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The U.S. Army Research Institute of Environmental Medicine (USARIEM) has been conducting a series of collaborative field research studies to develop real-time non-invasive markers of exertional heat illness and a physiological monitoring system that is both easy to use and provides actionable heat illness risk alerts. As part of this on-going study, in September 2019, a prototype Heat Illness Prevention System (HIPS) was trialed at the Marine Corps Recruiting Depot – Parris Island in collaboration with the Branch Health Clinic. From the results of this study, a concept of operations was developed for the real-time monitoring of the heat strain status of Marine recruits during their final Crucible event. In addition, the HIPS hardware algorithms, and supporting applications were revised to enable monitoring at scale to cover a full company of recruits. During the summer of 2021, the upgraded HIPS system was deployed and used to monitor all recruits during nine Crucibles with two objectives: (1) To demonstrate the feasibility and utility of monitoring upwards of 500 recruits during a 56-hour final field training exercise; and (2) to collect baseline physiological and perceptual data to characterize the stresses of the Crucible and capture physiological data of exertional heat

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U.S. Army Research Institute of Environmental Medicine

Natick, Massachusetts

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Physiological Monitoring of the Marine Corps Recruit - Depot Parris Island, SC Crucible Events

United States Army
Medical Research & Development Command

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USARIEM TECHNICAL REPORT T23-005

Physiological Monitoring of the Marine Corps Recruiting Depot Parris Island SC, Crucible Events

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LIST OF ACRONYMS

Acronym	Description of Acronym
aPSI	Adaptive Physiological Strain Index
CT	Core Body Temperature
DI	Drill Instructor
ECT	Estimated Core Temperature
EHI	Exertional Heat Illness
ESQ	Environmental Symptoms Questionnaire
HIPAA	Health Information Portability and Accountability Act
HIPS	Heat Illness Prevention System
HR	Heart Rate
HRAPS	Health Readiness and Performance System
HSI	Heat Strain Index
IRB	Institutional Review Board
MRDC	Medical Research Development Command
PSI	Physiological Strain Index
PSM	Physiological Status Monitor
RTR	Recruit Training Regiment
ST	Skin Temperature
TTL	Thermal Tolerance Limit
USARIEM	U.S. Army Research Institute of Environmental Medicine
WBGT	Wet Bulb Globe Temperature

BACKGROUND

The U.S. Army Research Institute of Environmental Medicine (USARIEM) has been conducting a series of collaborative field research studies to develop real-time non-invasive markers of exertional heat illness and a physiological monitoring system that is both easy to use and provides actionable heat illness risk alerts. As part of this ongoing study, in September 2019, a prototype Heat Illness Prevention System (HIPS) was trialed at the Marine Corps Recruiting Depot – Parris Island in collaboration with the Branch Health Clinic. From the results of this study, a concept of operations was developed for the real-time monitoring of the heat strain status of Marine recruits during their final Crucible event. In addition, the HIPS hardware, algorithms, and supporting applications were revised to enable monitoring at scale to cover a full company of recruits. During the summer of 2021, the upgraded HIPS system was deployed and used to monitor all recruits during 9 Crucibles with two objectives: (1) To demonstrate the feasibility and utility of monitoring upwards of 500 recruits during a 56-hour final field training exercise, and (2) to collect baseline physiological and perceptual data to characterize the stresses of the Crucible and capture physiological data of exertional heat illnesses as they occurred.

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EXECUTIVE SUMMARY

Occurrence of exertional heat illness (EHI) in the military has been observed and documented for millennia.[1] However, there is little understanding as to why some Warfighters succumb to EHI while others do not. This in turn makes it difficult to design and implement heat mitigation protocols that simultaneously allow military personnel to perform training that develops operational capability while also protecting soldiers from EHI. One proposed solution to this problem is the use of real-time physiological status monitors (PSMs) that allow command teams, trainers, and medical personnel to monitor the health status of their trainees and use this real-time information to make informed decisions on which heat mitigation procedures to deploy. To test this solution, the Heat Illness Prevention System (HIPS) was distributed and worn by recruits during 9 Crucible events (a 56-hour strenuous field training exercise). The purpose of deploying this system was to demonstrate the feasibility and value of monitoring large groups of Marine recruits during the Crucible, capture data of EHIs as they occurred and collect physiological data to gain a better understanding of individual responses to prolonged heat stress. The system consists of a chest belt and a PSM that measures heart rate (HR), single-point chest skin temperature (ST), 3-axis accelerometry and estimated core temperature (ECT). Throughout the duration of the event, a color code system was used to identify the level of risk for a recruit based on pre-determined thresholds for ECT. Various surveys were used to collect quantitative and qualitative data related to participant demographics, potential EHI risk factors, and perceived heat strain. Over the duration of the 9 Crucibles, 38 heat illnesses occurred, including 4 heat strokes and 25 heat exhaustions. Due to device errors and training conditions, 17 out of the 38 heat cases had complete data sets and were included in the final analysis. Using the pre-set thresholds for ECT as a means of identifying heat illness, only 10 out of the 17 heat illnesses were identified correctly, resulting in a false negative rate of 58%, indicating that ECT alone is a poor predictor of EHI. However, when HR, ECT and ST were combined into the adaptive physiological strain index (aPSI) and used to identify heat illness, all cases were correctly identified with no false negatives. These results demonstrate that using aPSI in conjunction with ECT proves valuable in providing an accurate estimate of exertional heat strain. The aPSI is simple enough that it can be implemented on a chest mounted device that measures HR and ST. These results also show that using real-time physiological monitoring has great potential to be deployed into training environments to minimize the instance of EHI and increase overall Warfighter readiness.

INTRODUCTION

Exertional Heat Illness (EHI) is both a historic and contemporary military problem owing to the continued confluence of risk factors including high work rates, protective clothing[1] and equipment, and often the requirement to work in environmental extremes[3]. Steinman's historical review[36] of the effects of heat on military operations cites multiple cases where heat illness played a significant degrading effect, such as in the Roman Army[21], the European Crusaders in the middle-ages[23], the Napoleonic wars[11], the British Army in India in the 19th Century[30], and during the First World War[38]. More recent examples from the Iraq War have also been cited.[17] Furthermore, as baseline temperatures in common areas of military operations and deployments appear to be climbing[12], military training in hot environments must continue to prepare active-duty soldiers for these relevant environments.

Physically strenuous activities are an essential part of military training and are often required to be executed in high ambient temperatures and humidity similar to operational environments. The combination of high levels of exertion, extremely hot environments, and intrinsic factors, such as individual motivation, make basic training events much more likely to have heat-related illnesses.

The need to put protocols in place to reduce the incidence of heat illness was pioneered by Schickele et al in their 1947 survey which identified the "heat death line" from WWII training deaths.[34] The Marine Corps Recruit Depot at Parris Island, SC was first to implement a standardized environmentally-based EHI mitigation protocol based upon the Wet-Bulb Globe Temperature (WBGT) stemming from work by Yaglou and Minard.[39,40] This pioneering work led to a significant drop in the incidence of EHI during Marine Corps basic training.[24,25] The approach has become ubiquitous across military training organizations around the world and became the basis for the colored flag system that is in use today.

Despite these mitigation efforts, heat-related illness continues to be a persistent threat to the U.S. military, which causes high rates of morbidity, mortality, and the consumption of costly and valuable medical resources.[37] In 2021 alone, there were 2,352 cases of EHI across active-duty service members[2], most of which occurred in training with over 500 cases of the potentially life-threatening exertional heat stroke (EHS). The number of cases has remained steady at these levels at least for the last 5 years.

In an effort to further refine and improve upon EHI prevention protocols, recent work has focused on identifying individual risk factors such as body mass index, prior illness, and heat acclimatization. However, specific risk factors being present in all cases of EHI have not been found.[13] Gardner et al found that when pinpointing certain risk factors that were used to identify individuals thought to be more at risk for EHI than their peers, less than one fifth of the recruits that fell ill were considered to be at high-risk.[16] Relying on variables such as WBGT and pre-existing risk factors during training can be a limitation in EHI prevention as these approaches do not account for the differences across individuals in response to heat stress.

Recently, investigators have started to focus on the use of PSMs for monitoring Warfighters during these high-risk training events. The purpose of PSMs is to acquire and interpret individual physiological data in real-time, providing valuable insight into the physiological state of a Warfighter during exertional events.[14] Information provided from PSMs can provide critical actionable information regarding a real-time thermal-work strain at an individual level and can alert training staff when an individual may be at impending risk of a heat illness so preventative actions can be taken early.[6] When heat strain state information is combined with a sensible human-in-the-loop protocol, there is a potential to significantly reduce the incidence of EHI. For success though, this approach needs accurate and actionable EHI state information.

