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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

United States Army
Medical Research & Materiel Command

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14. ABSTRACT

A new physiological status monitoring system, the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system was tested for form, fit, and function during operational chemical, biological, radiological, and/or nuclear (CBRN) training exercises held by Coast Guard Strike Teams. Data were collected on sixteen test participants wearing the system and three test participants using the EUD phone. Results from this test show that the heart rate and associated heat strain index (HSI) appear to be reliable and valid based on reasonableness of data based on the operational and environmental conditions. Skin temperature was not always physiological reasonable and showed great variability. The chest strap caused skin irritation in some but not all individuals. There appeared to be no issues with either the TNB or BLE modes of transmission. All personnel stated that a long-range communication of a minimum of 200 meters is necessary because within the concept of operations (CONOPS). The OBAN-PSM system was viewed as a valuable tool for CBRN operational safety if the above areas of concern are addressed.

15. SUBJECT TERMS

Physiological Status Monitoring; Open Body Area Network; PSM; OBAN; human factors acceptability; system engineering; military equipment design, heat injury; thermal strain; chemical, biological, radiological, and nuclear; CBRN; operational test

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

A new physiological status monitoring system, the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system was tested for form, fit, and function during operational chemical, biological, radiological, and/or nuclear (CBRN) training exercises held by Coast Guard Strike Teams at the Center for Domestic Preparedness, Anniston, AL. The OBAN-PSM system consists of a commercial off-the-shelf (COTS) Polar Pro chest strap (Polar OY, Kempele, Finland) and a custom-made hub developed and manufactured by the Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) and Odic, Inc. (Devens, MA) that is compatible with the Polar Pro chest strap. The OBAN-PSM system has been developed to specifically meet the needs of the military. It will be tactically acceptable for the military by using a tunable narrow band (TNB) radio to enhance security; and is designed to function for 72 hours or more. The system can also operate in Bluetooth Low Energy (BLE) mode when secure communications are not an issue. The test described in this report assesses the first productized prototype (Version 1.0). It assesses the form, fit, and function of the entire system, that is, the wearable part (chest strap and hub) and the end user device (EUD) a phone with OBAN-PSM applications (Apps) installed. Data were collected on sixteen test participants wearing the system and three test participants using the EUD phone. Results from this test show that the heart rate and associated heat strain index (HSI) appear to be reliable and valid based on reasonableness of data based on the operational and environmental conditions. Skin temperature was not always physiological reasonable and showed great variability even within a certain hub as well as across hubs. The chest strap caused skin irritation in some but not all individuals. There appeared to be no issues with either the TNB or BLE modes of transmission. Safety Officers and Emergency Medical Technicians (EMTs) who used the OBAN-PSM phone, all indicated the value of the OBAN-PSM system as a tool to aid in monitoring the safety of downrange personnel. However, the current system required the person monitoring those wearing the system to be within 20 meters of that individual. All personnel stated that a long-range communication of a minimum of 200 meters is necessary because within the concept of operations (CONOPS), that is, those monitoring encapsulated personnel in the contaminated hot zone, must stay out of the hot zone and they also do not don personal protective equipment (PPE). The top recommendations that came out of this test include:

- A reliability and validity study/test should be done with humans to assess heart rates, skin temperatures and movements against gold standard devices.

- An accurate sensor system to replace the current COTS chest strap is needed to minimize skin irritation while wearing the system for 72 hours or more.

- The OBAN-PSM system needs to have a long-range communication capability (200 meter threshold and 1000 meter objective).

- Software developed must be Defense Information Systems Agency (DISA) (Ft. Meade, MD) compliant.

INTRODUCTION

The dismounted warfighter is susceptible to excessive heat strain as a result of environmental and operational stressors. These effects are most pronounced when chemical, biological, radiological, and/or nuclear (CBRN) personal protective equipment (PPE) is worn. The CBRN-PPE compromises thermo-regulation primarily by preventing evaporative cooling (11). Recent physiological status monitoring (PSM) systems are capable of monitoring work intensity and heat strain/body core temperature (16). Use of PSM technology by an individual can improve medical and mission readiness awareness of self, his or her buddy, and/or team members by providing an objective measure of health state including thermal strain (16).

The Equivital™ Black Ghost with the EQ-02 Life Monitor system (Equivital™, Cambridge, UK) is an acceptable PSM system for some users (4). However, it is not always easy to use. Fitting the harness to the individual needs to be precise to obtain accurate data. There are nine sizes that add to the logistical burden. The Equivital™ system is relatively expensive, requiring up to $50 K for a functioning system to meet the needs of a Weapons of Mass Destruction – Civil Support Team (WMD-CST) mission. The entire system to meet mission needs includes the wearable harness and sensor electronics module (SEM), a computer, a phone per individual being monitored, licensed software, and radio repeaters to telemeter data from downrange personnel back to a command post. The Equivital™ system lacks the battery life needed to monitor for 72 hours or longer, the typical length of time of some military sustained operations. In addition, this system is not tactically acceptable in certain operations because communication of data uses commercially available wireless technologies such as Bluetooth or commercial WiFi, which is currently not approved for use in combat environments.

In response to these shortcomings, a new PSM development effort was jointly undertaken by the U.S. Army Research Institute of Environmental Medicine (USARIEM) and the Massachusetts Institute of Technology – Lincoln Laboratory (MIT LL). This new PSM system, the Open Body Area Network (OBAN) system attempts to address the above needs for a military acceptable PSM system. This prototype system uses a COTS chest strap with a custom-made sensor hub. Each hub can communicate to a hand-held end user device (EUD) (e.g., a smart phone was used during this test) for displaying the physiological data. The system was engineered to be tactically acceptable by using a tunable narrow band (TNB) radio for communications between the sensor hub and the hand-held device, and to function for 72 hours or more. Previous tests with an OBAN-PSM prototype system (Version 0.0) included laboratory/bench testing and field tests with U.S. Army soldiers participating in training exercises at Hanscom Air Force Base, MA and Camp Ethan Allen, VT and with U.S. Marines at Camp Geiger, NC (5, 12). Based on early test results, a newer productized version (Version 1.0) of the OBAN-PSM system was developed by Odic, Inc. (Devens, MA) and was the system tested and described in this report. The system was designed

based on form and fit feedback from a previous set of dummy OBAN-PSM prototypes tested with two experienced soldiers during simulated military training exercises (15).

