U.S. Army Research Institute of Environmental Medicine

Natick, Massachusetts

TECHNICAL REPORT NO. T22-03
DATE October 2021

REQUIREMENTS FOR HEAT STRAIN DETECTION DEVICE FOR USE AT THE MARINE RECRUIT DEPOT SAN DIEGO

Approved for Public Release; Distribution is Unlimited

United States Army
Medical Research & Development Command

DISCLAIMER

USARIEM TECHNICAL REPORT T22-03

REQUIREMENTS FOR HEAT STRAIN DETECTION DEVICE FOR USE AT THE MARINE RECRUIT DEPOT SAN DIEGO

William J. Tharion[1]
Melissa K. Mahoney[2]
Reed W. Hoyt[1]

[1]Biophysics and Biomedical Modeling Division, USARIEM
[2]Marine Corps Recruit Depot San Diego

October 2021

U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	10-26-2021
2. REPORT TYPE	Technical Report
3. DATES COVERED *(From - To)*	October 2020 - October 2021
4. TITLE AND SUBTITLE	Requirements for Heat Strain Detection Device for Use at the Marine Recruit Depot San Diego
5a. CONTRACT NUMBER	
5b. GRANT NUMBER	
5c. PROGRAM ELEMENT NUMBER	
5d. PROJECT NUMBER	
5e. TASK NUMBER	
5f. WORK UNIT NUMBER	H
6. AUTHOR(S)	William J. Tharion, Melissa K. Mahoney, and Reed W. Hoyt
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	Biophysics and Biomedical Modeling Division U.S. Army Research Institute of Environmental Medicine Building 42 - 10 General Greene Ave Natick, MA 01760
8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	U.S. Army Medical Research and Development Command, Fort Detrick, MD 21702
10. SPONSOR/MONITOR'S ACRONYM(S)	
11. SPONSOR/MONITOR'S REPORT NUMBER(S)	T22-03
12. DISTRIBUTION/AVAILABILITY STATEMENT	Approved for public release; distribution unlimited
13. SUPPLEMENTARY NOTES	

14. ABSTRACT

The objective of this research was to obtain product characteristics of a Heat Strain Detection Device (HDDD) for USMC training. Thirty Marines (28 men, 2 women) who serve as Drill Instructors and other training professionals at the Marine Corps Recruit Depot, Data were collected through the use of focus groups. An arm band system was significantly ($p < 0.001$) preferred by 73.3% of participants compared to 16.7% who preferred a chest strap system. There was a significant difference ($p < 0.001$) in the length of time participants thought they could wear each system (chest strap: 91.2 ± 89.8 min arm band: 875.0 ± 891.8 min. Watches or wrist-worn systems were the preferred form factor as 56.7% of participants mentioned this type of system. The ideal system would be a wrist-worn system but an acceptable system would be an arm band system similar to the ARMOR by Evalan BV system paired with a long range radio to transmit information off the recruit to a Drill Instructor. Estimated core temperature and a red/yellow/green risk color code would be the information needed to make a decision on a recruit's health status.

15. SUBJECT TERMS

PSM, Physiological Monitoring, Heat Strain, Marine Recruits, Drill Instructors, System Attributes, Requirements, Heat Injury, Training

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	Unclassified	35	William J. Tharion
					19b. TELEPHONE NUMBER *(Include area code)* 508-206-2400

Reset

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The authors would like to thank the Marines who participated in this study for their time, effort, and willingness to share their valuable thoughts and opinions. We specifically want to thank Maj Aemee Parrott and the rest of the leadership on the ground at the Marine Corps Recruit Depot, San Diego, for their assistance coordinating the study and their and enabling data collection under challenging COVID-19 restrictions and precautions. We appreciated the assistance provided by Tara Boettcher and Nancy DeLosa from the Massachusetts Institute of Technology – Lincoln Laboratory (MIT LL) in preparing the Buddy Display systems and providing logistical assistance. Finally, the support of Brian McGuire and the United States Marine Corps Training and Education Command (TECOM) is appreciated.

EXECUTIVE SUMMARY

Introduction: Physiological status monitoring (PSM) systems are being designed to enhance mission management and reduce the risk of heat illness or heat injury in military personnel. United States Marine Corps (USMC) leadership recognizes that heat illnesses/heat injuries are a significant issue for Marines in training. They also recognize that use of PSM systems capable of monitoring heat strain may help address this issue. However, specific system requirements and attributes have yet to be clearly defined. The present research was conducted to address this gap using a "demand pull" strategy where the functional characteristics of the proposed heat strain detection device (HSDD) are defined based on USMC subject matter expert's demands rather than on researcher or company-generated ideas. The objective of this research was to obtain product characteristics of a HSDD for USMC training that will be 1) acceptable to Marines, 2) easy to use, 3) affordable, 4) available in the near future, and 5) scalable for use by hundreds of Marines training in the same location. The results of this research should help developers and acquisition professionals develop and acquire HSDDs that meet USMC training needs.

Methods: Thirty Marines (28 men, 2 women) who serve as Drill Instructors and other training professionals at the Marine Corps Recruit Depot, San Diego (MCRD, San Diego)(San Diego, CA), participated in this study. Data were collected through the use of focus groups, enabling the moderator to delve into responses to general questions with specific follow-up questions.

Each test participant was provided a Polar OH-1 arm band system, a Polar H-10 chest strap system (Polar Electro Inc., Bethpage, NY, USA), and a Jelly phone (Unihertz, Shanghai, China) equipped with the "Heat Strain Index" application (app) developed by USARIEM and the Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) (Lexington, MA). Test participants were asked to familiarize themselves with these devices and how the Polar arm band (OH-1) or chest strap (H-10) systems transmit data to the Jelly Phone where personal heat strain information is displayed.

Test participants were also shown the ARMOR arm band system by Evalan BV (https://evalan.com/en/armor-heat-stress/) (Amsterdam, Netherlands), the Open Body Area Network (OBAN)/Heat Injury Prevention System (HIPS) by ODIC Inc. (Littleton, MA), and display concepts developed by MIT LL.

Results: The arm band system was significantly (p < 0.001) preferred by 73.3% of participants compared to 16.7% who preferred a chest strap system. There

was a significant difference ($p < 0.001$) in the length of time participants thought they could wear each system (chest strap: 91.2 ± 89.8 min (mean ± SD) vs. arm band: 875.0 ± 891.8 min (i.e., 14 hr: 31 min ± 14 hr: 52 min)). For the chest strap, only 10.0% of participants said they could wear the system for more than just a workout of two hours or less, compared to 83.3% of participants who said they could wear an arm band system for six hours or longer. When participants were asked how long recruits would need to wear a system, 46.7% of participants said recruits would need to wear a PSM system for 72 continuous hours or longer to account for monitoring during the "Crucible" exercise.

Watches or wrist-worn systems were the preferred form factor as 56.7% of participants mentioned this type of system even when informed of the accuracy and transmission issues associated with wrist-worn systems. No other system was preferred over an arm band system besides a wrist-worn system. When participants were asked how data should be displayed, 90.0% of participants wanted the data transmitted to a tablet or phone that the instructors would carry. A body worn Buddy Display where physiological data is simply displayed on a phone or some other wearable display attached to the outside of a uniform, was not desired. All participants wanted to see estimated core temperature and all but one mentioned they wanted to see the green-yellow-red color coded status indicator. Only 33.3% wanted to use the 0 to10 heat strain index (HSI), which reflects combined work strain and heat strain, to make decisions related to a Marine's thermal strain status.

Maintaining accountability, i.e., keeping track of the HSDD systems, was the most frequently stated concern with 96.7% of participants mentioning this issue. Participants were asked if a HSDD that was developed and acquired and met the required specifications would it help in preventing heat injuries; 90.0% of participants believed it would. When asked if they would they would use such a system, 93.3% said they would use it. When asked if they thought using a HSDD would improve the early detection of possible heat injuries and other health problems, 96.7% of participants believed it would improve medical monitoring over current practices.