While high core body temperatures (CT) are one of the indicators in diagnosing EHI and provide a good underpinning of general risk, CT alone lacks specificity in identifying those truly at risk of EHI.[19] Combinations of HR, ST, CT and sweat rate have also been proposed as providing a better indication of an individual's heat strain state.[18] Of note, the physiological strain index (PSI) (an equal weighting of HR and CT)[26] and its recent modification (aPSI) that adjusts the PSI based upon the difference between CT and ST, have both been proposed and show some success[20,26] as a means to accurately assess thermal-work strain state. However, thermal-work strain state does not necessarily directly relate to EHI risk. Davey et al appeared to show that these methods do not accurately identify individuals who withdraw from laboratory exercise protocols because of heat-related symptoms.[10] However, methods to relate thermal-work strain and EHI risk have not been demonstrated successfully in field settings with actual EHI cases.

The present study had two main objectives: 1) To evaluate whether real-time feedback of thermal-work strain state of field exercise participants provides useful information to drill instructors and command teams, and 2) To demonstrate the relationship between thermal-work strain and EHI risk.

METHODS

To meet these objectives, participants in nine U.S. Marine Corps Recruit Depot (USMCRD) - Parris Island final culminating Crucible exercise were instrumented and monitored. The Crucible is a 56-hour field training exercise graduation requirement for recruits completing basic training. The Crucible takes place on Page Field and starts on Thursday at about 0200 with a 6-mile road march from the company barracks to Page Field. Recruits are divided into teams of approximately 20 recruits and are instructed throughout the Crucible by their assigned Drill Instructor. At Page Field, recruits complete a series of exercises to test their prior training and face both mental and physical challenges, while receiving limited sleep each night. The event culminates in a 9-mile road march to Peatross Parade Deck on Saturday morning. Upon completion, recruits form on the parade deck to receive their Marine Corps globe and anchor insignia, officially becoming fully fledged Marines and return to their barracks for a Warrior breakfast.

PARTICIPANTS

A total of 3,093 U.S. Marine Corps recruits from 10 training companies participated in the study across 9 Crucible events from 15 July to 25 September 2021 (Table 1).

Table 1. Study participant population mean and standard deviation for each gender (mean ± SD).

Gender	N	Age (yr.)	Height (in.)	Weight (lbs.)	3 Mile Run Time (min.)
Males	2,476	19.2 ± 2	69.6 ± 2.7	160.3 ± 20.6	22.6 ± 2.2
Females	617	19.1 ± 1.8	63.7 ± 2.9	130.9 ± 14.8	26.6 ± 2.2

All recruits wore the Heat Illness Prevention System (HIPS, ODIC, Littleton, MA) physiological monitoring system as part of a safety requirement instituted by the Recruit Training Regiment (RTR). Recruits were also briefed about the research study and the collection of physiological data, prior EHI risk factors and perceptual data by the USARIEM study team. Recruits provided written consent for the study team to use their data according to the USARIEM research protocol approved by the U.S. Army Medical Research and Development Command (MRDC) Institutional Review Board (IRB), and the Marine Corps IRB.

MEASURES

Prior to the training event, questionnaires were administered to collect self-reported demographic and wellness information from individuals regarding age, height (ht.), weight (wt.), Marine Corps Physical Fitness Training (MCPFT) 3-mile run times (that can be related to aerobic fitness[22]), whether they were feeling unwell, currently taking medications, had any previous EHI events, currently using dietary supplements, received any immunizations within the last 30 days, whether they had visited a doctor or had an illness in the last 60 days, and their estimated fluid intake within the last 12 hours (Appendix A and B).

Heart rate (from ECG, recorded every 5s), chest skin temperature (recorded every 15s), and tri-axial accelerometry (128 Hz, ADXL362 chip; Analog Devices, Norwood, MA; ± 8g) were logged using a custom torso-worn physiological monitoring system (Heat Illness Prevention System - HIPS, Odic, Littleton, MA: Weight = 16g, Dimensions = 7.0 x 4.3 x 0.9 cm). Estimated core body temperature (ECT) was calculated according to the ECTemp method.[5] The HIPS chest belt system is a government-owned device developed in conjunction with the Health Readiness and Performance System (HRAPS) program of record. The HIPS is designed to provide high quality data in a size and form that is acceptable to the Warfighter (Figure 1). The HIPS used during the Crucible event consisted of a chest belt and small puck that has 7 days of battery life. The system both stores data to memory and transmits data via Bluetooth.

Figure 1. The HIPS Physiological Status Monitor Chest Belt and Puck

During the Crucible, if a participant experienced a heat illness, they were initially examined by a Corpsman. Field rectal temperatures would be taken prior to evacuation from Page Field to the Crucible Aid Station (located ~5 min from Page Field), where patients could be treated with ice water bath immersion. Depending on the severity of the heat illness, they were either sent to the Naval Hospital or Beaufort Memorial Hospital in Beaufort, SC, returned to Page Field to continue training, or removed from training. Diagnoses of the type and severity of heat illness were collected from the medical records of these participants.

Finally, heat illness symptoms were collected post Crucible using the 14-question Environmental Symptoms Questionnaire (ESQ, Appendix C).

Environmental Information

Environmental data in the form of Wet Bulb Globe Temperatures (WBGT) were obtained from the Marine Corps Automated Heat Stress System Website (https:// http://ahss.lejeune.usmc.mil/, accessed March 2021) every 10 minutes for the duration of each Crucible.

Environmental Symptoms Questionnaire (ESQ)

The ESQ is a 14-question component of the Environmental Symptoms Questionnaire (ESQ)[31] that has been shown to be valid to assess heat illness symptoms.[35] The questions are simply phrased (e.g., "During the Crucible I felt Hot") and participants rate how much the statement applied to them during the Crucible. For example, participants rated each question from 0 "Does not apply" to 6 "Fully applies". The full set of questions can be found in Appendix C. An overall heat symptom score is calculated by taking the mean of all 14 questions – reversing the score (e.g., 6 score) for the question "During the Crucible I did my best".

Exertional Heat Illness (EHI) Data

Marine recruits that experienced an EHI during the Crucible were treated by corpsmen. The EHI event was logged in the Parris Island Heat Tracker and in the medical database. De-identified EHI casualty counts were collected for each Crucible. For recruits who consented to be in the study and provided a HIPAA release form, additional data including field rectal temperatures and medical diagnoses were received.

Heat Strain Indices

While heat strain indices were not used during the Crucible events, these types of indices have been developed to provide insight into both the heat strain and physiological strain experienced by individuals. We calculated both the Physiological Strain Index (PSI)[26] and the adaptive Physiological Strain Index (aPSI)[6]. In place of a measured core temperature, we substituted the estimated core body temperature computed by the ECTemp.

Physiological Strain Index (PSI):

The PSI is calculated using an equally weighted combination of both HR and CT and incorporates a high HR threshold of 180 beats/minute and a high core body temperature threshold of 103.1°F:

$$PSI = 5\left(\frac{CT_t - CT_{rest}}{CT_{critical} - CT_{rest}}\right) + 5\left(\frac{HR_t - HR_{rest}}{HR_{critical} - HR_{rest}}\right)$$

For our computations, the indices were calculated using the Celsius scale where: PSI is the physiological strain index, CT is core body temperature, and HR is heart rate. The rest suffix denotes the HR or CT at rest prior to exercise. Moran defined the two critical parameters as fixed values: $CT_{critical}$ = 39.5 °C (103.1°F) and $HR_{critical}$ = 180 beats/min[26].

Adaptive Physiological Strain Index (aPSI):

The aPSI utilizes skin temperature to modify the PSI CT critical set point:

$$CT_{critical} = 39.5 + \frac{(CT - ST) - 4}{4}$$

Effectively, if the temperature difference between ST and CT is less than 4, the maximum core temperature is progressively reduced, and individuals can reach alerting thresholds faster.

Both the PSI and aPSI provide a heat strain score from 0 to 10+ and where: 1=little/no strain, 3=low strain, 5=moderate strain, 7=high strain, and 9=very high strain.

PROCEDURES

At the start of each week, the study team met with company command to brief on the heat monitoring system, how it worked, how their Drill Instructors (DIs) and training would benefit from it, and how the consent and issuing process would proceed. On the morning that the company had their final drill, typically Wednesday morning (the day prior to the Crucible), the team would go to the company barracks to brief, consent, and distribute equipment to all recruits in each platoon as they returned from drill. In the consent paperwork was the protocol consent form, Health Information Portability and Accountability Act (HIPAA) form, and demographic and heat risk surveys. Recruits were instructed to snap the puck onto the belt and then wrap electric tape around both the puck and strap, without covering any of the sensors, to help keep the puck from popping off the belt during training. From this point, it was expected that all recruits wear the puck and chest strap until the completion of the Crucible 3 days later unless otherwise instructed to take it off. For example, depending on command, recruits were instructed to remove the device to shower and/or for certain combative events, such as the Devil Dog Dome. Also, during the briefing and consenting process, DIs were issued smart phones with the individual Heat Optimization Training Tool (iHOTT) app that was able to receive and display the data transmitted by the HIPS.

During both days of the Crucible, the study team would visit the recruits on Page Field around midday and at the evening medical foot check (~7:00pm) to check on the status of recruits and HIPS devices. This was also time to help any DIs who may have been having technical issues with their phones and fix any other equipment issues. On the morning of day 3, after the company had completed the Crucible and returned to the barracks from warrior breakfast, the team would go to each platoon to gather all equipment and have the new Marines complete a retrospective ESQ. Each Marine was asked to remove the tape from their strap/puck and rinse both with water to get off excess dirt. Ideally, each platoon was able to inform the team of any missing pucks or phones at this time.