The purpose of this present test was to assess the form, fit, and function of the Odic, Inc./MIT LL developed prototype OBAN-PSM system during CBRN training with CBRN PPE donned. It is likely that CBRN personnel, both military and non-military, who participate in CBRN training and missions will be one of the first adopters of PSM systems including the OBAN-PSM system, provided these systems meet user requirements. As such, these test groups are relevant because they address the needs of one of the intended key customer groups.

METHODS

TEST PARTICIPANTS

Test participants wearing the system were 16 Coast Guard Strike Team Members (Atlantic, Gulf, and Pacific Teams included) (15 Men and 1 Woman). Physical characteristics included height of 181 ± 8 cm (minimum: 167 cm, maximum: 197 cm), weight of 90 ± 11 kg (minimum: 73 kg, maximum: 109 kg), and chest circumference of 38.8 ± 2.9 cm (minimum: 34 cm, maximum: 44 cm). In addition to these 16 test participants, two experienced safety officers (one with 20+ years of experience and the other with 2.5 years of experience) not wearing the system used the EUD/phone portion of the system to monitor those individuals wearing the OBAN-PSM system. One individual, an emergency medical technician (EMT) with 4 years of experience, wore the system and carried the phone for physiological monitoring of personnel.

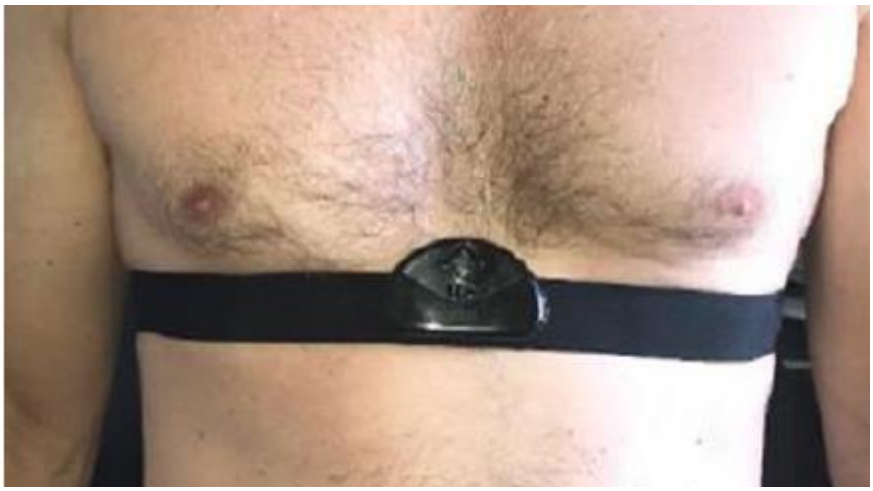
TEST PROCEDURE

Test participants wore the OBAN-PSM system (Figure 1) during two days of CBRN training at the Center for Domestic Preparedness, Anniston, AL. Physiological data from the OBAN-PSM system were saved from the hub and downloaded for examination for the likelihood of reasonableness of the data. Post-exercise subjective feedback of the system was obtained via survey.

Test Measurements

Standing vertical height was measured in duplicate to the nearest 0.1 cm using a stadiometer (e.g., Seritex, Inc. Carlstadt, NJ). Standing height was measured in stocking feet and standing on a flat surface, feet together, knees straight, and the head, shoulder blades, buttocks, and heels in contact with a vertical wall. Body weight of test participants wearing shorts and t-shirts was measured using a calibrated electronic

Figure 1. The Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system as worn on the body.



scale (Model 876, Seca, Chino, CA) accurate to 0.1 kg. Chest circumference measures were taken to ensure the proper sizing of the OBAN-PSM chest belt.

Brief demographic information was obtained using a self-report survey. This data were used to characterize the experience of Coast Guard personnel participating in this test.

Participants' heart rate, and skin temperature were measured by the OBAN-PSM system continuously during the training. The system has an accelerometer in the hub, however, the accelerometer data was not examined during this test. Training lasted a maximum of approximately four hours. Data collectors logged the various activities participants undertook while wearing the system. These logs of downrange personnel are shown in Appendix A. On the first day of training, test participants wore only their Coast Guard duty uniform. On the second day of training, test participants wore Level A PPE with self-contained breathing apparatus (SCBA). Some test participants did not go downrange, but all test participants wore the system, even if they served in a support role for the training exercise, and their data is included in this report.

Human Factors Assessment Survey

Participants filled out a survey on the OBAN-PSM system immediately after wearing the system (Appendix B). Similar assessments have been used previously (13) to assess the form, fit, function, acceptability, comfort, utility and durability of PSM systems. Questions are in the form of Likert rating scales, thermometer rating scales, and open ended questions.

For those who used the EUD smart phone, they filled out the Open Body Area Network Physiological Status Monitoring (OBAN-PSM) End User Device Satisfaction Survey (Appendix C).

TEST ARTICLES

Odic Inc.'s Open Body Area Network Physiological Status Monitoring (OBAN-PSM) System Overview

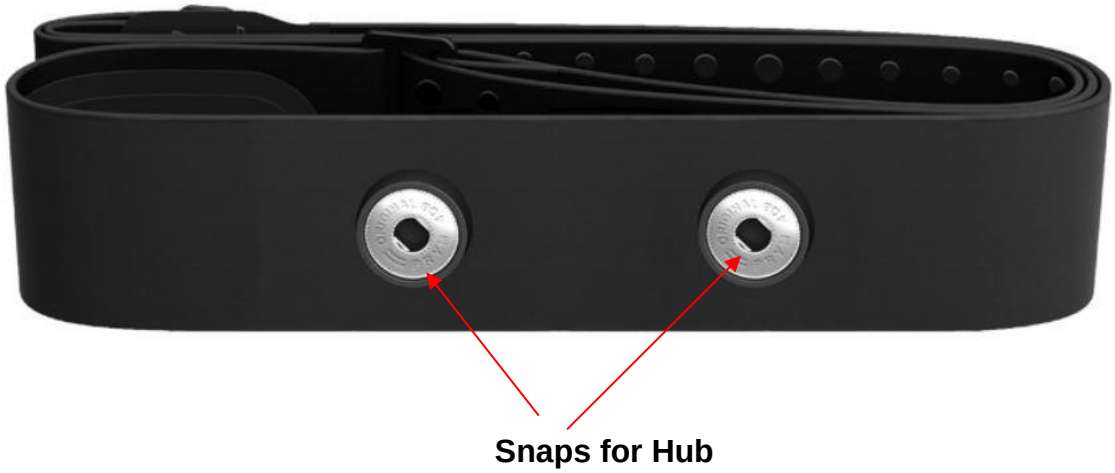
The OBAN-PSM system designed and manufactured by Odic Inc./MIT LL collects heart rate, skin temperature, body motion and body position data, and calculates estimated core temperature and a 1 to 10 scale of heat strain index (HSI). The system's hub sent a subset of this data (the heart rate and HSI data) in real time to the safety officers' or EMTs' EUD. All data on the hub was logged for download and data analysis. The system consists of three main elements.

