°C) values using the Initial Capability Decision Aid (ICDA) model.[15,23] This model uses a metabolic rate estimator developed by Berglund et al[14,15]:

$$\text{MET} = 0.68 + 4.69(\text{HRR} - 1) - 0.052(\text{HRR} - 1)(T_a - 20) \quad (1)$$

where MET refers to metabolic equivalent of task and HRR to heart rate ratio. An MET equals 58.1 W/m^2 and is generally considered the rate of energy expenditure of a sedentary person. HRR is the heart rate during exercise divided by the resting HR at 20°C in beats per minute (bpm). The MET ratio is converted into a rate (watts) using Equation 2:

$$\dot{M} = \text{MET}\left(58.1\,\frac{\text{w}}{\text{m}^2}\right)D_a \quad (2)$$

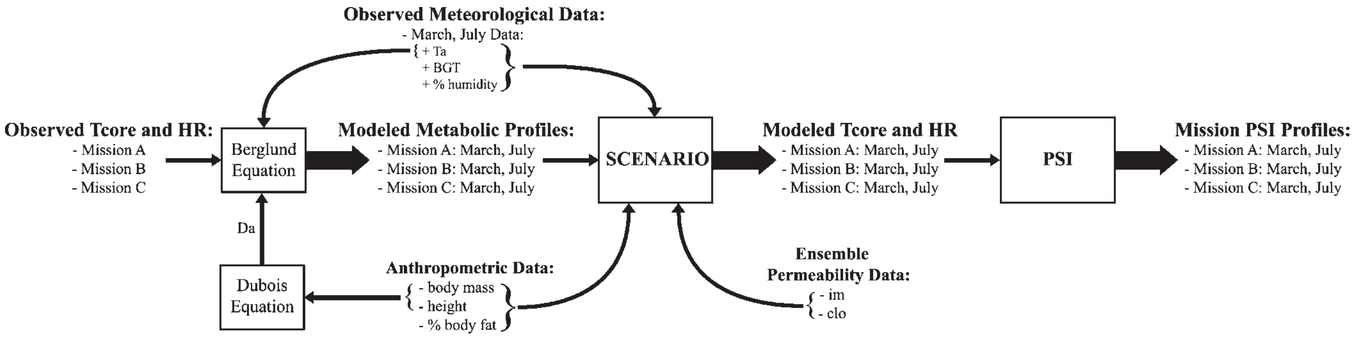
where $\dot{M}$ is metabolic rate measured in watts and D_a the Dubois surface area of the individual for whom $\dot{M}$ is being calculated. D_a is calculated based on an individual's height and weight using Equation 3:

$$D_a = 0.202B^{0.425}H^{0.725} \quad (3)$$

where B is the body mass in kilograms and H the height in meters.

Berglund's equation (Equation 1) has been used successfully in the ICDA model, but can overestimate $\dot{M}$ under some conditions.[24] Overestimation errors are pronounced for HRR > 2 where the equation is estimating $\dot{M}$ through extrapolation. To better estimate $\dot{M}$, we used Equation (1) for HRR values ≤2 and reduced its slope as well as modified its y-intercept for HRR values >2.

To identify the appropriate reduction of slope for HRR values >2, a series of equations were generated by incrementally reducing the slope of Equation (1). Metabolic rates were estimated for each subject and mission using the modified equations and used as inputs for the SCENARIO model. The T_{core} values produced by the SCENARIO model for each subject were then compared to their observed T_{core}'s and root mean square error (RMSE) was calculated. The modified slope and intercept which resulted in the lowest mean RMSE



Note: BGT is black globe temperature, Da is Dubois surface area, PSI is physiological strain index, and Ta is ambient temperature.

FIGURE 1. Schematic representation of model inputs and outputs and generation of the mission profiles.