Once the team received all the equipment, they would return to the Crucible aid station to clean and dry all of the HIPS devices and wash chest straps. A detailed inventory was completed to confirm which pucks may have been lost during the Crucible. The pucks were then plugged into the dock and downloaded to get all data from each consenting recruit saved. Once it was confirmed that the data for the puck was downloaded, it was then cleared of all data and left to charge for the next Crucible.

Concept of Real-Time Use

To provide real-time thermal-work strain state of individual recruits to their Drill Instructors and leaders, the HIPS was used in the following way:

***Recruits**:* wore the Heat Injury Prevention System (HIPS) chest belt for the duration of the Crucible (Figure 1).

Drill Instructors: were issued a smart phone with the iHOTT monitoring app configured to filter incoming data specific to their Crucible team (~20 Recruits, see Figure 2 panel B).

Company Leadership: were issued smart phones with the iHOTT app that could view all recruits (see Figure 2 panel A).

The phone app shows a colored grid with the initials of each team member. Team members can be color coded green, yellow or red, depending on their current heat strain state (Figure 2).

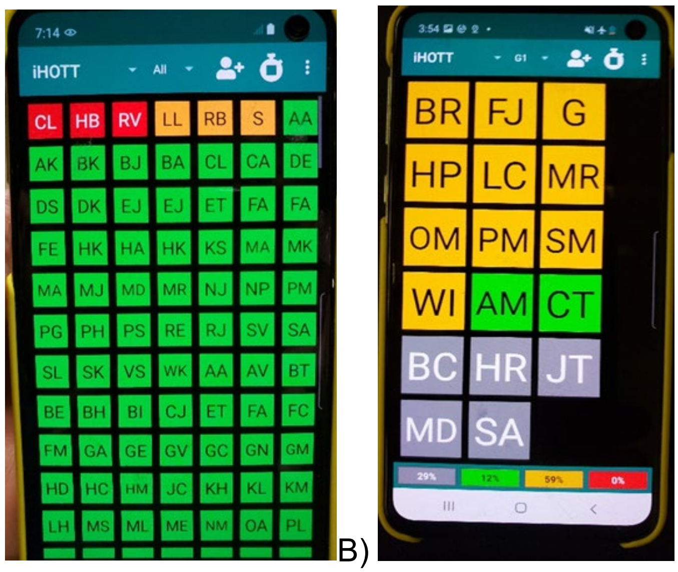
A)  B)

Figure 2. iHOTT Smart Phone App User Interface: Panel (A): Leadership "Airplane Seat" view of the individual heat strain for all recruits in the company within Bluetooth range. Panel (B): Team View of team members showing heat strain, and distribution of heat strain of all members in the team. Color thresholds are based upon ECT values. These thresholds can be set by leadership based upon risk tolerance.

Final actions for the drill instructors based upon the color codes of their teams were left to the company leadership. Importantly, in this concept of operations, it was instructed that the system does not replace the judgement of drill instructors, leadership, or corpsmen. It serves as a situational awareness tool to alert trainers of the possible state of an individual. Basic guidance for use of the system is as follows: green indicates "good to go", yellow indicates "take a look", while red indicates "take a look now". Given the intensity of some of the training and individual variability, some individuals may be "fine" at a yellow or red flag. Conversely, the system may also have someone colored green who is struggling with the heat. Further, Figure 3 shows an example of how a drill instructor could use the heat strain state color codes to manage heat strain in their team.

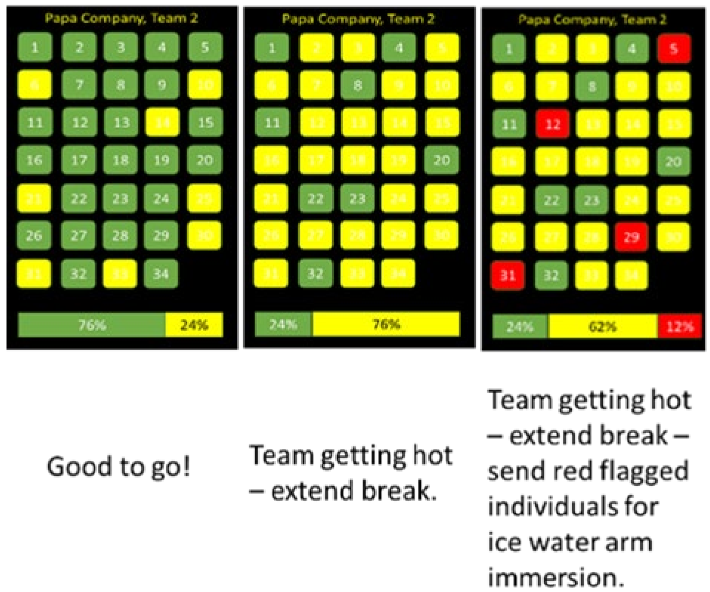


Figure 3. Possible use of the HIPS team view

The color codes for the system were set based upon ECT thresholds determined in consultation with the Branch Health Clinic at MCRD-PI and the Corpsmen. Yellow was set to temperatures above 102.1ºF and below 103.1ºF. Red was set for temperatures above 103.1ºF.

<u>Data Analysis</u>

To examine the relationship between thermal-work strain and EHI, we compared the number of EHIs during each Crucible with the overall mean WBGT, overall mean ECT, ST, HR, PSI and aPSI, and the overall subjective ratings from the post-Crucible ESQ using a Pearson's Correlation. We examined whether ECT, PSI, and aPSI could predict EHI cases, detailing the number of true positives and false negatives, where the yellow alerting thresholds were set at 102.1°F, 8, and 8.5 for the ECT, PSI and aPSI respectively. For the more urgent red threshold, we used 103.1°F, 10, and 10 for the ECT, PSI and aPSI respectively. Additionally, for the EHI cases, maximal ECT, PSI, and aPSI were correlated with the rectal temperatures (Tr) taken by the corpsman at the time of collapse. Finally, we used the overall distribution of aPSI to compute the likely number of false positives during the three hottest Crucibles based on WBGT (Kilo, Delta and Hotel). Note: temperature values are reported in degrees Fahrenheit (°F) to match the preferred unit used by the RTR. Calculations of PSI and aPSI use temperature values in degrees Celsius (°C) to match the scientific standard. Data are presented as means ± standard deviation (SD). The alpha value used is 0.05.

RESULTS

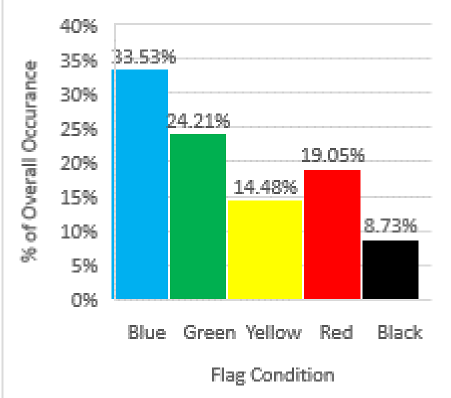
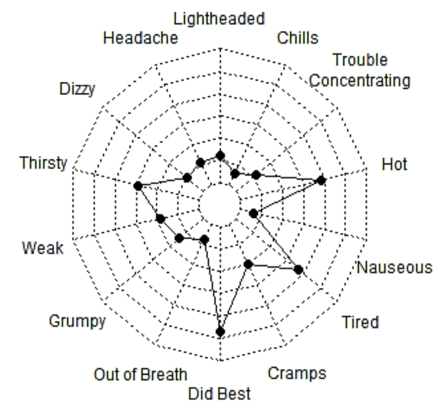
CRUCIBLE COMPARISONS

Mean WBGT conditions varied by Crucible and by weather monitoring stations across MCRD-Parris Island. Table 2 shows the mean WBGT temperatures and associated flag conditions for all weather monitoring stations across MCRD-PI. For subsequent analysis, the Page Field station readings were used. Table 3 lists the characteristics of each Crucible, including the dates, company, number of recruits who consented to be in the study, the amount of usable data, number of heat illness cases, WBGT flag condition distribution, and the overall mean of the perceptual questions. Tables 2 and 3 use the following abbreviations for each company that participated in the associated Crucible, “K” – Kilo, “C/N2” – Charlie/November 2, “L/O2” – Lima/Oscar 2, “D” – Delta, “H” – Hotel, “A/O3” – Alpha/Oscar 3, “E” – Echo, “I/N1” – India/November 1, “B/O1” – Bravo/Oscar 1

Table 2. Mean WBGT (°F) for each Crucible from the six weather stations at the depot, along with the average, lowest and maximum WBGT. Cell color = MCPI Flag Color.