1) An on-body chest strap and custom snap-on hub worn by individual team members.
2) A safety officers'/EMTs' display, a smart phone EUD that communicates wirelessly with multiple users' hubs to provide real time updates from the hubs.
3) A personal computer (PC) with custom software, and hub docking station that charges, enables pre-mission configuration, and post-mission download and analysis of sensor data collected by these devices.

Updates of individual team member's status were communicated between the hub and EUD via a custom data link known as the OBAN-TNB, which relies on low power, short range, and tunable transmission frequencies in the military radio bands. Alternatively, the OBAN data link can send data via Bluetooth Low Energy (BLE). Over the course of the test, testing occurred in both the TNB and BLE configurations.

Test participants wore a Polar chest strap (2017 Polar Pro model; Polar Electro Oy; Kempele, Finland) (Figure 2) as previously recommended (15), with the custom hub snapped to it. The Polar Pro is an improved model chest strap from Polar Electro Oy that became available in early 2017. It weighs 39.44 gm. This model is designed with anti-slip features, improved comfort, and an improved closure mechanism. Prior versions of the strap have been in widespread use for over two decades by practitioners and researchers in sports training, exercise physiology, and U.S. military combat training exercises (2).

Figure 2. Polar Pro chest strap (2017 model).

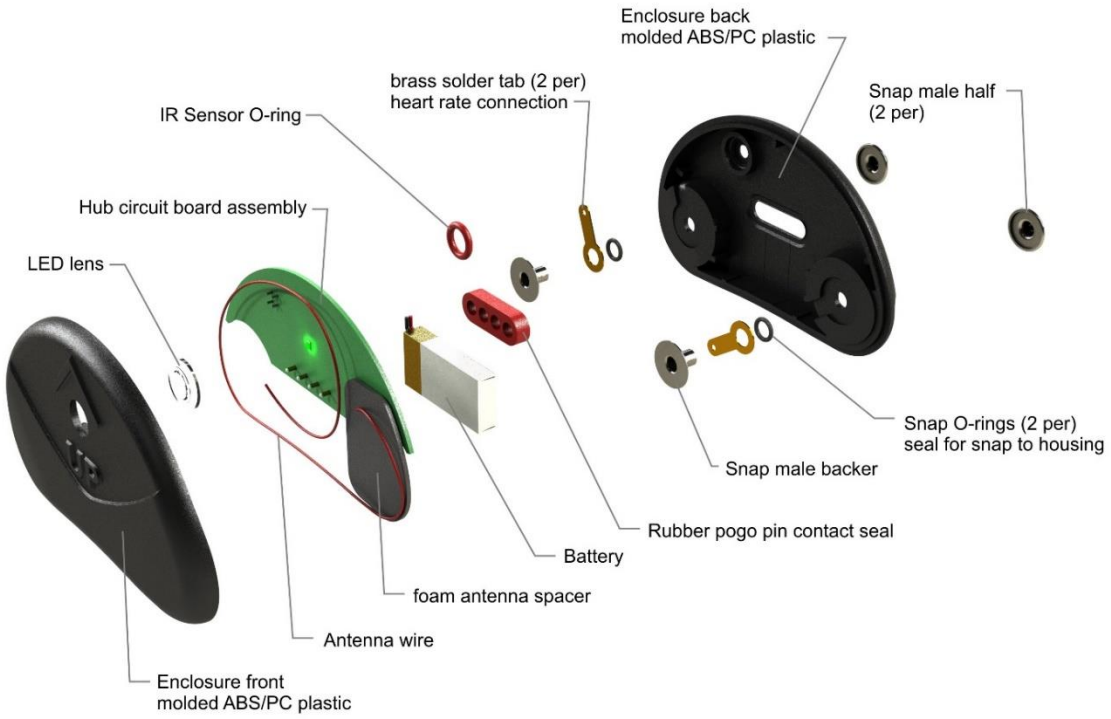


Odic, Inc. Customized OBAN-PSM system sensor hub

The OBAN-PSM hub (Figure 3) is designed to be worn under any outer garment such as the standard-issue U.S. Army infantry uniform, combat body armor, and/or CBRN PPE. It is worn against the skin under any clothing. The hub weighs approximately 20 grams and has approximate dimensions of 1.0 cm height x 7.0 cm weight x 4.2 cm depth. The figures below (Figures 4 and 5) show the hub package including top, bottom, and exploded views and their dimensions and notes of the salient package features. The hub has a minimum expected battery life of seven days when operated in mission mode, which is the default mode and the mode the end user holding the phone uses, i.e., the medical person or leader when periodically checking on his or her troops' physiological status. The OBAN-PSM system actively acquires heart rate, skin temperature, and accelerometry data using sensors located within the customized hub. Skin temperature is monitored via a non-contact infrared sensor on the skin-side of the hub, and heart rate is calculated from electrocardiogram (ECG) signals picked up from the skin transmitted through the Polar Pro chest strap electrodes. Acceleometry sensors record position data. The hub contains 1 GB of non-volatile memory to support up to seven days of data-logging. A red/green bicolor light emitting diode (LED) indicates battery charge status while attached to the dock and is off when off-dock. An orange indicated light indicates a problem with that hub.

Figure 3. The Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system sensor hub.

Figure 4. The Open Body Area Network – Physiological Status (OBAN-PSM) system sensor hub (exploded view).



Radio Systems – Communications between medical monitor and those wearing the system

The hub includes two low power data links that are mutually exclusive of each other, only one of which is available depending on configuration. The first link consists of the tactically-acceptable TNB radio connecting the safety officers' or EMT's display with all of the individual hubs in use. These radios are capable of sending data updates over approximately 20 meters, a range that is thought to be advantageous in terms of covertness and low power. The safety officer or EMT either manually queries (automatic updates are possible if set) the health status of team members by pushing a tab on the screen of the EUD smart phone. The second link is the BLE radio that sends heart rate and heat-strain information to a safety officer or EMT within range. The PC has firmware that allows one to switch the PSM hubs communication mode upon configuration to be either TNB or BLE. The safety officer's or EMT's device uses a custom OBAN TNB radio board or the phone's integrated BLE radio, depending on the mode configured for operation.