TABLE I. Observed March (Spring) and Average July (Summer) Environmental Conditions (Mean ± SD)

Mission		Air Temperature (°C)	Relative Humidity (%)	Dew Point (°C)	Black Globe (°C)	WBGT (°F)	WBGT Flag
A	March	25.5 ± 1.9	14.8 ± 2.2	−3.5 ± 2.5	33.6 ± 9.7	61.9 ± 5.2	White/No Flag
	July	30.4 ± 1.5	20.0 ± 3.4	4.9 ± 2.1	37.1 ± 5.7	70.4 ± 2.1	White/No Flag
B	March	21.4 ± 0.5	25.6 ± 3.4	0.8 ± 2.2	27.9 ± 5.9	58.7 ± 3.4	White/No Flag
	July	31.3 ± 1.0	18.0 ± 2.4	4.2 ± 2.0	41.1 ± 4.8	71.6 ± 2.0	White/No Flag
C	March	19.6 ± 2.9	20.2 ± 10.8	−5.1 ± 3.1	36.5 ± 8.0	58.2 ± 3.9	White/No Flag
	July	29.9 ± 1.1	20.4 ± 5.9	4.3 ± 2.9	46.5 ± 4.1	72.9 ± 2.9	White/No Flag

across all subjects for a given mission was then selected to model metabolic rate for all subjects participating in that mission when HRR exceeded 2.0.

Statistical Analysis

Predicted and observed T_{core}, HR, and PSI values for March were compared using Bland–Altman analysis[25] and linear regression. Estimated bias (mean difference between predicted and observed values) and the limits of agreement (LoA, bias ± 1.96 × SD of the differences) were calculated as were the coefficients of determination (R^2). The LoA provide a range of error within which 95% of our March predicted values should fall assuming a normal distribution. The analyses were performed using Microsoft Excel 2007 (Microsoft Corporation, Redmond, Washington).

RESULTS

Clothing and Equipment Characteristics

Analysis by thermal manikin found the Marine ensemble to have an insulation value of 1.50 clo, a permeability index (im) value of 0.39, and an im/clo value of 0.26.

Meteorological Conditions

Table I shows the air temperature, relative humidity, dew point, black globe temperature, wet bulb globe temperature (WBGT), and corresponding WBGT flag color for each of the mission periods during March and the mean values for July. The WBGT Index is currently used by all branches of the U.S. Armed Forces as well as the Occupational Safety and Health Administration to mark levels of and protect against environmental heat stress using a combination of work rest schedules, fluid replacement tables, and work intensity guidelines.[26,27]

Mission Profiles

The three mission profiles represent three distinct work profiles: heavy to moderate work separated by rest (Mission A), sustained heavy to moderate work (Mission B), and light work with bursts of very heavy work (Mission C). We defined these profiles as such using the definitions of work intensity according to metabolic rate found in TB MED 507.[26] Missions A and B ($\dot{M}$ = 517 ± 73 W and 544 ± 84 W, respectively) were dismounted patrols occurring from 4:00 to 7:00 p.m. on March 19, 2010 and 3:00 to 6:30 p.m. on March 22, 2010, respectively. Mission C ($\dot{M}$ = 297 ± 141 W) was more complex and contained dismounted and mounted patrol periods before training exercises with Afghani security forces. The training exercises included the assembly of a firing range, marksmanship training, squad rush exercises, and firing range breakdown before the Marines remounted and returned to base. Mission C occurred from 8:00 a.m. to 5:00 p.m. (11 hours) on March 23, 2010.