Start Date	7/15	7/22	8/5	8/12	8/19	9/1	9/9	9/16	9/23
	K	**C/N2**	**L/O2**	**D**	**H**	**A/O3**	**E**	**I/N1**	**B/O1**
1st BN	83.86	83.78	79.01	85.20	85.46	82.23	80.77	81.34	75.99
3rd BN	85.46	84.37	79.21	87.54	86.96	83.24	80.60	82.20	75.26
4th BN	86.35	85.58	80.32	88.49	88.02	84.51	81.80	83.04	76.43
WPNSBN	85.47	83.87	78.82	87.06	85.47	82.90	77.56	80.65	70.21
Page Field	84.38	82.94	78.44	86.18	84.38	81.69	79.64	81.16	74.71
Leatherneck	84.21	83.03	77.99	85.10	84.21	80.71	76.99	80.46	74.47
Average	84.96	83.93	78.96	86.59	86.34	82.55	79.56	81.47	74.51
Lowest	75.98	73.70	71.93	76.38	77.38	66.97	40.64	74.41	48.04
Highest	92.11	93.84	95.68	96.21	97.81	94.16	95.11	92.85	94.16

Table 3. Crucible events are summarized in columns A, B and C. Column A lists summary information for the Crucible including the dates, company of consented recruits, final usable data, and the number of EHI cases. Column B provides a histogram of the flag conditions during the duration of the Crucible. Column C shows the mean responses to the ESQ given to the recruits after completing the Crucible.

<table>
<tr><th>Crucible Summary</th><th>Weather Conditions</th><th>Mean ESQ Responses</th></tr>
<tr><td>7/15-7/17: K
# of Consented Recruits: 361
# of Usable Recruit Data: 279
# of Heat Cases: 10</td><td>
</td><td>
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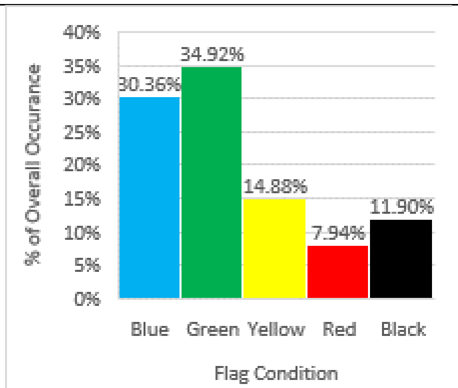
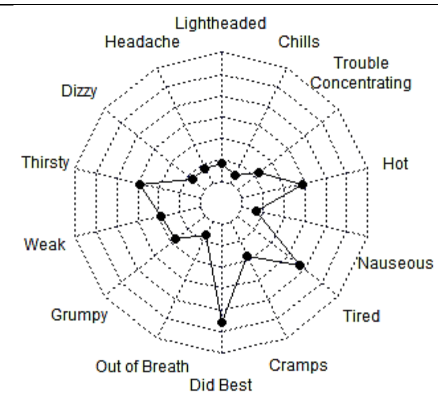
# of Consented Recruits: 371
# of Usable Recruit Data: 296
# of Heat Cases: 0</td><td>
</td><td>
</td></tr>
<tr><td>8/5-8/7: L/O2
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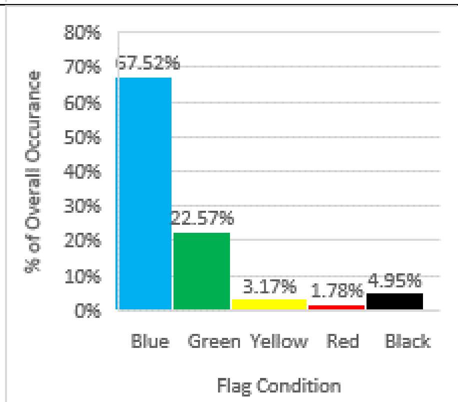
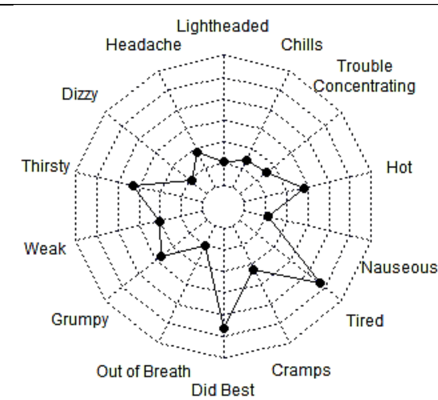
# of Usable Recruit Data: 106
# of Heat Cases: 2</td><td>
</td><td>
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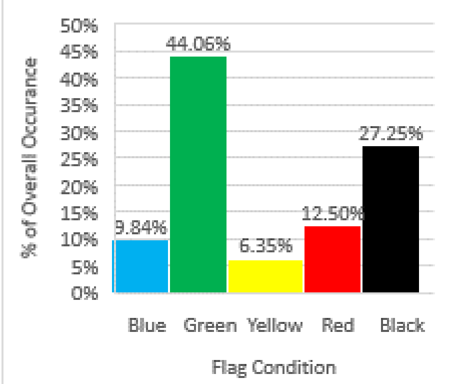
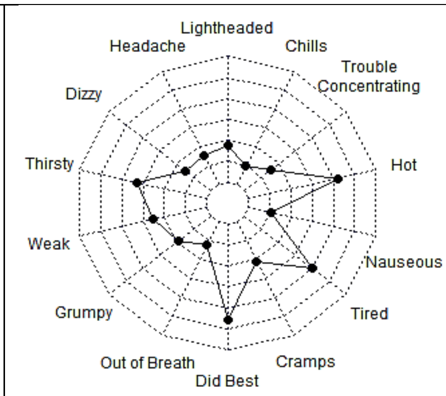
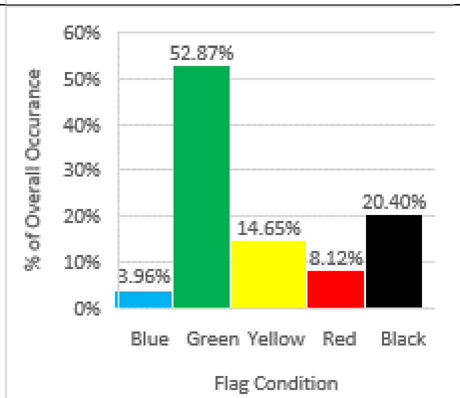
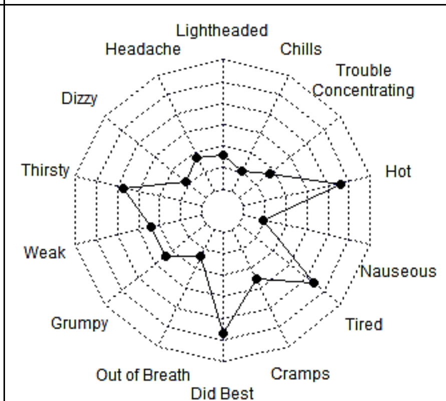
8/12-8/14: D	
# of Consented Recruits	282
# of Usable Recruit Data	274
# of Heat Cases	12



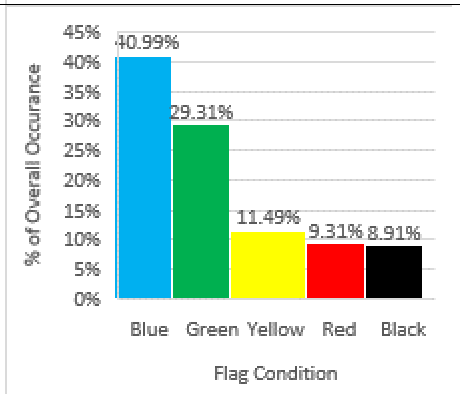


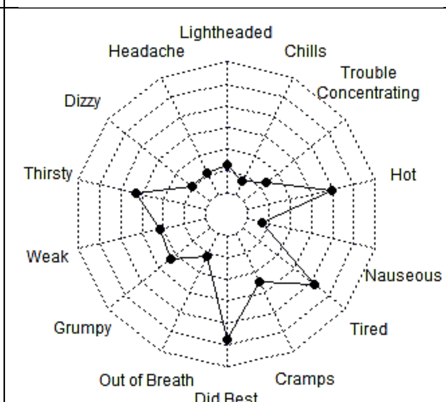
8/19-8/21: H	
# of Consented Recruits	317
# of Usable Recruit Data	306
# of Heat Cases	11



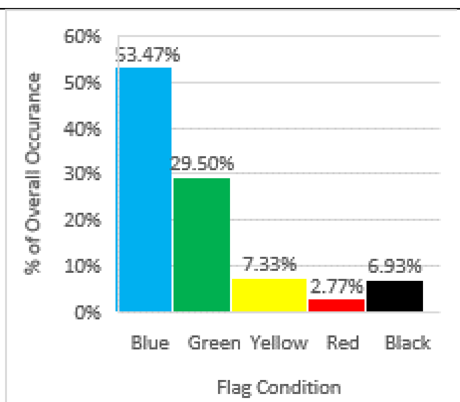


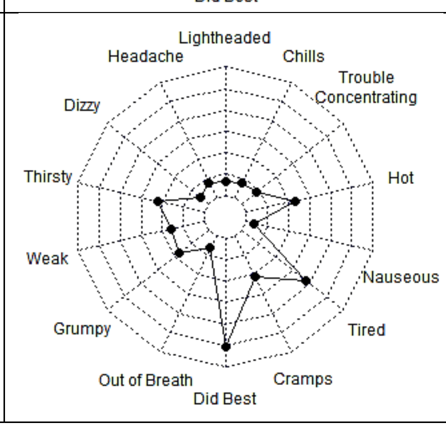
9/1-9/3: AO3	
# of Consented Recruits	421
# of Usable Recruit Data	417
# of Heat Cases	3