Safety Officer/Emergency Medical Technician (EMT) Display

The OBAN-PSM safety officer's or EMT's display is on a smart phone (Figure 5).

This device consists of:

1) A standard Android-based Moto Z phone (Motorola, Inc.; Schaumburg, IL).
2) The standard Motorola-provided Moto Mod development back.
3) A custom OBAN radio board (shown in green) that snaps into the Moto Mod back (the BLE mode uses the phone's BLE radio).
4) A see-through protective case (Figure 6).

Figure 5. End user device (EUD) components.

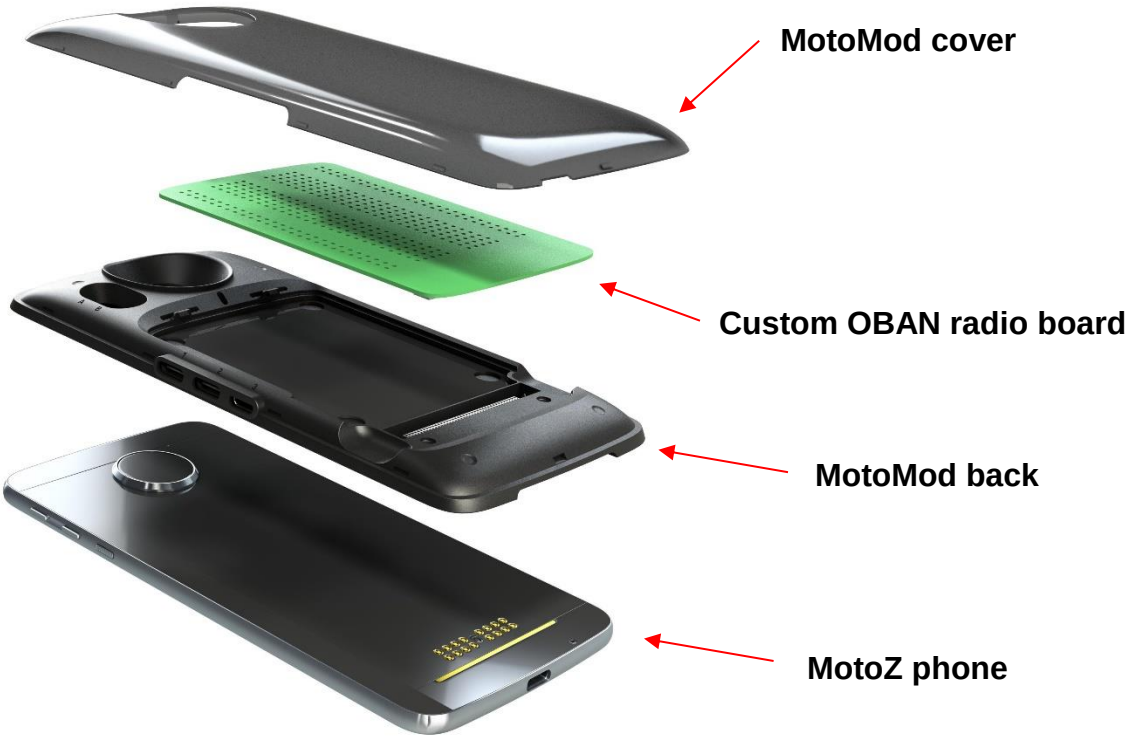


Figure 6. Phone with its protective case.

The OBAN-PSM EUD display provides an overview of the troops' thermal- work strain. The thermal work strain is the Physiological Strain Index (PSI) developed by Moran et al. (10) re-labeled HSI (for Heat Strain Index) (13,16).

HSI is a weighted sum of heart rate (HR) and core temperature (Tc), such that:

- HSI = 0 if HR is 71 bpm or lower AND Tc is 37.1 C or lower
- HSI = 10 if HR is 180 bpm or higher AND Tc is 39.5 or higher

For the OBAN-PSM, Tc is estimated from a series of minute-to-minute heart rate observations. Estimation from heart rate uses the method of Buller et al. (1) which applies an empirically-parameterized Kalman filter model to the heart rate data. In the case of the OBAN-PSM system, HSI uses direct measurement of HR calculated from the Polar strap collected ECG. Skin temperature is monitored and logged, but not used in the HSI calculation.

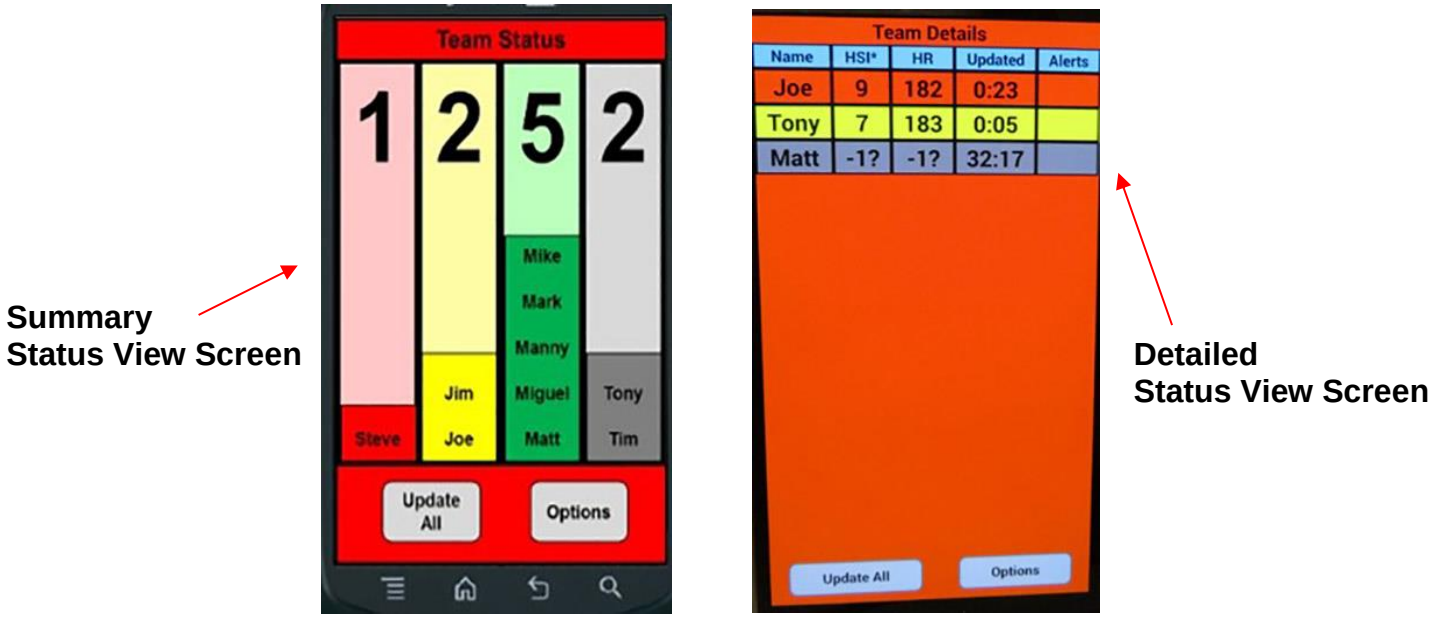
Key characteristics of the OBAN-PSM display include the following:

- Green indicates an HSI between 0 and 6, which is considered to fall within normal range.
- Yellow indicates an HSI of 7 or 8, a level of elevated concern that may require attention ("Look").
- Red indicates an HSI of 9 or 10, a level of high concern that merits immediate attention ("Take Action").
- Gray indicates the lack of recent data.
- The "Team Status" title and any background are color-coded to match the highest HSI on the team.
- The display can be set to automatically request updates from the squad hubs at regular intervals (e.g., every 30 seconds). In addition, updates can be requested

manually for all individuals at once. Whether the display receives an update response from an individual hub depends on whether the hub is being worn on-body and within range of the EUD display.

Examples of the display are shown below (Figure 7). Vertical bars correspond to the HSI ranges. Within each vertical bar are the names (could be call numbers or test participant numbers) of the individuals that have the listed HSI, as well as a visually prominent number indicating how many individuals fall within that range. A second screen, a detailed status view, is reachable from the first screen by swiping left. It contains a table listing the name of each individual along with his or her HSI score, heart rate, and the time elapsed since the last update was received.

Figure 7. End user device (EUD) display**.**



Configuration by Personal Computer (PC) and the OBAN-PSM System Custom Hub Dock

The configuration PC consisted of a Windows 7 laptop computer running the custom configuration software for the OBAN-PSM, and the PSM charging dock connected via Universal Serial Bus (USB). The PC is intended for use in off-body "configuration mode" in a controlled environment (such as at the Command Post) before or after the mission. Prior to the mission, all hubs in the OBAN-PSM are snapped into the dock (Figures 8 and 9) and connected via USB to the configuration PC. The hubs and EUD are configured for data collection and team member assignment. The dock size is approximately 44.5 cm (length) x 29.0 cm (width) x 6.6 cm (height); 7.6 cm (height) with hubs snapped in, and can be placed horizontally, or hung vertically, and the rear of the enclosure has a handle incorporated. Space is provided above each hub for standard 1.9 cm wide tape or other labeling material to indicate the user of the hub. The dock connects to the PC via a single USB cable, and requires a separate wall adapter for power. Up to 15 hubs can be charged simultaneously on the dock, and charging status is indicated via the bicolor LED on the hub. Following the mission, OBAN-PSM hubs are removed from their wearers and snapped into the dock to downloaded data for visualization and analysis, as well as to check the devices for correct operation and to charge batteries. Snaps hold down the hubs to make the USB connection, providing a data link. Hubs can be unsnapped by inserting the provided lever tool into the lever hold in the upper-right of each hub location.

Figure 8. Dock showing hub insertion slots and USB/power connections to personal computer (PC)**.**