Biomedical Modeling Analysis

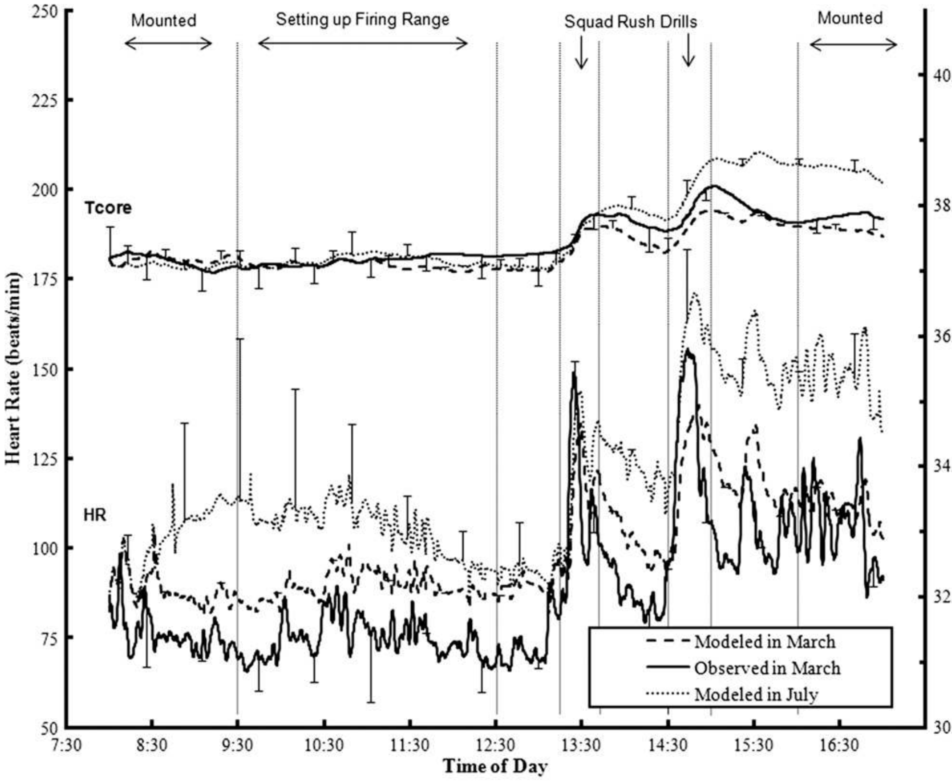
$\dot{M}$ was calculated using ambient temperatures of 25.5, 21.4, and 19.6°C for missions A, B, and C, respectively. When HRR exceed 2.0, a modified slope of 0.9 was used and the resulting intercepts were (A) 3.281, (B) 3.497, and (C) 3.589. The resulting mean RMSE values ± standard deviation (SD) for observed versus predicted T_{core} were 0.29 ± 0.02°C for mission A, 0.25 ± 0.22°C for mission B, and 0.29 ± 0.19°C for mission C. For 11 of 12 data collections, T_{core} RMSE values were between 0.10 and 0.38 with standard deviations between 0.08 and 0.30. The remaining data collection resulted in a T_{core} RME value of 0.42 with a standard deviation of 0.25.

Comparison of observed and predicted March PSI values by Bland–Altman analysis revealed a bias of 0.34 ± 0.93 PSI units LoA ± 1.83 PSI units. The R2 value for the linear regression of predicted versus observed March PSI value was 0.79. Similar analysis of predicted versus observed T_{core} values showed our modeling resulted in a bias of −0.02 ± 0.32°C and LoA ± 0.61°C. T_{core} linear regression resulted in a R2 value of 0.61. Finally, Bland–Altman analysis of HR

TABLE II. Observed and Predicted Mission Physiological Measures (Mean ± SD)

Mission		Month	HR (bpm)	T_{core} (°C)	PSI	Estimated Metabolic Rate (W)
A	O	March	121 ± 14	38.1 ± 0.2	5.4 ± 0.7	517 ± 73
	P	March	129 ± 12	38.1 ± 0.3	5.8 ± 0.9	
	P	July	142 ± 9	38.6 ± 0.4	7.0 ± 0.9	
B	O	March	119 ± 13	37.8 ± 0.1	4.6 ± 0.7	544 ± 84
	P	March	126 ± 11	38.9 ± 0.2	5.0 ± 0.8	
	P	July	153 ± 15	39.1 ± 0.7	8.2 ± 1.8	
C	O	March	87 ± 19	37.4 ± 0.4	2.2 ± 1.4	297 ± 141
	P	March	99 ± 14	37.3 ± 0.3	2.4 ± 1.2	
	P	July	118 ± 22	37.6 ± 0.6	3.8 ± 2.2	

O, observed data; P, predicted data.



Note: error bars only extend in one direction to avoid overlapping with plotted data.

FIGURE 2. Mean heart rate and core temperature for mission C: 0800-1700, 23 March 2010; dismounted/mounted patrol, firing range, and squad rush drills ($N = 3$).