Conclusions: A HSDD would be used by Drill Instructors if the system was designed to meet their requirements. The ideal system would be a wrist-worn system that transmits estimated core temperature and a color code to a tablet held by a Drill Instructor. An acceptable system would be an arm band system similar to the ARMOR by Evalan BV system paired with a long range radio to transmit information off the recruit to a Drill Instructor perhaps up to a thousand meters away. Estimated core temperature and a red/yellow/green risk color code would be the information needed to make a decision on a recruit's health status.

INTRODUCTION

Past research has shown that excessive heat strain can be a significant threat to Marine health and combat performance. For example, in a study of Marines on patrol in Iraq, it was shown that at the end of a two hour foot patrol they experienced significant thermal-work strain (4). Core body and skin temperatures indicated at least a 50% risk of succumbing to heat exhaustion. While most Marine training in the continental U.S. experiences lower environmental temperatures than those described in the 2008 field study in Iraq where environmental temperatures ranged from 39.0º C to 47º C (4), thermal strain and associated heat illnesses/heat injuries are still a significant problem in Marine training environments (16, 17). Furthermore, individual physiological responses to training in the heat are known to vary significantly. In Weapons of Mass Destruction – Civil Support Team (WMD-CST) personnel completing a chemical, biological, radiological, and/or nuclear (CBRN) self-paced approach march, these Soldiers had vastly different levels of heat strain by the end of the 40 to 50 min march (29). While some WMD-CST members were at risk for heat exhaustion by the end of the march, others were not. These data illustrated the wide range of individual responses and highlighted the need for better medical and training situational awareness of personnel during WMD-CST training. The same is true with Marine training. Physiological status monitoring (PSM) systems can provide that awareness. Awareness and subsequent early intervention to prevent heat illness/heat injury can minimize disruption to training and reduce or eliminate negative health effects.

Safe training in hot weather conditions usually involves following standard operating procedures such as adhering to military work-rest cycles (11). This approach usually limits training to levels that are safe for the majority of individuals, resulting in most individuals not being harmed during hot weather training. The drawback of this approach is that training may be far less intense and may not meet the intensity of physical exertion of what may be required during actual combat situations. In addition, individual recruits who are at elevated risk due to factors other than local meteorological conditions (e.g., not heat acclimated, less fit, carrying a heavier load than average, etc.) may still experience a heat illness/heat injury event because they are outside the normative bounds of the guidelines. The use of a heat strain detection device (HSDD) should improve situational awareness for all Marines undergoing training by notifying appropriate personnel in real time of a particular Marine's level of heat strain in response to training. This in turn should improve both training effectiveness and reduce the risk of heat illness or heat injury. Furthermore, use of the HSDD in both training and during missions should improve operational readiness by increasing the capability of small units to successfully perform their missions (10, 26).

The United States Marine Corps Training and Education Command (USMC TECOM) broadly recognizes that wearable PSM systems have the potential to provide health state information that could be used to improve safety and enhance training effectiveness. They are actively exploring the pros and cons of different PSM solutions. For example, should a solution be immediately available and at what cost? An immediate solution might necessitate being limited to commercial systems that could be less than ideal. Alternatively, if time and funds are available perhaps a solution that is tailored to the Marine training community needs could be developed. Regardless, the first step is to thoroughly understand the requirements of the Marine training community and how a HSDD can be integrated into training routines.

The United States Army Research Institute of Environmental Medicine (USARIEM) has experience developing and using a variety of PSM systems to include the Equivital™ (Equivital™ (Cambridge, UK) Black Ghost system (26), the Open Body Area Network (OBAN) PSM system developed by MIT LL (Lexington, MA) and Odic, Inc., (Devens, MA) (25), and the use of a USARIEM and MIT LL developed body-worn Buddy Display system (29) that was developed for WMD-CSTs but never adopted. The Equivital™ Black Ghost solution currently being used by WMD-CSTs requires a long-range radio solution and can be quite hard to maintain, especially the communications part of the system (i.e., radio and/or WiFi network) (26). Scalability constraint, e.g., cost and system complexity, are also issues. Typically, the WMD-CSTs are monitoring less than ten individuals at any one time. However, the adaptation of a Buddy Display system, where physiological data is simply displayed on a phone or some other wearable display attached to the outside of a uniform, may be a less complex, easier-to-implement solution that meets the needs of Marines in training. Regardless, a general set of requirements/system attributes to ensure the development and/or acquisition of a suitable and effective system for use by Marines in training is needed. While there are advantages to both a “technology push” and a “demand pull” approach to developing a desired product, this study’s effort used a “demand pull” strategy. Knowing the specific preferred attributes of a product being developed in response to a general need is a crucial element of the effort to direct the technology toward an end-state adoption (6).

The USMC TECOM recognizes that the occurrence of heat illness/heat injury casualties in training reduce training effectiveness and may result in adverse heat-related health effects that can have a sustained negative impact on the individual Marine’s career. The TECOM Commander, MG William Mullen is committed to sustaining combat readiness training but eliminating heat illnesses/heat injuries during training. Among strategies to meet this goal is to mitigate heat illness/heat injury by using a HSDD that provides an early warning of physiological heat strain of the individual. In 2018, the heat illness reporting incident rate within the USMC was

3.79 cases per 1000 person-years, and the rate of heat stroke was 0.91 per 1000 person-years. The problem of heat injuries/heat illnesses within the USMC, both in overall rate and heat stroke rate, exceed all other branches of active component service. For comparison, in the same time period, the Army had 3.67 overall cases and 0.75 heat stroke cases, the Navy at 0.48 overall cases and 0.10 heat stroke cases, and the Air Force at 0.71 overall cases and 0.08 heat stroke cases (16, 17). These annual rates have increased since 2014 illustrating that this is a growing problem for the armed services.

Specifically, with respect to training that takes place in Southern California, recruits train at the Marine Corps Recruit Depot, San Diego, and at the Marine Corps Base Camp Pendleton, California heat strain is a real concern. There were 432 heat injuries between 2013 and 2017 at Camp Pendleton (ranked 7th) representing 4.1% of all heat illnesses/heat injuries that occurred across military training facilities during that time period. Fort Benning, GA was the top ranked location with 12.7% of all heat illnesses/heat injuries reported (16, 17). This data and the commitment of USMC TECOM leadership to address the problem was the reason for this study. It is known that for PSM systems to be effective, they must produce accurate data and also be acceptable to wear and use (26). This study is the first step in that process.

The objective of this research was to obtain product characteristics of a HSDD for USMC training that will be 1) acceptable to Marines, 2) easy to use, 3) affordable, 4) available in the near future, and 5) scalable for use by hundreds of Marines that may be training in the same location. The results of this research should help developers and acquisition professionals develop and acquire HSDDs that meet USMC training needs.

METHODS

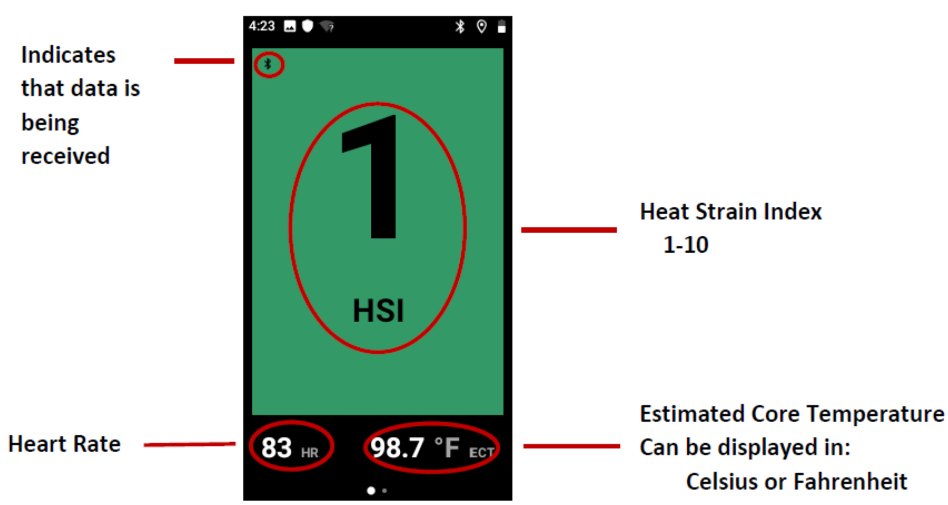
The study began by familiarizing the test volunteers with the Buddy Display product developed by USARIEM and MIT LL. The Buddy Display consists of a heart rate sensor system (i.e., a Polar chest strap (H-10) or arm-band (OH-1) based heart rate sensor) that connects wirelessly via Bluetooth Low Energy to an Android phone running an App that estimates core body temperature (3) (Figure 1) and displays the individual Marine’s level of heat strain (Figure 2) After participants were familiarized with the Buddy Display system, a focus group was conducted to elicit specific product characteristics that Marines would require to ensure that a HSDD for them would be acceptable and effective.