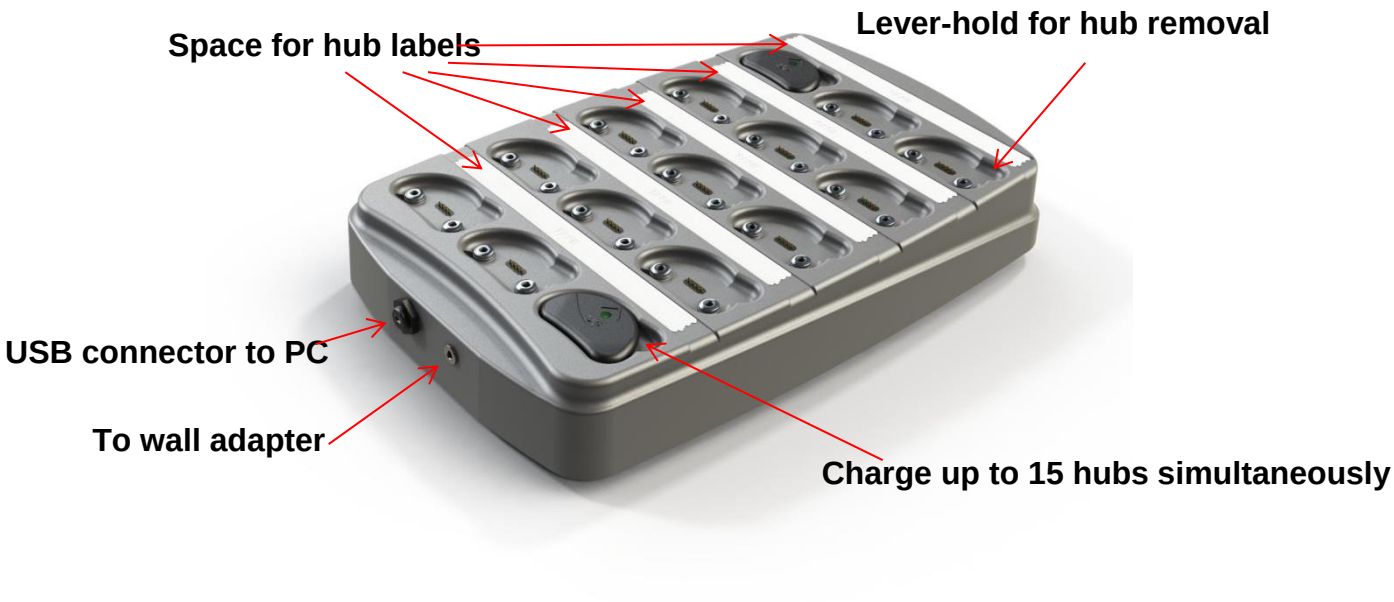
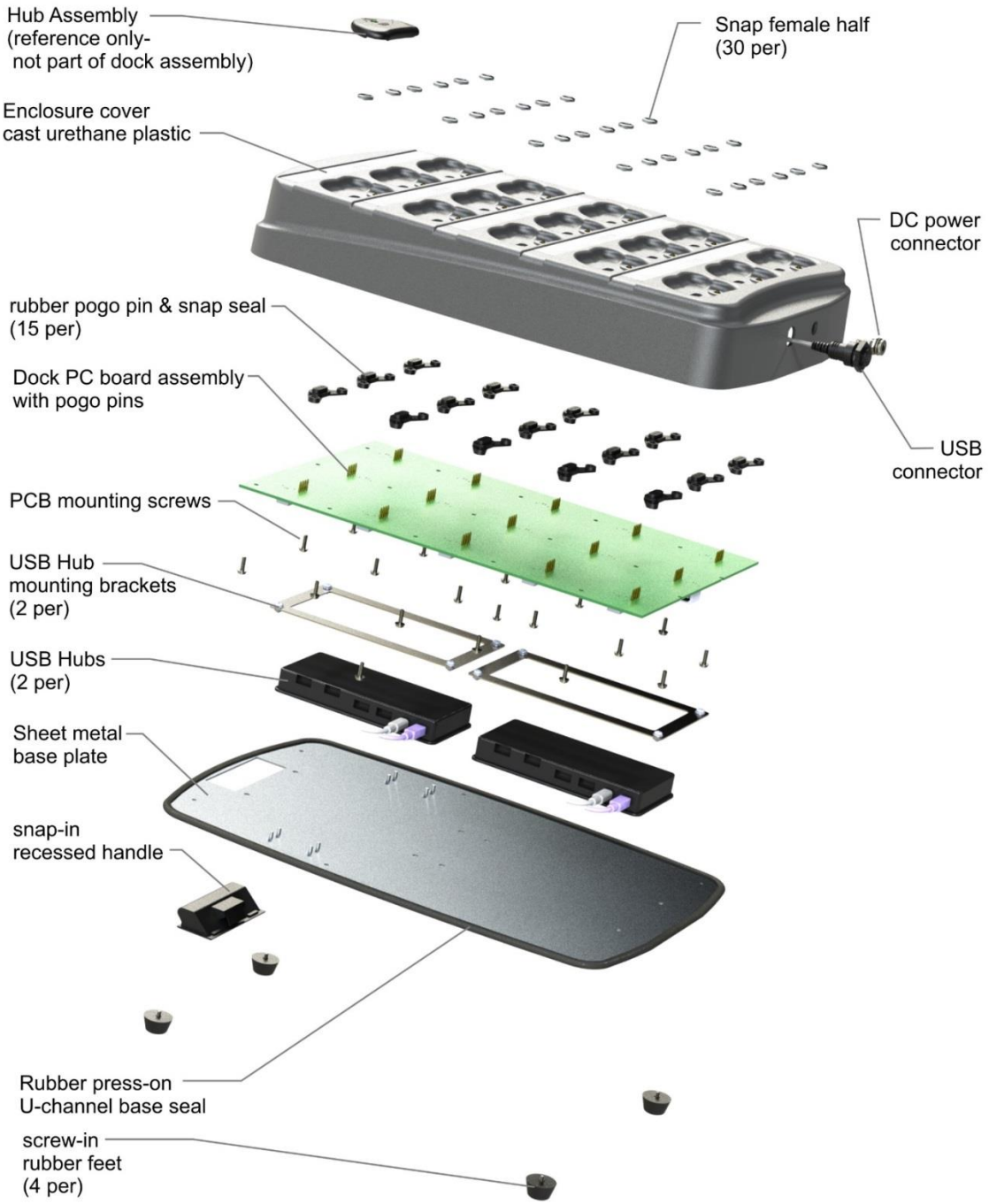


Figure 9. Dock showing hub insertion slots, and USB power connections to personal computer (PC) (exploded view).



DATA ANALYSIS

Individual time series data in five second intervals were graphed for heart rate and skin temperature by device. Means and standard deviations (SD) were calculated from the subjective rating scales. Frequencies of responses with proportions of various responses were tabulated for the survey data.

RESULTS

REASONABLENESS OF PHYSIOLOGICAL MEASUREMENTS

This field test was conducted under simulated but realistic CBRN conditions. The OBAN-PSM system was used without additional control devices or control methods. Therefore, no gold-standard device was used during this test. Evaluation of the physiological data obtained from the OBAN-PSM system was subjectively examined for reasonableness for the intensities of exercises the test participants engaged in. Figure 10 illustrates the data by device collected on the first day when the TNB mode of communication was used, whereas Figure 11 illustrates the data when the BLE mode of transmission was used. Data shown in the figures were data down-loaded from the hubs post-exercise. Therefore, transmission mode, TNB vs. BLE mode did not interfere with data recorded on the hub. There was no reason to suspect there would be an issue but this test confirms that hypothesis.

No data was available on the amount and nature of the data transmitted to the EUD, for example number of packets transmitted, or missing packets. When users carrying the phone were in range of the test participants they were monitoring (less than 20 meters away) they reported being able to pick up the physiology with no issues regardless of whether they were using the TNB mode or the BLE mode of transmission.

Heart Rate

The heart rates obtained were reasonable. There were no values below 50 beats per minute (bpm) or above 175 bpm. While some test participant/hub data shows some variability, it is within reason and this variability could be reduced by averaging this heart rate data over 15 seconds or a minute rather than 5 second intervals. These averaged values would be acceptable for mission planning decisions or field clinical assessments of the monitored personnel.

Figure 10. Time series measurements by hub number of heart rate and skin temperature for the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system operating in the Tunable Narrow Band (TNB) mode on Day 1.