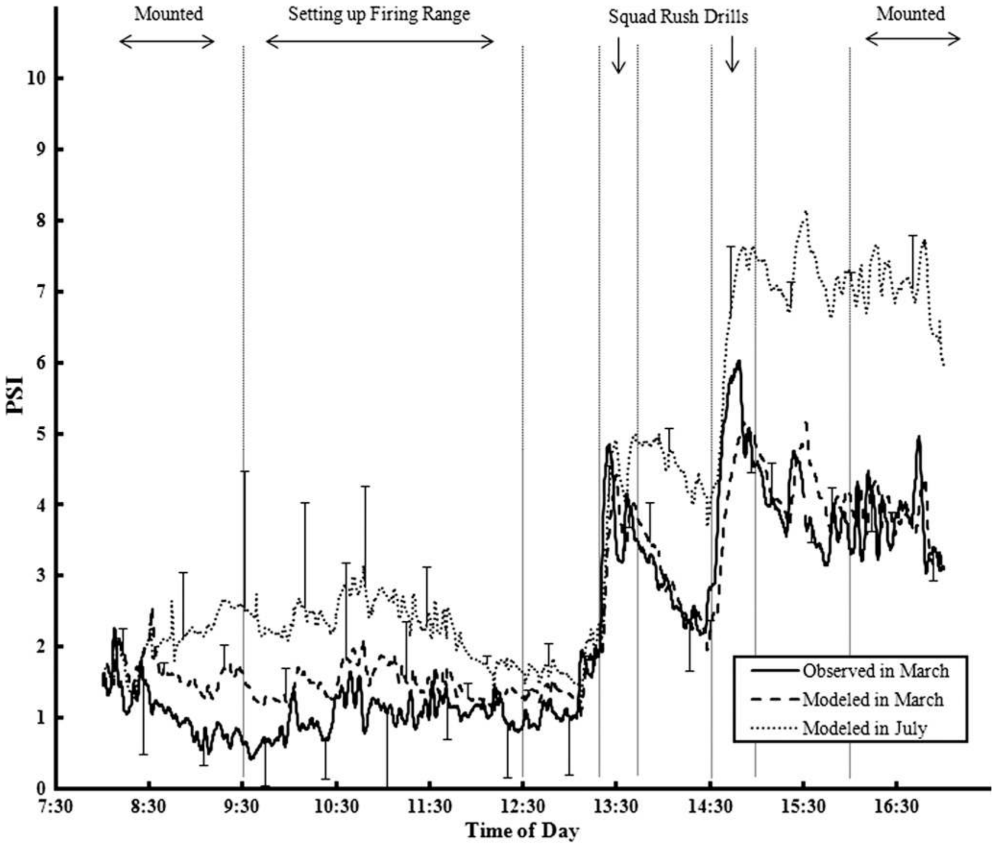
resulted in a bias of 9 ± 16 bpm with LoA ± 32 bpm and a R^2 value of 0.62. No data were collected during July because of lack of access to in-theater subjects and investigators.

Table II presents observed physiological data (T_{core}, HR), PSI value, and estimated metabolic rate summary information for each of the mission periods during March. Also shown are the modeled thermal-work strain data for both March and July. Figure 2 shows mean observed and predicted T_{core} and HR values for mission C, whereas Figure 3 shows the mean observed and predicted PSI values. Where data are available, changes in activity are indicated by vertical dotted lines, and error bars represent 1 SD (error bars only extend in one direction to prevent overlap with plotted data).

DISCUSSION

Bland–Altman analysis of predicted versus observed March PSI values revealed an overall bias of 0.34 ± 0.93 PSI units and limits of agreement of ±1.83 PSI units indicating small overprediction across subjects and missions. This overprediction may in part be due to a similar but larger bias for overpredicting HR (9 ± 16 bpm with LoA of ± 31 bpm). T_{core} appears to be predicted reasonably well given a small bias of -0.02 ± 0.32°C, LoA of 0.63°C, and predicted versus observed (March) RMSE values between 0.10 and 0.38 for 11 of the 12 data collections. Unfortunately, we did not have access to in-theater warfighters during July to collect data for comparison with our July predictions of HR, T_{core}, and PSI values but, a follow-up study is currently planned to gather this data from warfighters in Afghanistan during the summer of 2013. A follow-up study was conducted during the summer of 2012 but, no missions with suitable activity profiles were observed (data were collected but only during periods of little to no activity).

The relatively accurate modeling of T_{core} but overprediction of HR (and consequent overprediction of PSI) stands to reason as there was wider range of variability in subject HR data than T_{core} and we modified Berglund's equation (for HRR values greater than 2) to more accurately model observed T_{core} with SCENARIO. It is possible that overestimations of $\dot{M}$ led to overprediction of HR but this is paradoxical as our T_{core} predictions are generally effective and lower metabolic rates would result in further under prediction of T_{core}. It is also worth noting that the coefficients of determination for HR and T_{core} are approximately the same (R2 = 0.62 and 0.61). The consistent nature of the overprediction of HR values (Fig. 2) potentially indicates that the SCENARIO model is biased toward overprediction of HR but it requires future work specifically designed to determine this. Other potential solutions that might address under or overestimation of metabolic rate include the use of HR and accelerometry data as an alternate method of its estimation as well as further modification to Berglund's equation for values of HRR greater than 2.