9/9-9/11: E	
# of Consented Recruits	340
# of Usable Recruit Data	247
# of Heat Cases	0





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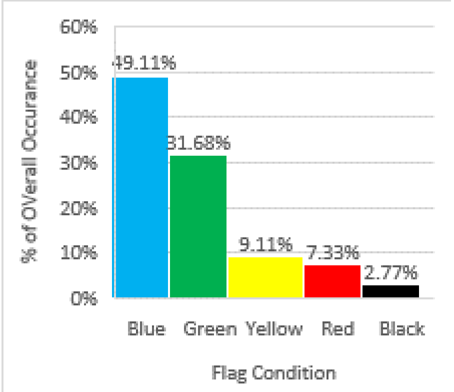
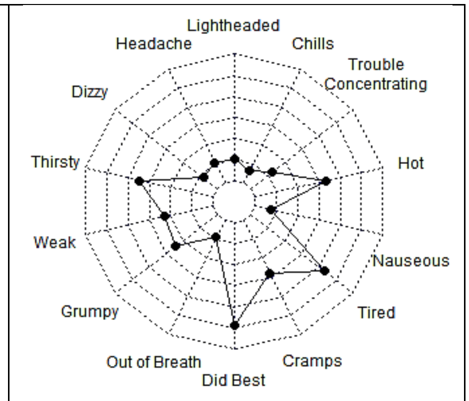
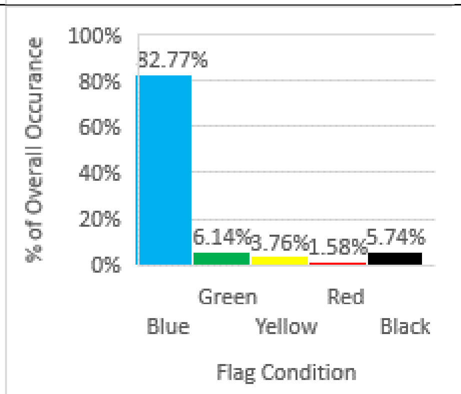
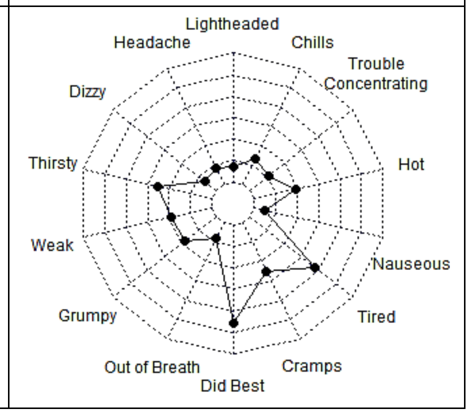
<tr><td colspan="2">9/16-9/18: I/N1</td><td rowspan="4">
</td><td rowspan="4">
</td></tr>
<tr><td># of Consented Recruits</td><td>512</td></tr>
<tr><td># of Usable Recruit Data</td><td>500</td></tr>
<tr><td># of Heat Cases</td><td>0</td></tr>
<tr><td colspan="2">9/23-9/25: B/O1</td><td rowspan="4">
</td><td rowspan="4">
</td></tr>
<tr><td># of Consented Recruits</td><td>380</td></tr>
<tr><td># of Usable Recruit Data</td><td>369</td></tr>
<tr><td># of Heat Cases</td><td>0</td></tr>
</table>

As one might expect, the larger number of EHIs occurred when there was a larger percentage of red and black flag periods. When there were 10, 12 and 11 EHI cases, there were red or black flag conditions for 27%, 39% and 28% of the time respectively. When there were three or fewer heat illnesses, the proportion of time with red and black flag conditions was less than 18%. Similarly, for the Crucibles with a higher incidence of EHI, recruits felt significantly hotter than recruits in Crucibles with less or no EHI cases. Post-Crucible ESQ responses to "I felt hot" were 4 or above (on a scale 0= "does not apply" to 6= "fully applies") for the hotter Crucibles compared to scores of 3 or below for all other Crucibles.

Figure 4 shows the mean HR (panel A), mean CT (panel B) and mean ST (panel C) for all 9 of the Crucibles plotted together. The HR and CT panels clearly show some of the major activities of the Crucible and how similar these events are across each Crucible. The road march out to Page Field can be seen as increased CTs and HRs beginning at 0200 on the first day. Similarly, the end of the day 1 and day 2 hikes at approximately 2000 also show these increases in CTs and HRs, along with the final march to the parade deck starting around 0200 on the last day. Sleep periods at the end of day 1 and day 2 around 0000 can be seen by the decrease in CT and HR. While a similar pattern exists for the skin temperature, it is less distinct and less homogenous between Crucibles.

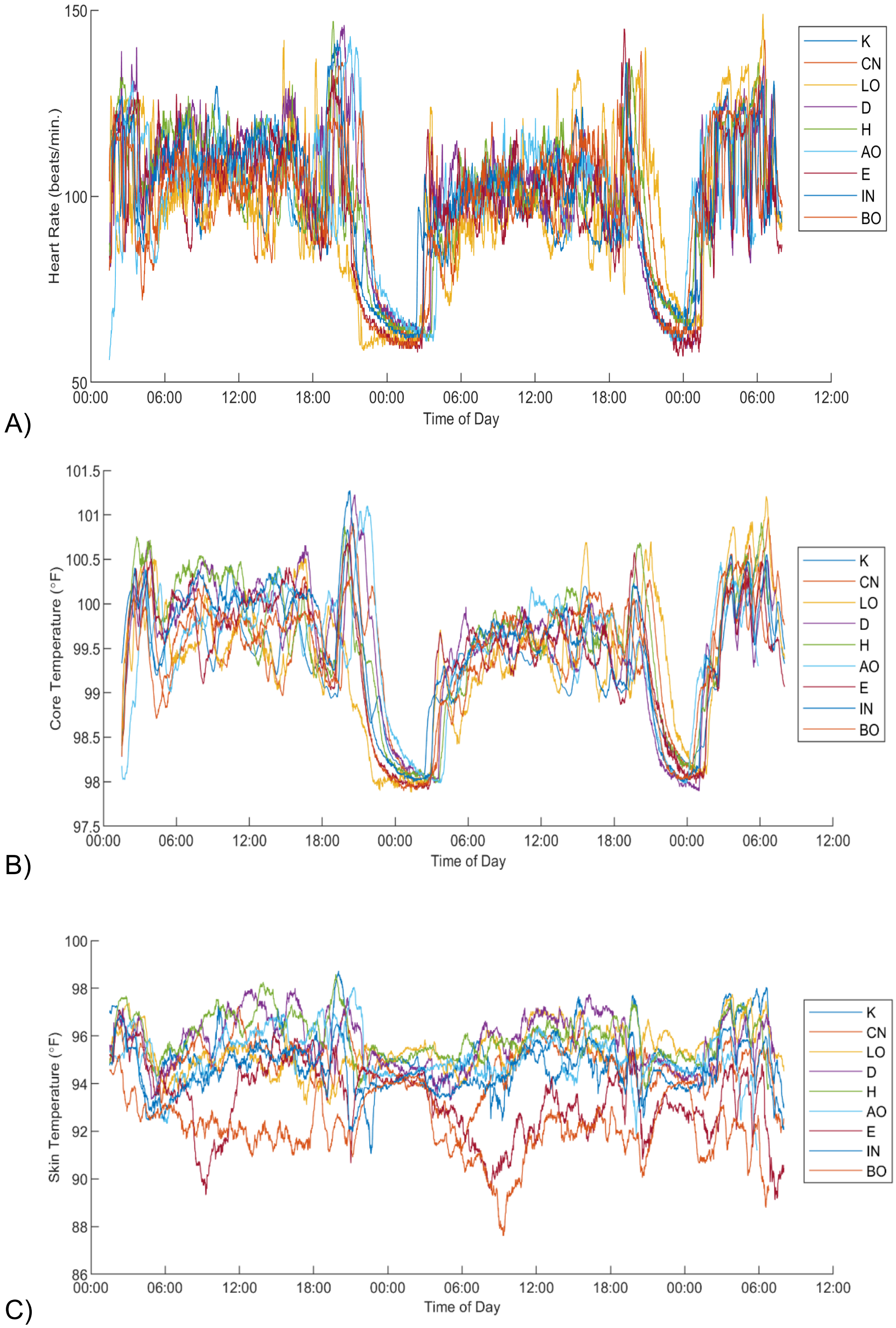


Figure 4. Mean heart rate (HR)- panel A, mean core body temperature (CT) – panel B, and mean skin temperature (ST) – panel C for all Crucibles.