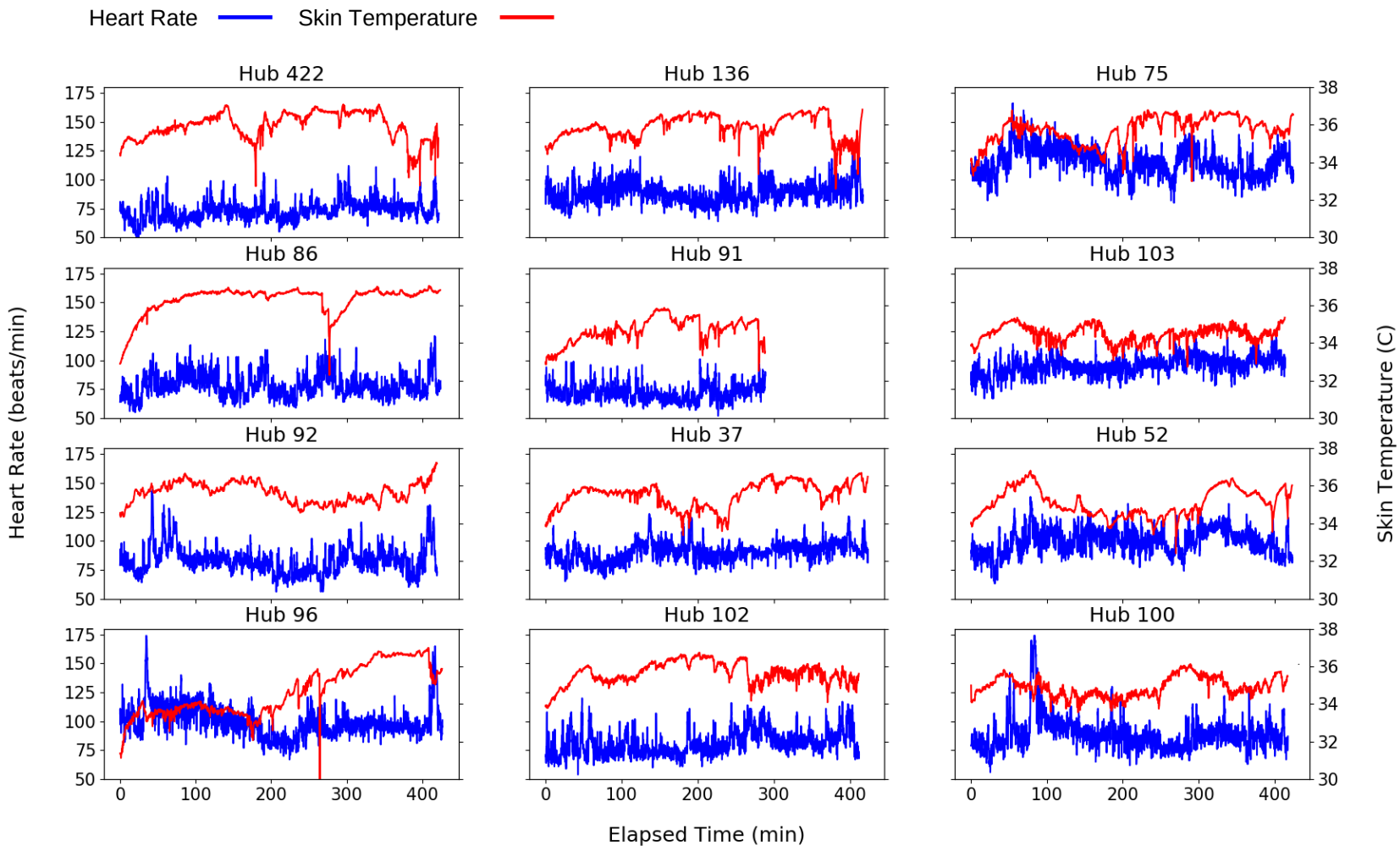
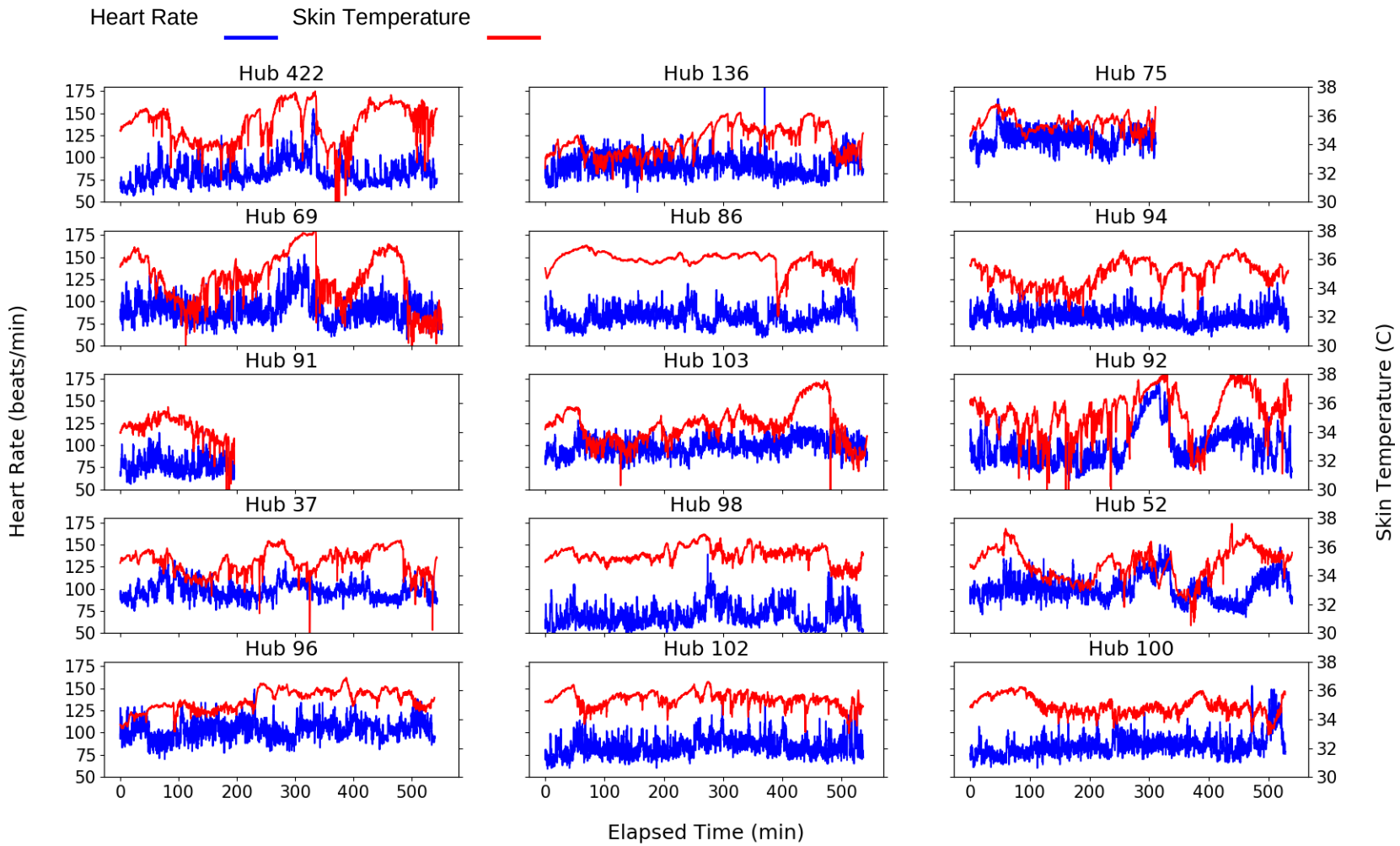


Figure 11. Time series measurements by hub number of heart rate and skin temperature for the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system operating in the Bluetooth Low Energy (BLE) mode on Day 2.