Note: error bars only extend in one direction to avoid overlapping plotted data.

FIGURE 3. Mean PSI values for mission C: 0800-1700, 23 March 2010; dismounted/mounted patrol, firing range, and squad rush drills (N = 3).

Although predicting HR remains a challenge and future work remains to be done, our modeling efforts still present a useful tool for analyzing a set of environmental conditions given a metabolic profile. Missions A, B, and C occurred during temperate environmental conditions typically associated with a low risk for heat injury. The WBGT flag conditions for each mission were white/no flag even when accounting for the addition of 2.8°C (5°F) to air temperature for individuals wearing body armor.[26] However, the maximum mean PSI values observed during these missions indicated that the subjects approached medium to high thermal-work strain at various points during each mission (PSI values of 5.4, 6.7, and 6.0 for missions A, B, and C, respectively). Given the brevity for which these maximum PSI values were reached and sustained, it is unlikely that any subject would have incurred thermal injury but the same levels of exertion modeled under July conditions indicate warfighters would be at increased risk of heat illness or injury.

Average summer environmental conditions were warmer (+~8°C) and exposed warfighters to greater solar radiation (+~10°C black globe) yet were still under white/no flag WBGT conditions as observed in March (Table I). Metabolic mission profiles involving chronic heavy work or acute very heavy work (B and C) under the warmer white/no flag July conditions resulted in predicted PSI values >8, which correspond to high thermal-work strain.[13] Unsurprisingly, the corresponding predicted T_{core} values for July conditions averaged greater than 38.5°C with mission B's predicted average peaking above 39.5°C (Table II). As the data displayed in Figure 2 illustrates, Bland–Altman analysis indicated that across all data points (Missions A, B, and C) there is a slight bias for under estimating T_{core} (–0.02 ± 0.32°C) values. Combined with our overprediction of HR this suggests that warfighters might experience even greater thermal-work strain than predicted and that our predictions should serve as lower bounds of thermal-work strain likely to be experienced.

Given the increased thermal load predicted for July, it is likely that warfighters would self-adjust their operational tempo to reduce thermal-work strain. Nevertheless, our modeling effort raises the point that conditions not usually associated with high thermal-work strain may still pose a risk of thermal illness or injury when combined with sustained heavy or acute very heavy work. This is especially relevant given Schickele's finding during her examination of training related heat stroke fatalities that "most fatalities associated with heavy exercise can occur at relatively low [air] temperatures, when the total heat strain is commonly underestimated."[28] Quantifying thermal-work strain may provide a more sensitive method for determining when specific training conditions (i.e., meteorological conditions, worn ensemble, and metabolic work profile) place warfighters at increased or lessened likelihood of thermal injury. Leaders can then maximize training time that might otherwise be excluded by the current WBGT flag system and avoid scenarios where warfighters are at actually at heightened risk of incurring thermal injury.

Although our study used both PSI and T_{core} values to quantify the thermal-work strain associated with different environmental conditions, a similar approach could be used to compare the thermal burden of different CIE ensembles. Our physiological data, CIE im and clo values, and estimated metabolic data can serve as control inputs for the SCENARIO thermoregulatory model while the permeability index and insulation of a new or modified ensemble serve as the experimental inputs. Differences in predicted PSI and T_{core} values between control and experimental ensembles would indicate the thermal-work strain impact that changes in ensemble permeability and/or insulation would have on dismounted warfighters under known meteorological conditions while engaging in three distinct mission work profiles. Unit leaders and materiel developers could use these metrics to weigh the thermal cost and benefit of “mission essential” equipment either currently deployed in the field or being developed for future use.

CONCLUSIONS

Using a modified metabolic estimator from the ICDA model and the rational SCENARIO model it is possible to quantitatively compare in-theater dismounted warfighter thermal-work strain during different sets of environmental conditions and metabolic profiles. This study’s comparison of March and July environmental conditions in Afghanistan highlights three important points: (1) the data necessary for predictive physiological modeling can be successfully collected during in-theater missions, (2) small increases in ambient temperature and solar load are likely to lead to high thermal-work strain when combined with heavy or very heavy work, and (3) similar modeling methods can be used to predict and compare the thermal burden resulting from various environmental conditions and CIE ensembles. Future modeling efforts will benefit from the development of more accurate methods of measuring or estimating $\dot{M}$ and HR in the field. The methods presented here should be valuable to field commanders and materiel developers seeking to predict and mitigate thermal-work strain experienced by dismounted warfighters.