Figure 1. Prototype Buddy Display Physiological Status Monitoring (PSM) system.

OR

AND

Figure 2. Buddy Display Physiological Status Monitoring (PSM) Graphical User Interface (GUI).



TEST VOLUNTEERS

The test volunteer group consisted of 30 active duty Marines (28 men and 2 women), each of whom had at least two years of experience training Marine recruits. Test volunteers were recruited from a pool of potential study volunteers briefed at the Marine Corps Recruit Depot, San Diego (San Diego, CA). There were no age, race, ethnicity, gender, or rank (e.g. officer/enlisted) limitations. The study was approved by the U.S. Army Medical Research and Development Command (Ft. Detrick) and U.S. Marine Corps (Quantico, VA) Institutional Review Boards (IRBs). Volunteers were briefed on the procedures, and provided their verbal informed consent prior to any data collection. The only demographic information obtained from each volunteer was "What is your job title?" and "How many years have you been a Marine?" The test volunteer group consisted of 19 Drill Instructors, 3 Chief Drill Instructors, 2 Series Commanders who are primarily charged with supervision and safety during recruit training, and 6 Marines serving in other various training supervisory positions. All those in supervisory roles had previous experience as Drill Instructors. These Marines averaged 8.0 ± 2.4 years of Marine experience. All data were collected at the Marine Corps Recruit Depot San Diego.

TEST PROCEDURE

Physiological Status Monitoring (PSM) Familiarization

Participants were provided with an example PSM system solution, composed of commercial off-the-shelf (COTS) items and a custom App. The intent was to familiarize the test participants with one potential approach to meeting the USMC need for a heat strain monitoring system. It was emphasized to participants that the PSM system provided, or the other PSM systems demonstrated, were only a starting point for a discussion on what the necessary requirements are for a HSDD to meet Marine needs. Participants were instructed not to be constrained by the technologies they used or viewed.

Participants were provided a Buddy Display system which was comprised of the Polar OH-1 (Polar Electro Inc., Bethpage, NY, USA) arm band heart rate monitor, or a Polar H-10 chest belt heart rate monitor and a small Jelly Phone (Unihertz, Shanghai, China) (Figure 1). The Polar OH-1 Optical Heart Rate Sensor, which is typically worn on the upper arm, consists of a sensor (5 g) (~30 mm in diameter x 9.5 mm height) that mounts in a clip (3.5 g) that attaches the sensor to the arm band (12 g); Polar H-10 systems consists of a chest strap (~39 g) and a snap-on electronics module (21 g;

34 mm x 65 mm x 10 mm); and the Jelly Phone (~60 g with battery) was 92 mm x 43 mm x 13 mm. The OH-1 and H-10 systems have been shown to produce reliable and valid data (7, 12, 13, 20). The Jelly phone had an App comprised of the USARIEM-developed estimated core temperature algorithm (3) and the physiological strain index algorithm (18) which has been re-labeled the Heat Strain Index (HSI) (29).

Participants were asked to wear each of the heart rate monitoring systems for at least two hours to become familiar with its function and what it feels like to wear the system for an extended period of time. In addition, participants were shown the ARMOR system by Evalan BV (https://evalan.com/en/armor-heat-stress/) (Amsterdam, Netherlands), the Open Body Area Network (OBAN)/Heat Injury Prevention System (HIPS) by ODIC Inc. (Littleton, MA), and some display concepts developed by MIT LL.

Focus Groups

The attributes of the envisioned HSDD were obtained from focus group responses. Focus group questions focused on what information provided by the current Buddy Display system needed to be retained, improved, or eliminated. Participants were also asked if they would feel the HSDD provided useful information, assuming it was developed with their recommended attributes, and would it allow them to make timely heat-strain related decisions regarding the individual Marines they are overseeing. The first level questions asked were broad in nature and then more detailed questions were asked depending on the nature of the answers to the broad questions.

Focus group sessions were led by a moderator with 4 to 6 Marine Drill Instructors as participants. Size of the focus groups were consistent with standard practice (9). Focus groups were video-taped to ensure no information was lost and to capture the tone and context of any agreements or disagreements between or among test participants. The moderator had no financial or professional stake in the evaluation outcome. Since COVID-19 conditions existed, social distancing procedures were used. The moderator followed the guidelines recommended by Aaker and Day (1) such as not using jargon, making sure all test participants contributed their ideas and/or experiences, not allowing any one participant to dominate, and validating each idea as important. Topics proceeded from general to more specific as recommended by McQuarrie and McIntyre (15).

STATISTICAL ANALYSIS

Frequency of responses were tabulated and presented as percent responding. For many questions, participants gave multiple responses. Therefore, in the tables in this report the percent totals represent percent of participants that gave that response. As such, a column total could equal more that 100%. Comparisons of frequencies were done using cross tabulations. Continuous variables were summarized using means and standard deviations. Differences in means were assessed using *t* tests. Level of significance was set at $p \leq 0.05$. Statistical analyses were conducted using SPSS® (SPSS® Version 24, IBM®; Armonk, NY).

RESULTS

CHEST STRAP VS. ARM BAND SYSTEM

Participants were asked if they preferred the Polar H-10 chest strap or the Polar OH-1 arm band system. The arm band system was significantly ($p < 0.001$) preferred (Preferred Arm Band: 73.3% vs. Preferred Chest Strap: 16.7% vs No Preference: 10.0%). Table 1 presents the stated reasons for choosing the arm band system or the chest strap system. When participants were asked if the chest strap would be acceptable to wear, 76.7% said it would be acceptable to wear even if it was not their preferred system, while 100% stated that the arm band system would be acceptable. When participants were asked if they would wear the system if asked to (even if they did not find it acceptable) 93.3% responded that they would wear the chest strap system, while 100% said they would wear the arm band system. There was a significant difference ($p < 0.001$) in the number of minutes that participants said they could wear each system (length of time to wear chest strap: 91.2 ± 89.8 min vs. length of time wear the arm band: 875.0 ± 891.8 min) (i.e., 14 hr: 31 min ± 14 hr: 52 min). For the chest strap, only 10.0% of participants said they could wear the system for more than just a workout of two hours or less, compared to 83.3% of participants who said they could wear the arm band system for six hours or longer. When participants were asked how long recruits should be able to wear a system, 46.7% of participants said that recruits would need to wear a HSDD for 72 continuous hours or longer to enable monitoring of recruits during the Crucible exercise.