Crucible Heat Illness Correlational Analysis

Table 4 lists each Crucible with the overall number EHI cases, the overall mean Page Field WBGT, overall mean ratings for “I felt hot”, “I felt dizzy”, and “I felt lightheaded” from the ESQ, and overall mean HR, ECT, ST, PSI, and aPSI.

As expected, higher overall mean WBGT correlates with the number of EHI cases, with overall mean WBGTs above 84°F relating to 10 or more heat illness cases. Similarly, the ESQ question “I felt hot” has a significant correlation to the number of casualties (r=0.81) with ratings close to 4 or above relating to incidents of 3 or more heat illnesses. While the ratings for “I felt dizzy” and “I felt lightheaded” are also significantly correlated with the number of heat illnesses, there is such a small difference in the ratings between Crucibles that these differences do not seem meaningful.

Table 4. Overall means of WBGT, ESQ Perceptions (those with significant correlations), Physiological and Heat Strain Indices by Crucible and Correlations with the number of Heat Illness Cases. Where r = Pearson’s correlation coefficient, 0 = no correlation, and 1 = fully correlated. p = statistical significance (†p<0.05; ‡p<0.06).

	Crucible Company									**Correlation**	
	K	**CN**	**LO**	**D**	**H**	**AO**	**E**	**IN**	**BO**	r	p
Heat Illness (n)	10	0	2	12	11	3	0	0	0		
WBGT (°F)	84.4	82.9	78.4	86.2	84.4	81.7	79.6	81.2	74.7	0.75	0.02†
I felt hot	3.8	2.9	2.8	4.2	4.6	4.0	2.3	3.3	1.9	0.81	0.01†
I felt dizzy	1.0	0.7	0.9	1.5	1.2	1.0	0.5	0.8	0.6	0.85	0.00†
I felt lightheaded	1.2	0.9	1.1	1.8	1.6	1.3	0.6	1.0	0.7	0.88	0.00†
Heart Rate (bpm)	97.0	98.4	96.1	100.6	100.8	98.9	97.0	99.5	96.7	0.52	0.14
Est. Core Temp. (°F)	99.4	99.5	99.4	99.5	99.6	99.5	99.4	99.5	99.4	0.41	0.28
Skin Temp. (°F)	95.1	94.8	95.4	95.8	96.0	95.1	93.3	94.6	92.1	0.66	0.05‡
PSI	2.7	2.8	2.7	3.0	3.1	2.9	2.8	3.0	2.7	0.47	0.20
aPSI	2.9	3.0	2.9	3.3	3.4	3.1	2.8	3.1	2.7	0.65	0.06‡

Surprisingly, there is no significant correlation between the number of EHI cases and either HR or CT, nor with the PSI. In fact, overall mean CTs vary little between Crucibles, while overall mean HRs only vary by at most 6 beats/min. However, ST and aPSI show correlations that are close to being significant. The aPSI uses ST to adapt the heat strain thresholds of the physiological strain index. In fact, STs can vary by as much as 6°F between Crucibles.

Heat Illness Case Analysis

Over the 9 Crucibles, there were a total of 38 reported heat illness cases that required evaluation by corpsmen. Recruits who were evacuated to the CAS were evaluated by medical professionals, and if their illness/injury was identified as an EHI or a possible EHI, they were entered into the MCRD-PI Heat Case Tracker. Prior to evacuation, corpsmen would obtain a rectal temperature (shown as Tr in Table 5). Of the 38 heat illness cases, 36 recruits consented to be in the study and 35 signed a HIPAA form. HIPS data were available for 24 of the 35 remaining individuals.

Complete physiological data, where both HR and ST were available during the period when the recruit became ill, were available in 17 of the remaining EHI cases. Most cases where the data were lost was due to the HIPS pucks stopping early (a fault that was fixed mid-way through the summer). Table 5 shows a breakdown of the 35 EHI cases evacuated from the Crucible by diagnosis.

Table 5. Rectal Temperatures (Tr), Demographics, and Risk Factors for Types of all Exertional Heat Illness Cases.

Diagnosis	N	Tr Range (ºF)	Mean Tr ± SD (ºF)	Age (yr.)	Height (in.)	Weight (lb.)	3 Mile Run (min.)	Risk Factors (No.)
Dizzy	1	97.9	97.9	22	70	155	26.4	0
Rhabdo	3	98.3 – 103.1	100.0 ± 2.8	19.7 ± 0.5	69.3 ± 2.1	138.3 ± 2.4	23.3 ± 1.9	3
Heat Fatigue	4	98.2 – 99.1	98.5 ± 0.4	20.8 ± 2.1	71.3 ± 6.3	166.3 ± 23.3	24.2 ± 1.5	4
Heat Exhaustion	21	100.6 – 104.6	102.5 ± 0.9	19.6 ± 1.6	67.6 ± 3.8	150.1 ± 23.4	24 ± 2.1	12
Heat Stroke	6	105.0 – 109.0	106.8 ± 1.3	20.4 ± 0.8	70.8 ± 1.9	183.4 ± 10	23.4 ± 2.3	4

For our EHI cases, five main symptoms or diagnoses were recorded: dizziness, rhabdomyolysis (rhabdo), heat fatigue, heat exhaustion, and heat stroke. Rhabdo can occur individually or in conjunction with heat exhaustion. In our analysis, heat exhaustion cases with rhabdo, (8 of the 21), are pooled into the heat exhaustion category. Of the reported EHI cases, 2 heat exhaustion cases and 1 heat stroke case had an EHI within 10 days prior to the Crucible. One heat exhaustion case was COVID-positive at the time of medical evaluation. One rhabdo case had been diagnosed with Strep the day prior to starting the Crucible and had a fever with a 102°F temperature. One heat exhaustion case had received their 2nd COVID vaccine the week prior.

For some cases, a final diagnosis by the medical staff was fairly subjective. The non-standard term “heat fatigue” reflects the difficulty of the diagnosis problem within EHI cases. This term was used to describe an individual who had experienced some symptoms of heat illness but did not rise to the level of a heat exhaustion. Table 6 lists the breakdown of EHI cases from the 17 individuals who had complete sets of physiological data.

Table 6. Rectal Temperatures (Tr), Demographics, and Risk Factors for Types of EHI cases.

Diagnosis	N	Tr (ºF)	Age (yr.)	Height (in.)	Weight (lb.)	3 Mile Run (min.)	Risk Factors (No.)
Dizzy	1	97.9	22	70	155	26.42	0
Rhabdo	3	98.3, 98.6,103.2	19.7 ± 0.5	69.3 ± 2.1	138.3 ± 2.4	23.3 ± 1.9	3
Heat Fatigue	2	99.1, 98.4	19, 21	69, 77	160, 170	21.6, 25.2	1
Heat Exhaustion	9	102.8 ± 0.9‡	19.3 ± 1.3	67.6 ± 3.8	153.6 ± 24.6	23.7 ± 1.8	7
Heat Stroke	2	105.8, 107.8	20.5 ± 0.9	70.3 ± 1.8	186.3 ± 9.2	24.3 ± 1.8	3

†Rectal temperature not recorded in the field. ‡Mean ± Standard Deviation

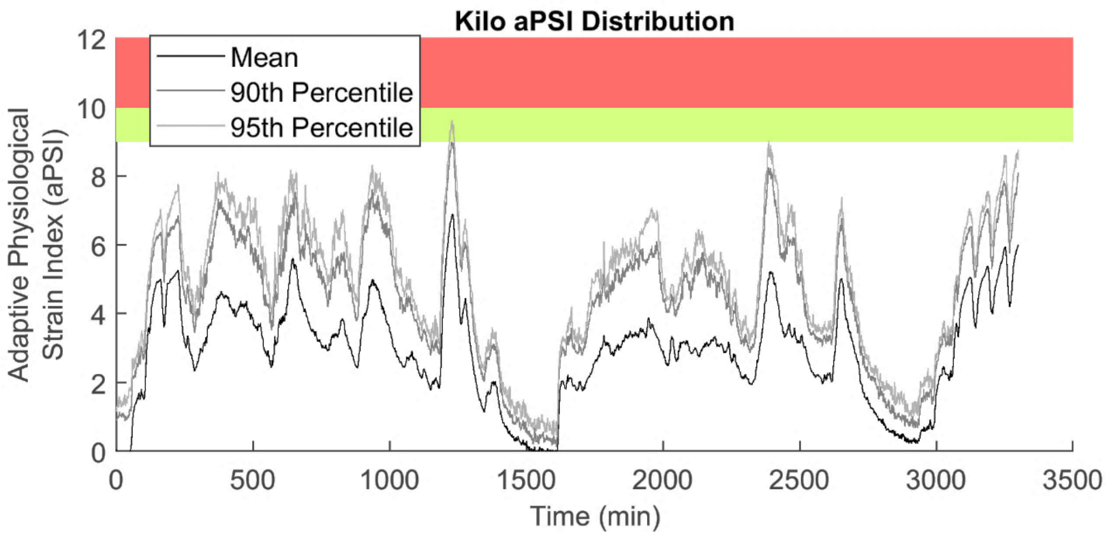
For our classification purposes, we broke the diagnoses down into cases where Tr was greater than 102.1°F, which included all the exertional heat strokes, exertional heat exhaustions, one heat fatigue and one rhabdo case. For this analysis, heat fatigue and rhabdo cases with Trs below 102.1°F were not considered to be heat illness cases that should be alerted. If an EHI case received a yellow or red flag from the HIPS device, where ECT, PSI and aPSI were above 102.1 °F, 8, or 8.5 respectively, they were considered accurately identified or a true positive. Table 7 shows the confusion matrix for ECT, PSI, and aPSI for the 17 EHI cases with real time data.