REFERENCES

1. FM 3-0 Operations: Department of the Army Field Manual. Washington, DC, Headquarters, Department of the Army, February 27, 2008. Available at http://downloads.army.mil/fm3-0/FM3-0.pdf; accessed March 26, 2013.
2. FM 21-18 Foot Marches: Department of the Army Field Manual. Washington, DC, Headquarters, Department of the Army, June 1, 1990. Available at http://armypubs.army.mil/doctrine/DR_pubs/dr_a/pdf/fm21_18.pdf; accessed March 26, 2013.
3. Sawka MN, Leon LR, Montain SJ, Sonna LA: Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. Compr Physiol 2011; 1: 1883–928.
4. Santee WR, Gonzalez RR: Characteristics of the thermal environment. In: Human Performance Physiology and Environmental Medicine at Terrestrial Extremes, Chapter 1, pp 1–43. Edited by Pandolf KB, Sawka MN, Gonzalez RR. Indianapolis, IN, Benchmark Press, 1988.
5. Sawka MN, Cheuvront SN, Kenefick RW: High skin temperature and hypohydration impair aerobic performance. Exp Physiol 2012; 97(3): 327–32.
6. Cheuvront SN, Kenefick RW, Montain SJ, Sawka MN: Mechanisms of aerobic performance impairment with heat stress and dehydration. J Appl Physiol 2010; 109(6):1989–95.
7. Buller MJ, Tharion WJ, Karis AJ, et al: Demonstration of real-time physiological status monitoring of encapsulated 1st Civil Support Team—Weapons of Mass Destruction (CST-WMD) Personnel. Technical Report No. T08-01. Natick, MA, U.S. Army Research Institute of Environmental Medicine, August 2007. Available at http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA473188; accessed March 26, 2013.
8. Muza SR, Banderet LE, Cadarette B: Protective uniforms for nuclear, biological, and chemical warfare. In: Medical Aspects of Harsh Environments, Chapter 36, pp 1084–127. Edited by Pandolf KB, Burr RE. Falls Church, VA, Office of the Surgeon General, Unites States Army, 2002.
9. Pandolf KB, Givoni B, Goldman RF: Predicting energy expenditure with loads while standing or walking very slowly. J Appl Physiol 1977; 43: 577–81.
10. Beidelman BA, Hoyt RW, Pearce FJ, et al: User acceptability of design concepts for a life sign detection system. Technical Report T04-02 (ADA 421578). Natick, MA, U.S. Army Research Institute of Environmental Medicine, 2003. Available at http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA421578; accessed March 26, 2013.
11. Gunga AW, Sattler JK: Thermal monitoring systems. In: RTO-TR-HFM-132: Real-Time Physiological and Psycho-Physiological Status Monitoring. NATO Research and Technology Organization Report, Chapter 3, pp 34, March 2010. Available at http://www.rto.nato.int/Pubs/rdp.asp?RDP=RTO-TR-HFM-132; accessed March 26, 2013.
12. Goodman DA, Kenefick RW, Cadarette BS, Cheuvront SN: Influence of sensor ingestion timing on consistency of temperature measures. Med Sci Sports Exerc 2009; 41: 597–602.
13. Moran DS, Shitzer A, Pandolf KB: A physiological strain index to evaluate heat stress. Am J Physiol Regul Integ Comp Physiol 1998; 275: 129–134.
14. Berglund LG: Heart rate as an indicator of metabolic rate in hot environments. In: Proceedings of 30th Annual Conference on Engineering in Medicine and Biology, Los Angeles, CA, November 5–9, 1977, Volume 19, pp 274. Bethesda, MD, Alliance for Engineering in Medicine and Biology.
15. Yokota M, Berglund LG: Initial Capability Decision Aid (ICDA) Thermal Prediction Model and Its Validation. Technical Report No. T06-03. Natick, MA, U.S. Army Research Institute of Environmental Medicine, January 2006. Available at http://www.dtic.mil/docs/citations/ADA446078; accessed April 5, 2013.
16. Wright HF, Wilmore JH: Estimation of relative body fat and lean body weight in a United States Marine Corps population. Aerosp Med 1974; 45: 301–6.