Table 1. Reasons participants preferred the chest strap vs. the arm band system

Reasons	*n*	%
Reasons for Preferring the Arm Band System		
Chest strap felt uncomfortable/arm band felt comfortable	15	50.0
Arm band I forgot I was wearing it	10	33.3
Chest strap slipped/moved from proper position/arm band stayed in place	7	23.3
Snap-on electronic module fell off or could fall off of the chest strap	5	16.7
Arm band easier to verify it is working when on the recruit	2	6.7
Arm band is similar to other things that I wear	1	3.3
Chest strap limited mobility	1	3.3
Chest strap caused pressure on the chest	1	3.3
Chest strap caused sweat build-up on my chest	1	3.3
Reasons for Preferring the Chest Strap System		
Believe that the chest strap will get more accurate data	5	16.7
Chest strap stays in place better	4	13.3
Arm band is more likely to get snagged on something or get pulled off	4	13.3
Chest strap I don't feel but the arm band I can feel when moving my arms	2	6.7
Prefer the chest strap but want the arm band when wearing body armor	1	3.3

When participants were asked about the negative effects on the body of each system, the primary reason (76.6%) participants objected to the chest strap was they felt it was uncomfortable, while 83.3% of participants had no issues with the arm band. Table 2 is a summary of the participant responses regarding negative effects of each system on the body. Participants also mentioned other non-body impact adverse events when wearing both the chest strap and arm band systems. The most frequent issue mentioned with the chest strap was that the strap or the electronics module is likely to get lost with 80.0% of participants stating this would be an issue. The top issue for the arm band was also that at least part of the system could be lost with 66.7% of participants mentioning that would be an issue. Table 3 is a summary of adverse issues for the chest strap and arm band systems not related to impact on the body. Most participants, 83.3%, felt the arm band system was a wear and forget system for training events lasting two hours or less. One participant thought that different systems might be better depending on the event. For example, if a recruit was doing pull-ups or running the obstacle course the chest strap system might be better, while if doing something where body armor was worn the arm band system would be better. Another participant mentioned that the chest strap system should have a light on the electronics module to show that it was operational.

Table 2. Impact on the body of chest strap and arm band systems

Adverse impact of the system on the body	*n*	%
Chest Strap System		
Was uncomfortable	23	76.7
Wearing body armor or landing on the chest will cause issues	15	50.0
Puts pressure on the chest	5	16.7
Causes skin irritation	5	16.7
Causes me anxiety	4	13.3
No issues	2	6.7
Will not fit properly with a sports bra	1	3.3
Causes excessive sweat in the chest area	1	3.3
Pulls on my chest hairs	1	3.3
Causes pressure on the chest	1	3.3
Causes sweat build-up on my chest	1	3.3
Causes rashes	1	3.3
Arm Band System		
No issues	25	83.3
Causes skin irritation	3	10.0
Causes rashes	3	10.0
Was annoying to wear	2	6.7
Causes skin to itch	2	6.7
Certain events could hurt (falling on the arm)	1	3.3
Could cause circulation problems	1	3.3
Could cause infections	1	3.3
Plastic piece digs into arm	1	3.3

Table 3. Adverse issues of using the chest strap and arm band systems not related to impact on the body

Adverse issues with using the system	*n*	%
Chest Strap System		
System or part of the system will get lost	24	80.0
Sanitation issues	15	50.0
Likely to get damaged	12	40.0
Electronics module or system will fall off during use	6	20.0
System does not properly stay in place on the chest	3	10.0
Hard to put the system on properly	3	10.0
No issues	1	3.3
Chest strap will interfere with the use of a Camelbak™ drinking system	1	3.3
Arm Band System		
System or part of the system will get lost	20	66.7
System durability (strap or plastic pieces will break)	15	50.0
Sanitation issues	15	50.0
System can fall off during use	9	30.0
Sensor part of the system with the LED lights is easy to flip over	4	13.3
No issues	1	3.3

OTHER FORM FACTORS PREFERRED

Watches or wrist-worn systems were the preferred system; as 56.7% of participants would like a watch for the HSDD even when informed that at present time most watch based systems have problems with accuracy of data or transmission of that data off the body. No other type of system other than watches or an arm band (46.7%) were preferred by the participants. However, other systems that participants recommended could be considered are listed in Table 4.

The most frequently detailed reason (17.6%) of those who preferred watch based systems was that it would be easier to account for the system because people wear watches anyway so it would be unlikely that they would lose them. An arm band based system was generally thought to be the 2nd most preferred system but of those that preferred the arm band system, 21.4% believed that the sensor should be changed from a circle to one that is square in shape but with rounded corners. Participants believed this change in shape would limit it from flipping over inadvertently. Having rounded corners would make it less likely to cause skin irritation from an edge of the sensor cutting into the skin. When participants were asked if a ring would be an acceptable or preferred form factor only one participant (3.3%) said that it would be. Four participants (13.3%) said that the two form factors demonstrated (chest strap and arm band systems) were acceptable, but that they would want a system that assessed sleep in addition to heat strain risk assessment. They thought a watch based system would most likely accomplish that objective.

Table 4. Other physiological status monitoring systems to be considered besides chest strap, arm band, or watch-based systems

Systems	*n*	%
Shoe based system	2	6.7
Patch based system	2	6.7
Ankle/leg based system	2	6.7
Any system that is flush with the skin	1	3.3
Dot on skin that is chemically based	1	3.3
Clothing based system	1	3.3

END USER DEVICE (EUD) FOR DATA DISPLAY

When participants were asked what end user device (EUD) they preferred, 70.0% of participants wanted data transmitted to a tablet that the instructors would hold, carry and look at. Another 20.0% of participants preferred data sent to a phone and only 10.0% felt that data should be displayed on a phone or some other device worn by the recruit as envisioned with a Buddy Display system. Elaborating on why a Buddy Display would not be a good system, many stated they: 1) they don't want recruits seeing their or another recruit's data because it will be an excuse to curtail the intensity of the training, 2) they or another decision maker would need to be too close in proximity to the recruit to see a change in status, 3) it likely will be too costly to have a phone or other reliable display device on every recruit where data from many recruits could be transmitted to just one EUD used by the Drill Instructor, 4) accountability of a phone or other type of display device would be an issue given they could easily fall off a recruit and be lost, and 5) batteries dying on the phone or other display device would entail frequent re-charging which would be impractical when at least 72 hours of continuous monitoring is needed during the Crucible exercise. A tablet was preferred as the EUD because participants believed the amount of information to be displayed would be more manageable with the use of a tablet compared to a phone (hand held EUD). A total of 93.3% of participants believed that the system needed to have a long range communications capability. These participants said it was extremely important when training at Camp Pendleton where a Drill Instructor could be responsible for many recruits who could be spread out over the training area in excess of a square mile.

WHO SHOULD VIEW THE DATA

Specifically, 36.7% of participants believed recruits should not see their data, 56.8% said Drill Instructors should receive the data, while 33.3% believed everyone should have access to the data. Table 5 is a summary of who should be able to view the recruits' physiological data. There was some debate among participants regarding recruits seeing their or their buddy's data. One person made the comment that if everybody viewed everyone's data then everyone is looking out for each other, but this same person said that seeing one's own data or that of a fellow recruit could "start messing with the recruits' heads and their training." Another person said as a compromise that having an alert on the recruit that went off only when in the "Red" or "Take an urgent look now" state might be worthwhile. Overall, though as noted above, most participants did not want information or a notification device on the recruit, but rather wanted data sent to a tablet or phone for Drill Instructors or other supervisory people to make the decisions on recruits' health status.

Table 5. Who Should Be Able to View Data

Person Who Views Data	*n*	%
Drill Instructors	17	56.8
Everybody	10	33.3
Not Recruit	10	33.3
Corpsman	9	30.0
A Chief	8	26.7
Commander	7	23.3
Athletic Trainers	6	20.0
Chief Drill Instructor	5	16.7
Series Commander	5	16.7
Series Chief	4	13.3
Series Officer	4	13.3
Another Recruit	3	10.0
Everybody except for recruits	1	3.3

WHAT DATA SHOULD BE VIEWED

All participants (100%) wanted to see estimated core temperature and all but one (96.7%) mentioned they wanted to see the green-yellow-red color code alert status. Only 33.3% wanted to use the HSI for decision making regarding thermal strain status. A few participants mentioned parameters that are currently not available on most PSM systems such as displaying a person's allergies or blood type, although this information could be easily inputted along with a recruit's name, identification number etc. as a one-time data entry into the system. These input parameters would not change in real time. More challenging would be the request to identify a specific recruit's location with a global position system (GPS) needed as part of the sensor system worn (especially if a phone with a built in GPS system was not used on the recruit's body). Also, sought by some participants was for a HSDD to have real-time blood glucose levels, blood oxygenation levels, and estimates of energy expended.