Table 7. Confusion matrix for EHI cases compared to heat strain indices. Where TP=True Positive, FN=False Negative, FP=False Positive, TN=True Negative

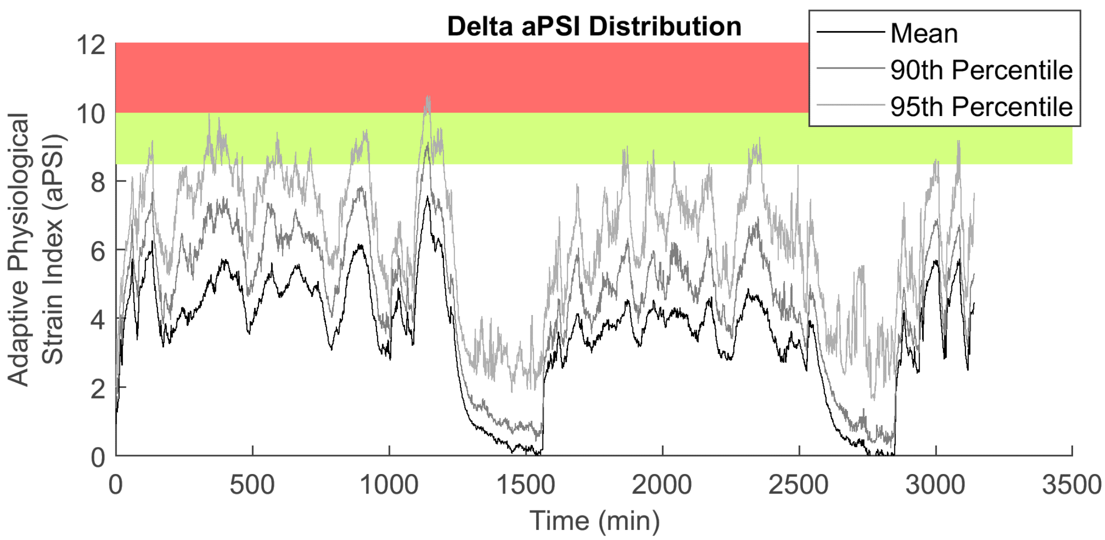
	ECT (Thresh: 102.1 °F)		PSI (Thresh: 8)		aPSI (Thresh: 8.5)	
	Classified EHI	Classified Non EHI	Classified EHI	Classified Non EHI	Classified EHI	Classified Non EHI
Observed EHI Cases (n=12)	5 (TP)	7 (FN)	7 (TP)	5 (FN)	12 (TP)	0 (TN)
Observed Non EHI Cases (n=5)	0 (FP)	5 (TN)	0 (FP)	5 (TN)	2 (FP)	3 (TN)

The overall accuracy of the three heat strain indices was 59%, 71%, and 88% for ECT, PSI and aPSI respectively. The correlation of each heat strain index with Tr taken by a corpsman before evacuation was 0.46, 0.40, 0.65* for ECT, PSI, and aPSI, where the aPSI correlation was significant ($p<0.01$).

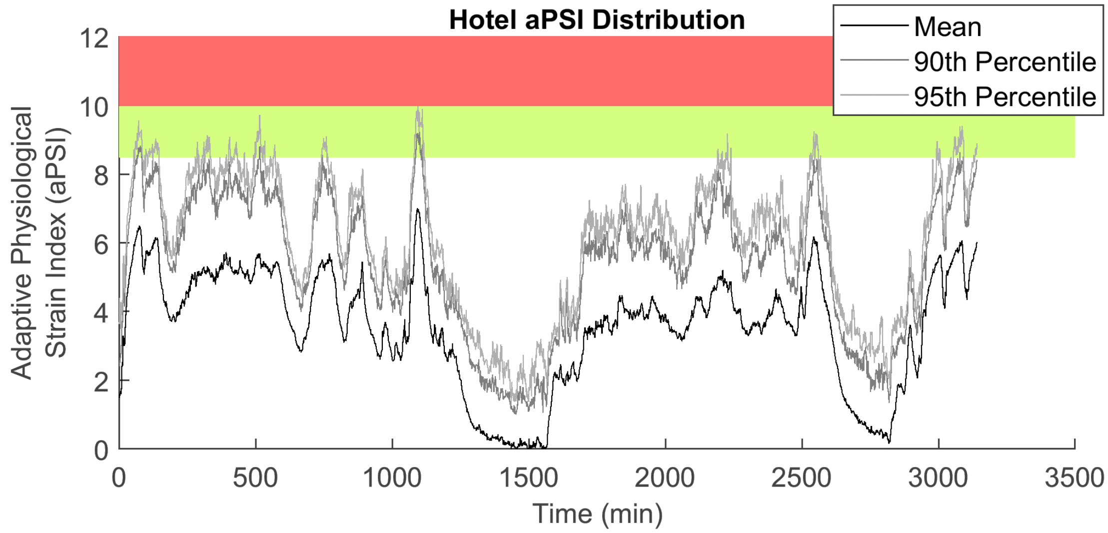
Figure 5 shows the aPSI distributions for the three hottest Crucibles (Training Companies Kilo, Delta, and Hotel) showing the mean, 90th and 95th percentiles. With a yellow alert ("take a look") set at 8.5, the number of alerts is at most 15% from Hotel company during the day 1 evening foot march (Figure 5 panel C around min. 1200).



A)



B)



C)

Figure 5. Adaptive Physiological Strain Index distribution for Companies Kilo (A), Delta (B), and Hotel (C), showing the mean, 90th and 95th percentiles. Yellow and red bands represent the yellow and red alert at 8.5 and 10 aPSI respectively.

LESSONS LEARNED

As the data collection progressed throughout the 9 Crucibles, there were various lessons learned from company leadership, DIs, and the research team. After the first Crucible with Kilo company, it was found that during some of the events involving low crawls and obstacle courses, many devices were popping off the chest strap. As a solution, electrical tape was used to secure the device to the chest strap by wrapping the tape around both the chest strap and device.

In addition, during the first few Crucibles, it was discovered that there was a firmware bug on the devices that caused the devices to turn off prematurely. This limited the data collection for those Crucibles but would not have been discovered so easily had there not been so many HIPS on recruits at once. The bug was fixed and implemented between the 3rd and 4th Crucibles.

From visits to Page Field during each Crucible, DIs were reporting very high ECT values seen on the phones for specific recruits who were not engaging in any rigorous activities that would result in higher ECTs. There were multiple possible reasons for this error depending on the recruit, which were either the strap had fallen to their waist without the recruit realizing or the device/strap being worn incorrectly. Once the device location or wear was fixed, the ECT value would be corrected and normalized. This supports the idea of creating an adjustment to the chest strap that brings another strap over the shoulder(s) to help keep the device in the correct location. Some initial ideas can be seen in Appendix D.

Additionally, because of the rigorous training that the recruits were enduring, the HIPS devices and straps were also enduring those same environments, causing additional failures. For example, if there was rain during the Crucible, this could cause dirt to turn to mud and when recruits participated in low crawling events, the device could become covered in mud, especially the skin temperature sensor, impeding the device's ability to collect accurate skin temperature measurements. This required extra cleaning of both the devices and chest straps.

DISCUSSION

In the present study, we sought to evaluate the feasibility, accuracy, and user acceptability of a real-time PSM system designed to evaluate EHI risk. We tested the overarching hypothesis that EHI risk could be assessed using real-time measures of heart rate and skin temperature. These real-time measures were used to calculate estimates of core body temperature, the Physiological Strain Index (PSI - a combination of HR and CT), and the adaptive Physiological Strain Index (aPSI – a combination of HR, CT, and ST). We demonstrated that the number of EHI cases evacuated and medically assessed was highly correlated with the average WBGT ($P<0.02$). Additionally, the subjective rating of "I felt hot" from the ESQ was both significantly and meaningfully correlated to the number of EHI cases.