17. ASTM Standard F1291-10: Standard Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin. West Conshohocken, PA, ASTM International, 2010.
18. ASTM Standard F2370-10: Standard Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin. West Conshohocken, PA, ASTM International, 2010.
19. ASTM Standard F1868-09: Standard Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot plate. West Conshohocken, PA, ASTM International, 2009.
20. Weather Calculator. Peachtree City, GA, National Weather Service Weather Forecast Office. Available at http://www.srh.noaa.gov/ffc/html/metcalc.php; accessed March 26, 2013.
21. Kraning KK, Gonzalez RR: A mechanistic computer simulation of human work in heat that accounts for physical and physiological effects of clothing, aerobic fitness, and progressive dehydration. J Therm Biol 1997; 22: 331–42.
22. Kraning KK, Gonzalez RR: SCENARIO: A military/industrial heat strain model modified to account for effects of aerobic fitness and progressive dehydration. Technical Note TN07-1 (ADA 278323). Natick, MA, U.S. Army Research Institute of Environmental Medicine, 1997. Available at http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA323872&Location=U2&doc=GetTRDoc.pdf; accessed March 26, 2013.
23. Yakota M, Berglund LG, Cheuvront SN, et al: Thermoregulatory model to predict physiological status from ambient environment and heart rate. Comput Biol Med 2008; 38: 1187–93.
24. Degroot DW, Goodman DA, Montain SJ, Cheuvront SN: Validation of the ICDA model for predicting body core temperature. Med Sci Sports Exerc 2008; 40(5): S367.
25. Bland JM, Altman DG: Statistical methods for assessing agreement between two methods of clinical measurements. Lancet 1986; 1 (8476):307–10. Available at http://armypubs.army.mil/med/DR_pubs/dr_a/pdf/tbmed507.pdf; accessed March 26, 2013.
26. TB MED 507: Heat Stress Control and Heat Casualty Management. Department of the Army and Air Force Technical Bulletin, TBMED507/AFPAM 48-152(1), Washington, DC, Headquarters Department of the Army, March 7, 2003.
27. OSHA Technical Manual (OTM), Section III: Chapter 4: Heat Stress. Occupational Safety and Health Administration Technical Manual, Directive Number: TED 01-00-015, Washington DC, U.S. Department of Labor, 20, 1999. Available at http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html; accessed March 3, 2013.
28. Schickele E: Environment and fatal heat stroke: an analysis of 157 cases occurring in the army in the U.S. during World War II. Mil Surg 1947; 100: 235–56.

UNITED STATES POSTAL SERVICE®

Statement of Ownership, Management, and Circulation
(All Periodicals Publications Except Requester Publications)

1. Publication Title MILITARY MEDICINE	2. Publication Number 349 – 160	3. Filing Date 9/9/2013
4. Issue Frequency MONTHLY	5. Number of Issues Published Annually 12X	6. Annual Subscription Price $170 Domestic/$225 Foreign

7. Complete Mailing Address of Known Office of Publication *(Not printer) (Street, city, county, state, and ZIP+4®)*
9320 OLD GEORGETOWN RD
BETHESDA, MD 20814

Contact Person
TONYA LIRA

Telephone *(Include area code)*
301-897-8800 X586

8. Complete Mailing Address of Headquarters or General Business Office of Publisher *(Not printer)*
SAME AS ABOVE

9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor *(Do not leave blank)*

Publisher *(Name and complete mailing address)*
MIKE COWAN, M.D.
9320 OLD GEORGETOWN RD, BETHESDA, MD 20814

Editor *(Name and complete mailing address)*
WILLIAM H. J. HAFFNER M.D.
9320 OLD GEORGETOWN RD, BETHESDA, MD 20814

Managing Editor *(Name and complete mailing address)*

10. Owner *(Do not leave blank. If the publication is owned by a corporation, give the name and address of the corporation immediately followed by the names and addresses of all stockholders owning or holding 1 percent or more of the total amount of stock. If not owned by a corporation, give the names and addresses of the individual owners. If owned by a partnership or other unincorporated firm, give its name and address as well as those of each individual owner. If the publication is published by a nonprofit organization, give its name and address.)*