Many participants reported they did not believe and/or understand the HSI numbers. One issue bought up by many participants was why were HSI numbers color-coded as green (safe zone) from 0 to 6, while only two numbers (7 and 8) were assigned to the yellow zone and two numbers 9 and 10 were assigned to the red zone. Participants were made aware of the Moran et al. (18) research and how the scale and thermal strain risk were determined and validated but most participants found the HSI confusing or did not understand it, while stating they preferred not to use it. Three participants specifically reported that if a system was backed with science and a color-coded display based on HSI was incorporated they would use the system and they would not need the actual HSI numbers. Furthermore, standard practice for these Drill Instructors is to identify and remove a recruit from training due to excessive heat strain through a visual observation (e.g., facial flushing, poor coordination), and assessment of demeanor (e.g., compromised mental capacity), and ultimately a Corpsman checking rectal temperature. Having an estimate of core temperature that accurately approximates the rectal temperature measurements they are using now to assess a recruit's heat strain status was preferred.

Table 6. Data That Should Be Viewed

Data to be Viewed	*n*	%
Estimated core temperature	30	100.0
Color code (green, yellow, red) alert heat strain alerts	29	96.7
Heart rate	13	43.3
Heat strain index (HSI)	10	33.3
Recruit's name	8	26.7
Allergies recruit has	6	20.0
Blood type recruit has	6	20.0
Recruit's location	5	16.7
Recruit's blood glucose levels	5	16.7
Ambient temperature	1	3.3
Blood oxygen level	1	3.3
Recruit's training group	1	3.3
Calculated energy expenditure in calories	1	3.3

Participants were briefed on the estimated core body temperature and HSI algorithms at the time they were provided their Buddy Display systems. When participants were asked if they thought the briefing provided to them was clear and that they understood generally how the algorithms worked, 90.0% of participants said the explanations were clear and they understood how the algorithms worked. However, when asked to explain generally how these algorithms work, only one participant (3.3%) could accurately explain what the inputs into the algorithms were. For example, many thought the estimated core temperature algorithm used skin temperature or ambient temperature as inputs despite knowing the Buddy Display system provided an estimated core temperature, but had no skin temperature or ambient temperature sensors. With regard to the HSI algorithm, most test participants (90.0%) did not realize that heart rate alone was the single measured input for a system demonstrated or an HSDD developed for Marines.

Participants were also asked what information needs to be captured and saved if a heat casualty does occur. All 30 participants (100%) thought that estimated core temperature at the time of the heat injury should be captured and saved when a person experienced a heat illness or injury event. Table 7 summarizes the frequency of responses for all the information that should be captured and saved when a heat illness or injury event occurs. When asked if data should be saved for After Action Reviews (AARs) that occur after a heat casualty has been experienced, 93.3% believed the data should be saved for this purpose. When participants were asked where the data should be saved, 16.7% of participants thought it should be saved on the tablet the Drill Instructor maintained and 16.7% thought it should be saved on the phone (EUD) attached to or worn by recruits. Table 8 is a summary of participant's thoughts regarding who should manage the saved data. There was significant disagreement who should manage the data, though 23.3% of participants thought it should be the Drill Instructors. A comment made by 16.7% of participants was that athletic trainers or others that are likely to be more permanent staff at the Marine Corps Recruit Depot, San Diego should manage the data because it will be problematic if people like Drill Instructors or other Marines that move in and out of their positions managed the data. Furthermore, 13.3% of participants mentioned that a system needs to be set up where data can be shared easily among all relevant parties. For example, data should not be saved on a particular recruit's phone (EUD) or a particular Drill Instructor's tablet but rather to a centralized database where, with appropriate permissions, access to a recruit's data would be available.

Table 7. What Data Should Be Captured and Saved if Heat Casualty Occurs

Data to be Captured and Saved	*n*	%
Estimated core temperature at time of heat injury	30	100.0
Heat strain index (HSI)	9	30.0
Heart rate	7	23.3
Time of heat injury event	6	20.0
Estimated core temperature before and after heat injury	5	16.7
Ambient temperature	2	6.7

Table 8. Who Manages Saved Data

Person	*n*	%
Drill Instructor	7	23.3
Other staff besides Drill Instructors	6	20.0
Senior Drill Instructors and others up the supervisory chain	5	16.7
Athletic Trainers	5	16.7
Chief	4	13,3
Series Officers	4	13.3
Officers	3	10.0
Medical personnel	2	6.7
Series Commanders	1	3.3
Not Drill Instructors	1	3.3

COLOR OF DISPLAY

When participants were asked "What colors should the display on the tablet have?", in particular "Should it be a "green, yellow, red display" or would a "black, white, grey display" suffice?" all participants (100%) stated that a "green, yellow, red display" should be used. One individual mentioned that there should be another distinguishing characteristic about differences in status besides display color because he was color-blind, though the color-schemed system he thought would be preferred for most people.

INFORMATION DISPLAYED ON BODY OF RECRUITS

Because there are technological challenges with transmitting information from many recruits to a single tablet held by a Drill Instructor, questions were asked about the nature of a display on the body of the recruit even if that was not the ideal mode of operation of a HSDD for use by Drill Instructors during Basic Training. Participants were asked "if a body-worn display was used, where on the body should it be located?" The majority of participants (63.3%) stated it should be located on the upper arm, while 30.0% of participants said it should be able to be adjustable to different parts of the body and 6.7% of participants thought it should be placed on the back. The following were additional characteristics described for the Buddy Display device.

Size of Display

When asked about the size of the display, 56.7% of participants said it was not relevant because they would not want the display on the person regardless. Of those providing a response with regard to size of the display, 30% of participants felt it should be the size of the Jelly Phone they were provided during the familiarization period on this study. One participant each said the following: 1) the size of an Apple (Apple Inc., Cupertino, CA) watch face, 2) the size of a regular Apple iphone, and 3) smaller than the Jelly Phone display.

Brightness of Display

When participants were asked about how bright the display should be, 50.0% of participants thought is should be as bright as possible, whereas 20.0% of participants thought the display should be adjustable. Other responses included bright enough to see in the daylight, and brightness similar to what was used on the Jelly Phone, with 13.3% of participants reporting each of these responses. One participant said that the display should be bright enough to be able to see from 10 meters away. When participants were asked to qualify their brightness responses, 33.3% of participants mentioned that the brightness of the mid-day sun in San Diego makes it very difficult to see a phone screen from any distance, hence any solution will likely have challenges in implementation.

Color of Display

Similar to data displayed on a Drill Instructor's tablet, participants were asked what colors should be displayed on a body display device, and 100% of participants stated that a "green, yellow, red display" should be used. One participant stated that there should be no "yellow," just "green" for when the recruit is ok, and a "red" warning when the recruit is beginning to overheat.

Alerting Function

When participants were asked about how they should be alerted when someone was in the red alert state, 50.0% of participants believed an audible noise alert should accompany the color change, 16.7% of participants thought the display should flash or if there was a flashing light built into the system the light should flash, and 16.7% of participants thought the system should vibrate to let the wearer know there was an alert.

RUGGEDIZE SYSTEM FOR MARINE USE

Within this topic, some participants provided answers specific to the arm band system where others provided more general strategies to ruggedize any type of HSDD. Table 9 summarizes these specific strategies for the arm band systems and the general strategies to ruggedize an HSDD.