While the dynamic nature of physiological strain during the Crucible was clearly shown by the real-time parameters of HR and ECT, they were not correlated with the number of EHI cases. When we examined the efficacy of ECT and PSI in providing alerts of possible EHI cases we found that they were 59% and 71% accurate respectively. More troublingly, ECT and PSI had very high false negative rates, missing 58% and 42% of the EHI cases respectively. This inability to predict an EHI case is mirrored in the findings of Hunt and colleagues who found a "disassociation" between CT and individuals experiencing EHI symptoms.[19]

However, even though ST showed less of a pattern of physiological strain across the Crucibles, it did show a correlational trend with the number of EHI cases ($p=0.051$). Similarly, when ST is added into the PSI using the aPSI equations, this too showed a correlational trend ($p=0.060$) with the EHI cases. Skin temperature has been a significant predictor of thermal comfort, stemming from the original work of Gagge et al through to many modern machine learning approaches.[15,28] Thus, correlation of both the thermal sensation question "I felt hot" and correlation trend with ST would be expected.

With the added ST, the aPSI shows an 88% accuracy in identifying the EHI cases from non-EHI cases. Upon closer examination, the aPSI performs even better on the most critical metric, identifying 100% of EHI cases with zero false negatives. During the foot marches on the hottest Crucibles, the false positive rate for an aPSI alert is at most 15%. The aPSI was developed as a means to automatically adjust the PSI's output to account for different CT tolerances given different levels of clothing encapsulation. It was based on the idea that as the difference between ST and CT decreases, a greater cardiac output is necessary and thus the individual is experiencing greater physiological strain.[32] Recent studies have shown that a reduction in the ST to CT difference is strongly associated with a reduction in level of aerobic performance in the heat.[7,8,33] These results suggest that the ST to CT gradient is also useful in identifying EHI risk.

This appears to correspond with the work of Pandolf and Goldman[29] who suggest the ST to CT gradient could be used as a means to predict time to fatigue.

Our use case has two main differences. First, CT is estimated using the ECTemp algorithm, and second, the ST is a single point on the chest (rather than a mean ST value taken from multiple sites across the body surface). Nevertheless, the CT estimate and chest ST appear to have enough information to accurately identify medically diagnosed EHI cases. In addition, while ECT and CT alone are not predictors of EHI cases, case severity appears to be correlated with the rectal temperature taken at the time of collapse. The adaptive PSI shows a significant moderate (0.65) correlation to these rectal temperatures.

The aPSI appears to be a good indicator of EHI risk. EHI cases are accurately identified and the aPSI score correlates with rectal temperature taken at the time of collapse. These findings appear to stand out against the recent work of Davey and colleagues who conclude that both PSI and aPSI do not reliably identify individuals at risk of reaching a thermal tolerance limit.[10] This discrepancy is likely due to definitions. Davey et al suggest a thermal tolerance limit (TTL) can be set by Hyperthermia Induced Fatigue (HIF) or an EHI. Their paper focuses on several laboratory studies, where volunteers withdraw because of HIF versus experiencing an EHI. Relying on HIF alone can be problematic especially in laboratory settings. Sawka has demonstrated that CT limits for volunteers experiencing HIF in the field can be at least 1ºC hotter than volunteers experiencing HIF in the lab.[27] Our work here differs in that it examines TTL's derived from medically diagnosed EHI cases of Marine recruits participating in field training.

LIMITATIONS

The results from this study are obtained from one location that has a hot-wet climate for Marines dressed in combat uniforms with long sleeves and long pants. The clothing appears to provide a more insulated ST with less effect from the environment.[3] With other clothing configurations, such as shorts and t-shirt, the chest ST may be more susceptible to environmental conditions, limiting the efficacy of aPSI as an EHI risk indicator. Additionally, the utility and efficacy of aPSI has not been assessed in hot and dry climates.

During this study, the HIPS had several technical limitations that reduced its overall performance. Early in the summer, the HIPS firmware issue resulted in a loss of approximately 50% of the data by the end of the 3 days of use. Alerts for the system were based upon ECTemp which has a poor ability to predict EHI. Additionally, because the system did not have error-checking to flag aberrant HR's, all erroneous HR values would often be input into the ECTemp algorithm, resulting in very high ECT's and false positive alerts.

CONCLUSIONS

Evidence from this study suggests that the combination of estimated core temperature, heart rate, and chest skin temperature using the adaptive physiological strain index can accurately predict exertional heat illness, thus suggesting that the aPSI shows potential as an accurate index of EHI risk.

Even though the HIPS had some technical difficulties and at times, would show some very high estimated core temperatures, company leadership and drill instructors found utility in the system. The display of team and company recruits on the phone app provided situational awareness to both check hot individuals and manage training tempo.

Applying lessons learned for the hardware, HR filtering, and adding the aPSI algorithm for heat illness situational awareness, the HIPS system should result in a major advance in the current options for physiological monitoring devices. Currently, leadership, trainers and medical personnel are relying on visible warnings and risk mitigation methods to help prevent heat injuries in training. By utilizing a PSM that can identify EHI risk prior to occurrence, can reduce the incidence of illnesses, the number of resources required and time away from training. Knowing the physiological status of each individual as they progress through rigorous training is a tool leadership can use to take action and prevent heat injuries from occurring.

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APPENDIX A – DEMONGRPHIC, MILITARY HISTORY, AND PREVIOUS HEAT ILLNESS QUESTIONNAIRE

1. How old are you? _________

2. What is your gender? ○ Male ○ Female

3. What group or groups best describe your racial or ethnic heritage?
   - ○ Asian
   - ○ Black (African American)
   - ○ White (Caucasian)
   - ○ Hispanic or Latino
   - ○ Native American
   - ○ Other (please describe):_____________

4. Where were you born? ____________

5. What state do you consider home? _________

6. What is your height? ______

7. What is your weight? ________________

8. What is your most recent, 3 mile run time? _____________

9. What is your MOS? _____________

10. Which unit are you assigned to? _____________

11a. How long have you been stationed at this base? Years ______, Months______

b. Where were you stationed or where did you live before coming to this base? (City, State)

____

12. How long have you been on active duty? Years ______, Months______

13. Have you experienced a previous heat illness? ○ YES or ○ NO

IF YES:

14. How many heat illness episodes have you experienced? ___________

15. Roughly, when was your last episode? ___________

16. With what type of heat illness have you been diagnosed (Check all that apply)?

- ○ Heat Stroke
- ○ Heat Exhaustion
- ○ Heat Injury
- ○ Rhabdomyolysis
- ○ Syncope or fainting
- ○ Other (please describe):_____________

17. Have you ever been treated in the Emergency Department/Clinic/Aid Station for a heat illness? ○YES or ○NO

18. Have you ever been admitted to the hospital overnight for a heat illness? ○ YES or ○ NO

19. Please describe what happened: (Continue on the back of the survey if you need more space).

APPENDIX B – EXERTIONAL HEAT ILLNESS – RISK FACTORS QUESTIONNAIRE

We are asking you the following questions to help us understand how these factors may play into any heat related illness.

1. How many hours of sleep did you receive last night? _________

2. When was your last meal? Date: _________ Time: _________

3. Please list what you ate:

4. How big a meal was this compared to your normal meals?

- ○ Much smaller than normal
- ○ Smaller than normal
- ○ NORMAL size
- ○ Larger than normal
- ○ Much larger than normal

5. Are you taking any of the following workout/dietary supplements? (Check all that apply)

- ☐ None
- ☐ Pre-workout
- ☐ Creatine
- ☐ Protein Powder
- ☐ Vitamins
- ☐ Others: ____________

6. How much water have you consumed in the last 12 hours? ________ (Qts.)(1 canteen = 1 qt)

7. Are you currently taking any medications (prescription or over the counter)? ○ YES or ○ NO

If YES please list the medications you are taking:

8. Are you currently feeling unwell or “under the weather”? (Check all that apply)

- ☐ No, Feeling Good
- ☐ Cough
- ☐ Nasal Congestion
- ☐ Fever
- ☐ Headache
- ☐ Nausea
- ☐ Other: ________________

9. Have you had an illness or seen a physician in the last 60 days? ○ YES or ○ NO

If YES please list what you had and the date:

10. Have you had any recent immunizations in the last 30 days? ○ YES or ○ NO

If YES please list the immunizations you had and the dates:

APPENDIX C – ENVIRONMENTAL SYMPTOMS QUESTIONNAIRE

Please circle the number you feel most applies to how you felt for <u>all questions</u> between 2 – 15

During the Crucible I felt / I was …		**does not apply at all**						**fully applies**
1.	I felt lightheaded	0	1	2	3	4	5	6
2.	I had a headache	0	1	2	3	4	5	6
3.	I felt dizzy	0	1	2	3	4	5	6
4.	I felt thirsty	0	1	2	3	4	5	6
5.	I felt weak	0	1	2	3	4	5	6
6.	I felt grumpy	0	1	2	3	4	5	6
7.	It was hard to breathe	0	1	2	3	4	5	6
8.	I performed at my best	0	1	2	3	4	5	6
9.	I had a muscle cramp	0	1	2	3	4	5	6
10.	I felt tired	0	1	2	3	4	5	6
11.	I felt sick to my stomach (nauseous)	0	1	2	3	4	5	6
12.	I felt hot	0	1	2	3	4	5	6
13.	I had trouble concentrating	0	1	2	3	4	5	6
14.	I had ‘goose bumps’ or chills	0	1	2	3	4	5	6

APPENDIX D – CHEST STRAP MODIFICATIONS