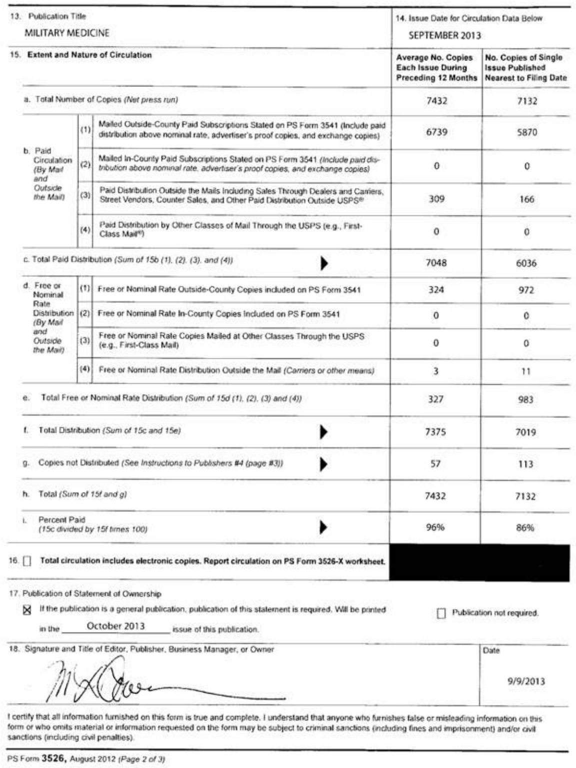
Full Name	Complete Mailing Address
AMSUS	9320 OLD GEORGETOWN RD, BETHESDA, MD 20814

11. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, or Other Securities. If none, check box ► ☒ None

Full Name	Complete Mailing Address

12. Tax Status *(For completion by nonprofit organizations authorized to mail at nonprofit rates) (Check one)*
The purpose, function, and nonprofit status of this organization and the exempt status for federal income tax purposes:
☐ Has Not Changed During Preceding 12 Months
☐ Has Changed During Preceding 12 Months *(Publisher must submit explanation of change with this statement)*

PS Form **3526**, August 2012 *(Page 1 of 3 (Instructions Page 3))* PSN: 7530-01-000-9931 **PRIVACY NOTICE:** See our privacy policy on www.usps.com



13. Publication Title MILITARY MEDICINE	14. Issue Date for Circulation Data Below SEPTEMBER 2013	
15. Extent and Nature of Circulation	**Average No. Copies Each Issue During Preceding 12 Months**	**No. Copies of Single Issue Published Nearest to Filing Date**
a. Total Number of Copies *(Net press run)*	7432	7132
b. Paid Circulation *(By Mail and Outside the Mail)* (1) Mailed Outside-County Paid Subscriptions Stated on PS Form 3541 (Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)	6739	5870
(2) Mailed In-County Paid Subscriptions Stated on PS Form 3541 *(Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)*	0	0
(3) Paid Distribution Outside the Mails Including Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside USPS®	309	166
(4) Paid Distribution by Other Classes of Mail Through the USPS (e.g., First-Class Mail®)	0	0
c. Total Paid Distribution *(Sum of 15b (1), (2), (3), and (4))* ►	7048	6036
d. Free or Nominal Rate Distribution *(By Mail and Outside the Mail)* (1) Free or Nominal Rate Outside-County Copies included on PS Form 3541	324	972
(2) Free or Nominal Rate In-County Copies Included on PS Form 3541	0	0
(3) Free or Nominal Rate Copies Mailed at Other Classes Through the USPS (e.g., First-Class Mail)	0	0
(4) Free or Nominal Rate Distribution Outside the Mail *(Carriers or other means)*	3	11
e. Total Free or Nominal Rate Distribution *(Sum of 15d (1), (2), (3) and (4))*	327	983
f. Total Distribution *(Sum of 15c and 15e)* ►	7375	7019
g. Copies not Distributed *(See Instructions to Publishers #4 (page #3))* ►	57	113
h. Total *(Sum of 15f and g)*	7432	7132
i. Percent Paid *(15c divided by 15f times 100)* ►	96%	86%

16. ☐ **Total circulation includes electronic copies. Report circulation on PS Form 3526-X worksheet.**

17. Publication of Statement of Ownership
☒ If the publication is a general publication, publication of this statement is required. Will be printed in the October 2013 issue of this publication.
☐ Publication not required.

18. Signature and Title of Editor, Publisher, Business Manager, or Owner
Date 9/9/2013

I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including civil penalties).

PS Form **3526,** August 2012 *(Page 2 of 3)*