Table 9. Strategies to Ruggedize the Heat Strain Detection Device (HSDD)

Strategy	*n*	%
Arm Band		
Make the arm band strap more durable	16	53.3
Have multiple points of failure in arm band; build in redundant reinforcement	5	16.7
Have the arm band electronics module be flat with rounded corners	3	10.0
General		
System needs to be waterproof	18	60.0
System needs to come with a hard protective storage case	7	23.3
System needs to be dustproof	4	13.3
System needs to be shockproof	4	13.3
Study or research needed on materials to be used	4	13.3
Have a wrist worn system like an Apple watch system	3	10.0
Need to have system pieces not black – too hard to find if you drop at night	2	6.7
Have system be a ring-based system	1	3.3

CONCERNS WITH ANY TYPE OF SYSTEM

Participants were asked what concerns, if any, they had regarding any type of HSDD that might be employed. They were told to think if they could have the system that they wanted, what concerns would they still have? Table 10 is a list of concerns participants would still have. Accountability of systems is by far the most frequently stated concern with all but one participant (96.7%) citing this as a concern. Another 16.7% of participants suggested any system should have a built in function like the Apple Watch or Apple iPhone has where you can type into another phone, tablet or computer “Where is my HSDD?” and the geo-location of the lost HSDD would be displayed. In addition to the general accountability of the system, if it does indeed get lost, who is responsible for the replacement cost? Will it be the Drill Instructor, the recruit, or will it come out of the unit’s budget? These participants saw negative impacts on use of the system regardless of who would be responsible for replacement. If the recruit is responsible, the recruit themselves will likely not want to take on that responsibility. If it is the Drill Instructor who is responsible, these participants didn’t think it would be fair that they should have to pay for what one of their recruits does, while if it comes out of the unit fund, without additional funds, those costs will impact the unit for other “more necessary” training equipment. In addition to accountability, a concern was will it take an unacceptable amount of time for the Drill Instructor to use the system properly (charging the system, to distributing systems, accounting for the systems, etc.). All of this additional time means that Drill Instructors will either have to work harder, longer hours, or training time will be compromised.

Table 10. Concerns with Use of a Heat Strain Detection Device (HSDD)

Concern	*n*	%
Accountability (system or part of the system gets lost)	29	96.7
Charging of the systems (too complicated/takes too much time)	14	46.7
Resupply of missing or broken systems	12	40.0
Won't work with complexity of training environment (up to 500 recruits)	8	26.7
Keeping systems clean for both hygiene and functioning of systems	7	10.0
Problems with too many electronic signals interfering with one another	7	10.0
If phone used by recruits, disable other functions needed	5	16.7
Too much time needed by Drill Instructors; reduction in training time	5	16.7
Durability of systems (not durable enough)	5	16,7
Won't be waterproof/dustproof/shockproof enough for use	4	13.3
Recruits seeing their data resulting in negative impact to training	3	10.0
If phone used for display, recruit accidently or intentionally turning off display	2	6.7
If phone used for display, too much time/too complicated to do pairings	1	3.3

NEW EQUIPMENT TRAINING (NET) TIME NEEDED

Recruits

The majority of participants (83.3%), thought that no training or limited time training (e.g., 2 minutes or less) would be needed by recruits using the HSDD. Two other participants (6.7%) thought up to five minutes of NET should be provided, while one participant (3.3%) thought multiple hours would be acceptable. Two participants did not answer this question.

Drill Instructors

The estimated length of NET time needed that was thought to be acceptable for Drill Instructors to learn to use the HSDD was between 15 minutes and an hour; with 83.3% of participants reporting that much time to be trained would be acceptable. A few participants (13.3%) thought NET could be as long as two or multiple hours for Drill Instructors to learn the system, and one participant thought multiple hours of training on a continuous basis would be needed and appropriate. In more detailed comments, 20.0% of participants thought that Drill Instructors should just have enough training to operate the system and to be able to properly train recruits on the wear of the system. Furthermore, they reported that no system should be so complicated to learn that it should take more than 15 minutes to an hour to properly use. A minority of participants (10%) thought that supervisory individuals could have more extensive training on the system and the data obtained if needed, but Drill Instructors need a system simple enough that NET time is limited for them.

PERCEIVED UTILITY OF HEAT STRAIN DECTECTION DEVICE (HSDD)

Participants were asked if a HSDD was developed and acquired that met the desired specifications that they described, would such a system help in preventing heat injuries in the recruits. The majority (90.0%) of participants believed that having such a tool would aid them in preventing heat injuries in their recruits. Some participants (16.7%) believed having a HSDD would allow them to proactively respond to heat strain issues their recruits were having. These same participants noted that often times overheating can occur when the ambient temperature is not that great, but the workload was perhaps more than some recruits could handle without overheating. Having a HSDD in place would be especially helpful in these situations where awareness to impending thermal strain in recruits might not be readily apparent. A caveat that these participants who believed in the utility of a HSDD had, is that a HSDD should not replace personal judgement of assessing the thermal strain condition of their recruits (18.5% of these participants stated this belief). Drill Instructors are regularly trained to look for signs and symptoms related to impending heat illnesses and injuries. These participants believed that use of a HSDD should not replace “eyes on” a recruit’s face, or actions and demeanor that could be a precursor to a problem regardless of what the HSDD indicates. Those that did not believe the system would be useful, stated 1) they did not believe heat issues in recruits were that big of a problem, 2) it could be useful for a new Drill Instructor but not that useful for an experienced instructor who knows how to manage the health status of his/her recruits, and 3) they thought they have been able to detect adequately when a person is having a problem without the use of this kind of technology.

When participants were asked if they would use a HSDD if it was developed and acquired with the specifications they described, 93.3 % of participants said they would use such a device. The number one reason stated for why they would use it as stated by 16.7% of participants was that while a system like this may have a significant monetary cost, you cannot place a price on the loss of a life due to a heat injury, regardless of how rare an occurrence it might be. One individual, who thought it might not be that useful in detecting heat injuries, believed a HSDD system would be useful for other reasons. While he responded that he did not think it would be helpful in detection of heat problems, he wanted to use the system for other reasons (e.g., to improve training effectiveness, or to alert a Drill Instructor to a recruit’s underlying previously undetected heart problem. When participants were asked if they thought using a system as they described would improve the early detection of possible heat injuries and other health problems, 96.7% of participants believed it would improve current heat injury management practices.

DISCUSSION

Based on the findings of this study, which included a clear preference for an arm band sensor rather than a chest strap sensor, we conclude that an acceptable but not ideal solution that could be implemented in the near term, is combining the Evalan BV ARMOR arm band system (<https://evalan.com/en/armor-heat-stress> accessed 08 OCT 2021) or possibly the forearm mounted Scosche (Oxnard, CA) Heart Rate Monitor (https://www.scosche.com/scosche-rhythm-plus-2-0-heart-rate-monitor-armband accessed 08 OCT 2021) with a long range radio capability. The ARMOR system is currently in use by the Dutch Army. In the longer term, a watch-based system preferred by the Drill Instructors, combined with a long range radio capability, could be pursued.

The primary rationale for the above recommendation is the reported issues associated with wearing chest straps is they cause skin irritation or are uncomfortable to wear. Additionally, the placement of the electronics module in the center of the chest strap was thought to interfere with some activities, e.g., landing on the chest while navigating over a log during the obstacle course, resulting in pushing the electronics module into the chest causing discomfort. Chest-belt electrocardiographic heart rate monitors, in spite of their accuracy, low cost and long battery life, have been poorly accepted by a variety of military groups (21-25). In contrast, an arm band solution was deemed acceptable.

The ideal form factor from the perspective of a majority of Drill Instructors in the present study was a sensor system that could be worn on the wrist like a watch. However, wrist worn sensors are susceptible to motion artifact, and bony and complex wrist surface anatomy which makes optical sensing of heart rate more difficult Wrist-worn devices have historically not produced accurate heart rates (2, 27), though the Apple watch has recently been shown to be accurate during both exercise and rest (2, 8). Use of watch-based, or forearm mounted systems that produce valid and reliable heart rate data (2, 8, 19) needs to be considered. While an arm band system like the ARMOR system which uses the Polar OH-1 arm band sensor could be acceptable from a comfort and acceptability standpoint, another important concern raised was the challenge of maintaining accountability of systems. For example, it was envisioned that an arm band system would need to be issued out and turned in for charging on a consistent basis. Providing a watch that would not need to be charged or could be charged simply by the recruits would be less likely to be lost if worn continuously. Hence, it would accomplish two goals, have continuous monitoring with an acceptable form factor and be less likely to be misplaced or fall off during training. Studying issues surrounding system accountability could offer an opportunity to address questions such as, “Is a watch sensor less likely to be lost than other form factors?” For example, the textile based sensor system developed by Cornerstone Research Group (Miamisburg, OH) (5) that has a sleeveless undershirt as its form factor that should be comfortable and less likely to have some of the accountability issues of chest belts or arm band systems.

As noted earlier, the preferred concept of operations (CONOPS) for monitoring Marine recruits in Basic Training would be to have heat strain information for each recruit transmitted to a Drill Instructor some distance away. This CONOPS is similar to that described previously by WMD-CSTs (29) and Coast Guard Strike Teams (25). That is, WMD-CSTs health care providers and leadership found the Buddy Display approach, with heat strain information collected and displayed on the individual wearer of the system was unacceptable which is in agreement with what these Drill Instructors expressed in the present study. The WMD-CST leadership and medical staff wanted the downrange individual’s heat strain information transmitted to a central location to be evaluated by medical and command staff (29). Their rationale was the same as the Drill Instructors in this study, that mission or training will be compromised if individuals or their buddies are making medical and tactical decisions themselves. They believed that downrange WMD-CST personnel are unqualified to make health care decisions for themselves or their buddies. Similarly, Drill Instructors in this study voiced the same concerns. Therefore, like the WMD-CSTs or the Coast Guard Strike Teams needs, a long range radio system capable of handling data from multiple recruits needs to be incorporated into the use of the HSDD to allow data to be transmitted from a recruit to a Drill Instructor's tablet. Transmission range distance was not analyzed in this study but would likely be in the hundreds of meters to perhaps a thousand meters distance.

Currently, standard operating procedures (SOPs) regarding recruits with incipient heat injuries is for the Drill Instructor to monitor the behavior, signs and symptoms common to heat illnesses, and to question the recruit on how they are feeling. If a recruit is suspected of overheating, he or she is temporarily removed from training and has rectal temperature checked. If the recruit's core temperature is elevated he or she is given time to rest, or if in a critical state sent for medical attention. The use of a valid and reliable HSDD would remove the need for spot checks of rectal temperature. A HSDD capability was desired by most participants in this study. The use of estimated core temperature as a proxy for directly measured core temperature was also desired. In contrast, the HSI "heat strain index", which reflects combined work strain and heat strain, was considered unclear and not desired.

In addition to an accurate and reliable estimate of core temperature, the study participants wanted a color coded (green / yellow / red) indication of heat strain level. One caveat mentioned by a color-blind Drill Instructor was that the green, yellow, red status indication should be associated with a symbol or other status alert (e.g., audible notification). Previously, a circle, square, diamond symbol was proposed to be paired with the colors to address this issue (28). Use of estimated core temperature would be associated with minimal changes to current heat management SOPs which Drill Instructors are very familiar with. During the focus group sessions there was a lack of understanding on how estimated core temperature could be obtained from heart rate alone. Perhaps, a layman's version of the information in the scientific literature (3) could assist in the understanding of what estimated core temperature is, and how it is derived and used in the proposed HSDDs. Appendix A is an information sheet that describes in layman's terms how core temperature can be estimated from a series of heart rate measurements. Additionally, it was reported that estimated core temperature data around the time of a heat injury should be saved within a database that can be accessed by medical and training personnel that have a need-to-know.

A critical point made by the Drill Instructors was that the HSDD would supplement but not replace their judgement regarding the work strain and heat strain being experienced by their recruits. Most agreed that having a HSDD would assist them in making their decisions. However, they emphasized that they have had extensive training in recognizing early signs of heat illness and in how to treat heat casualties when they do occur. They did not want any system to tell them what to do or override their experienced judgement. This same concern has been raised previously with Army medics on potential use of PSM systems (14, 28).

In summary, Drill Instructors participating in this study believed having a HSDD, if it was simple to use and met the requirements described in this report, would make a difference in enhancing training and reducing the likelihood of heat casualties from occurring. Almost all Drill Instructors would use a HSDD to supplement their standard methods of monitoring heat strain level, e.g., facial flushing, truncal ataxia (upper body incoordination), and irritability. The Drill Instructors believed a HSDD would be useful for monitoring their personnel and would advocate for having use of such a system during training.

CONCLUSIONS

The USMC Drill Instructors would use a HSDD if the system met the requirements described in this report. The ideal system, from a Drill Instructor's point of view, would be a watch that transmits estimated core temperature and a red/yellow/green or red/green color coded indication of recruit status to a tablet held by the Drill Instructor. An acceptable system would be an arm band system similar to the ARMOR by Evalan BV system paired with a long range radio to transmit information off the recruit to a Drill Instructor who could be as far away from the recruit as a thousand meters. Drill Instructors would use estimated core temperature and a color coded indication of the individual Marines' level of heat strain provided by a HSDD to identify recruits experiencing excessive heat strain and take remedial action (e.g., rest, provide hydration, loosen clothing, seek shade, call Corpsman etc.).

REFERENCES

1. Aaker D.A., and Day, G.S. *Marketing Research.* New York: John Wiley and Sons, 1986.

2. Bent, B., Goldstein, B.A., Kibbe, W.A., and Dunn, J.P. Investigating sources of inaccuracy in wearable optical heart rate sensors. *NPJ Digital Medicine* 2020; 3:18, 2020. https: doi.org/10.1038/s41746-020-0226-6

3. Buller, M.J., Tharion, W.J., Cheuvront, S.N., Montain, S.J., Hoyt, R.W. and Jenkins, O.C. Estimating human core temperature from heart rate. *Physiological Measurement,* 34: 781-798, 2013.

4. Buller MJ, Wallis DC, Karis AJ, Herbert NJ, Cadarette BS, Blanchard LA, Amin MM, DiFilippo JL, Economos D, Hoyt RW, Richter MW. *Thermal-Work Strain During Marine Rifle Squad Operations In Iraq (Summer 2008).* Technical Report T09-01. Natick, MA: U.S. Army Research Institute of Environmental Medicine, 2008. ADB345494

5. Cable, C., Young, T., and Cowgill, M. *Health Monitoring Garment with Distributive Sensing*. Small Business Innovative Research (SBIR) Final Report for Contract #W81XWH18C0093 submitted to the United States Research Institute of Environmental Medicine, William Tharion (COR), Miamisburg, OH, Cornerstone Research Group Inc., 2021.

6. Di Stefano, G., Gambardella, A., and Verona, G. Technology push and demand pull perspectives in innovation studies: Current finding and future research directions. *Research Policy*, 41: 1283-1295, 2012.

7. Etiwy, M., Akhrass, Z., Gillinov, L., Alashi, A., Wang, R., Blackburn, G., Gillinov,, S.M., Phelan, D., Gillinov, A.M., Houghtaling, P.L., Javadikasgari, H., and Desai, M.Y. Accuracy of wearable heart rate monitors in cardiac rehabilitation. *Cardiac Diagnostic Therapy*, 9: 262-271, 2019.

8. Falter, M., Budts, W., Goetschalckz, K., Cornelissen, V., and Buys, R. Accuracy of Apple Watch measurements for heart rate and energy expenditure in patients with cardiovascular disease: cross-sectional study. *JMIR Mhealth Uhealth*, 7(3):e11889, 2019. doi: 10.2196/11889

9. Fern, E.F. The use of focus groups for idea generation: the effects of group size, acquaintanceship, and moderator on response quantity and quality. *Journal of Marketing Research*, 19: 1-13, 1982.

10. Friedl, K.E., Buller, M.J., Tharion, W.J., Potter, A.W., Manglapus, G.L., and Hoyt, R.W. *Real Time Physiological Status Monitoring (RT-PSM): Accomplishments, Requirements, and Research Roadmap.* (Technical Note TN-16-2). Natick, MA: United States Army Research Institute of Environmental Medicine, 2016. ADA630142

11. Headquarters, Department of the Army and Air Force. *Technical Bulletin: Heat Stress Control and Heat Casualty Management.* Technical Bulletin Medical (TB MED) 507/Air Force Pamphlet (AFPAM) 48-152. Washington, D.C.: Headquarters Department of the Army and Air Force, 7 March 2003.

12. Hermand, E., Cassirame, J., Ennequin, G., and Hue, O. Validation of a photoplethysmographic heart rate monitor: Polar OH1. *International Journal of Sports Medicine*, 40: 462-467, 2019.

13. Hettiarchchi, I.T., Hanoun, S., Nahavandi, D., and Nahavandi, S., Validation of Polar OH1 optical heart rate sensor for moderate and high intensity physical activities. *PLOS/ONE,* 1/1 to 13/13, May 23, 2019.

14. Kaushik, S. and Tharion, W.J. U.S. Army medic recommendations for a graphical user interface for a new battlefield medical monitoring system. *Military Medicine,* 174: 1190-1195, 2009.

15. McQuarrie, E.F., and McIntrye, S.H. Focus groups and the development of new products by technologically driven companies: some guidelines. *Journal of Product Innovation Management*, 2 March: 40-47, 1986.

16, Medical Surveillance Monthly Report (MSMR) – No Individual Author. Update: Heat Illness, Active Component, U.S. Armed Forces, 2017. *Medical Surveillance Monthly Report*, 25 (4): 6-10, April 2019.

17. Medical Surveillance Monthly Report (MSMR) – No Individual Author. Update: Heat Illness, Active Component, U.S. Armed Forces, 2018. *Medical Surveillance Monthly Report*, 26 (4): 15-20, April 2019.

18. Moran, D.S., Shitzer, A., and Pandolf, K.B. A physiological strain index to evaluate heat stress. *American Journal of Physiology (Regulatory Integrative and Comparative Physiology*, 44: R129-R134, 1998.

19. Reece, J.D.; Bunn, J.A.; Choi, M.; Navalta, J.W. Assessing Heart Rate Using Consumer Technology Association Standards. Technologies 2021, 9, 46. https://doi.org/10.3390/technologies90300461

20 Schubert, M.M., Clark, A., and De La Rosa, A.B. The Polar OH1 Optical heart rate sensor is valid during moderate-vigorous exercise. *Sports Medicine International Open,* 2: E67-E70, 2018.

21. Tharion, W.J., Buller, M.J., Clements, C.M., Dominguez, D., Sampsonis, C., Mullen, S.P., Karis, A.J., and Potter, A.W. *Human Factors Evaluation of the Hidalgo Equivital™ EQ-02 Physiological Status Monitoring System.* Technical Report T14-2. Natick, MA: U.S. Army Research Institute of Environmental Medicine, 2013. ADA592523

22. Tharion, W.J., Buller, M.J., Karis, A.J., and Hoyt, R.W. Development of a remote medical monitoring system to meet soldier needs. In: *Advances in Understanding Human Performance: Neuroergonomics, Human Factors, Design, and Special Populations.* Marek, T., Karwowski, W. and Rice, V. (Editors), Boca Raton, FL: CRC Press, Taylor and Francis Group. Pp. 491- 500, 2010.

23. Tharion, W.J., Buller, M.J., Karis, A.J., and Mullen, S.P. Acceptability of a wearable vital sign detection system. *Proceedings of the Human Factors and Ergonomics Society 51st Annual Meeting*, Volume 51 (p. 1006-1010), Santa Monica, CA: Human Factors and Ergonomics Society, 2007.

24. Tharion, W.J., Buller, M.J., Potter, A.W., Karis, A.J., Goetz, V., and Hoyt, R.W. Acceptability and usability of an ambulatory health monitoring system for use by military personnel. *IIE Transactions on Occupational Ergonomics and Human Factors*, 1(4): 203-214, 2013.

25. Tharion, W.J., DeLosa, N.D., Boettcher, T.L.S., Halford, E., and Welles, A.P. *Test Report of the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system during a field test of chemical-biological operations by Coast Guard Strike Teams.* (Technical Report T19-10). Natick, MA: United States Army Research Institute of Environmental Medicine, 2019. AD1081166

26. Tharion, W.J., Friedl, K.E., M.J., Buller, M.J., Henao Arango, N and Hoyt, R.W. Evolution of Physiological Status Monitoring for Ambulatory Military Applications. In: *Human Performance Optimization: The Science and Ethics of Enhancing Human Capabilities.* Matthews, M.D., and Schnyer, M. (Editors), Oxford, UK: Oxford University Press, Pp. 142-164., 2019.

27. Tharion, W.J., Karis, A.J., and Richardson, E.N. *Heart Rate Validity of the Georgia Tech Research Institute's Integrated Soldier Sensor System (ISSS) Candidate Physiological Status Monitoring (PSM) System.* (Technical Report T-16-4). Natick, MA: United States Army Research Institute of Environmental Medicine, 2015.

28. Tharion, W.J. and Kaushik, S. *Graphical User Interface (GUI) for the Warfighter Physiological Status Monitoring (WPSM) system – U.S. Army Medic Recommendations.* (Technical Report T-07-04). Natick, MA: United States Army Research Institute of Environmental Medicine, 2006. ADA459019

29, Tharion, W.J., Potter, A.W., Duhamel, C.M., Karis, A.J., Buller, M.J., and Hoyt, R.W. Real-time physiological monitoring while encapsulated in personal protective equipment. *Journal of Sport and Human Performance,* 1(4): 14-21, 2013.

APPENDIX A

ECTemp – Accurate Core Body Temperature in the Field

POC: Mark Buller, USARIEM, 10 General Green Avenue, Natick, MA 01760
(mark.j.buller.civ@mail.mil)

What:
The ECTemp™ uses a mathematical equation by taking minute-to-minute measures of heart rate to estimate core body temperature within 0.2 °F of what would be obtained with a rectal thermometer.

Physiological Basis:
The ECTemp™ assumes heart rate is related to core body temperature but it is not a perfect relationship. Physiologically, heart rate reflects the rate of blood flow to the muscles and the rate of blood flow to the skin. Because of this, heart rate is related to both heat production (blood flow to the muscles) and heat loss (blood flow to the skin).

How:
The ECTemp™ was developed from data collected on 17 U.S. Army Soldiers engaged in 24 hours of field training. They had actual core temperatures measured with a temperature pill that is as accurate as rectal thermometers and heart rates were also measured. Data was collected continuously over an environmental air temperature range of 75 to 97 °F and a relative humidity range of 42 to 97%. Soldier activities ranged from sleep to fox-hole digging in intensity. The data used to develop the mathematical model included core body temperatures from 96.8 to 104 °F.

Validation:
The ECTemp™ mathematical model was validated with 11 laboratory and field data collections with data from over 130 test volunteers that included U.S. Marines (Iraq/Afghanistan), U.S. Special Forces, U.S. Ranger students, and Australian Special Forces. These studies examined cool (52 °F) to very hot (108 °C) air temperature, various clothing conditions (shorts and t-shirt, to full combat uniforms with body armor), work rates from sleep to heavy exercise, hydrated versus under-hydrated conditions and heat acclimated versus non-heat acclimated conditions. A separate validation of the algorithm was completed in simulated chemical, biological, radiological, nuclear and explosive (CBRNE) environments with various levels of personal protective clothing for CBRNE environments. The Massachusetts Institute of Technology, Lincoln Laboratory, has also independently validated the model using U.S. Marine Corps data collected during 12 days of jungle warfare training.

Application:
The ECTemp™ algorithm can be used with any accurate commercial off-the-shelf heart rate monitoring device.