Skin Temperature

Skin temperature values displayed noise. In Figures 10 and 11 it can be seen that skin temperature values were reasonable and stable in some cases whereas in other cases were more variable than desired. Skin temperatures were within the range one would expect, 30º to 38º C but should not change rapidly, especially given the nature of these training scenarios where there was no rapid external heating or cooling. For example, the readings from Hub 86 (in both Figures 10 and 11) with the exception of the dip just prior to 300 minutes (Figure 10) is what would be expected. A relatively smooth increase was observed as the device warms to the skin temperature with small fluctuations but generally stable skin temperatures. This was especially true on Day 1 when exercises were performed without PPE (also while data was being transmitted via TNB). In contrast, the majority of skin temperature measurements were noisy, especially on Day 2 when wearing PPE (also while data was being transmitted via BLE). It should be noted that even on Day 1, some data were not believable; e.g., Hubs 75 and 52. On Day 2 only Hub 86 appears to produce reasonable, relatively stable data.

HUMAN FACTORS ASSESSMENTS

Ease of Donning

The vast majority of test participants (93.8%) were able to put the system on themselves after brief instructions. One test participant was initially unsure of how to wear the system, specifically where the hub connected to the chest strap and how it should be positioned on the chest. This person was informed by the test staff that the hub should be positioned in the center of the chest. After this was done there were no issues regarding integrity of the data from that hub as assessed by the test staff using the system's EUD, i.e., the system's phone. Another test participant snapped the hub on the belt upside-down. This test participant was shown the labelling and believed a simple mistake was made on his part and no change to the system was necessary.

Fit

Test participants generally reported that the OBAN-PSM system fit them comfortably. Test participants were instructed and allowed to adjust the strap so that it would fit comfortably, snug but not too tight, with the only requirement that a good heart rate signal could be detected by the EUD. No test participant had to loosen or tighten the strap to obtain a better signal. The only fixes were to reposition the system slightly on the chest or to remind participants to wet the electrodes. When test participants were asked to rate the overall fit of the system, and the fit around the chest and the back, all ratings were positive (see Table 1) and the mean score was equivalent to "Like Moderately."

Table 1. Fit ratings of the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system on various body area regions.

Body Area of Fit	Mean ± S.D.
Overall	6.1 ± 1.0
Chest	5.5 ± 1.6
Back	6.4 ± 0.8

1 = Dislike Very Much, 2 = Dislike Moderately, 3 = Dislike Slightly, 4 = Neither Like nor Dislike 5 = Like Slightly, 6 = Like Moderately, 7 = Like Very Much

Table 2 compares the reported tightness-looseness of fit of the OBAN-PSM system. A rating of "4" is optimal, while values less than "4" represent feelings that the system was too tight on the body, and values greater than "4" indicate the system was too loose on the body. Table 2 shows the average rating was between "Slightly Tight" and "Neither Tight nor Loose" indicating that the subjective fit was appropriate. The objective fit is the ability to detect heart rates for transmission with a belt not fitting too tight. This was done successfully during this test.

Table 2. Tightness-looseness ratings of the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system.

Body Area of Fit	Mean ± S.D.
Overall (*n* = 15)	3.3 ± 1.0
Chest (*n* = 15)	3.2 ± 0.9
Back (*n* = 14)	3.5 ± 0.7

1 = Very Tight, 2 = Moderately Tight, 3 = Slightly Tight, 4 = Neither Tight nor Loose, 5 = Slightly Loose, 6 = Moderately Loose, 7 = Very Loose

There were no comments with regard to fit, per se. Some individuals commented about skin irritation in the fit section, but repeated their comments when asked about skin irritation and discomfort. Those comments are described below.

Comfort

The overall comfort and specific area comfort levels could have been impacted by specific system components' impact on the body, which in turn could be related to clothing or gear worn on top of the OBAN-PSM system. That said, all comfort ratings were rated between "Neither Comfortable nor Uncomfortable" and "Slightly Comfortable" as shown in Table 3. The lowest rated, most problematic area is the belt material which caused skin irritation described in more detail below. For all components, there was significant variability between test participants' ratings as evidenced by the standard deviation scores greater than 1.0 on a 1 to 7-point scale. The lowest rated component, belt material, had the highest variability in ratings. These

comfort ratings are likely influenced by the impact of the system on the body (see next section below in this report for those ratings). However, in general, these ratings may be viewed as more detailed comfort ratings as evidenced by the 75% of test participants that felt the system was “Neither Comfortable nor Uncomfortable” or more positive in their ratings. Therefore, it is likely that when the system is not causing skin irritation, it is a comfortable system to wear.

When asked in an open-ended question if there were “certain areas that caused discomfort, please describe why they were uncomfortable”, the following responses (7 of the 17 test participants) were obtained:

- “Just uncomfortable.” (*n* = 2)
- “The monitoring device stuck out too much and it felt uncomfortable.” (*n* = 1)
- “Edges of the belt and rubber grips caused skin irritation.” (*n* = 1)
- “Mostly caused discomfort on the sides of the body, such as itching and skin irritation.” (*n* = 1)
- “Chest band stuck to the skin, and when taking it off, peeled off some skin.” (*n* = 1)
- “Chest strap pushed into the chest and this was compounded by interfering with the fit of my sports bra.” (*n* = 1)

Similar comments were voiced (and listed below) when specifically asking about skin irritation or other discomfort problems. When test participants were asked if there was a particular activity that caused skin discomfort, all but one said there was no particular activity. The one test participant that said there was an activity indicated that sitting down was most uncomfortable.

Table 3. Comfort ratings of the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system components.

Comfort of System Component	Mean ± S.D.
Overall System	4.7 ± 1.6
Electrodes	4.6 ± 1.3
Area Under the Hub	4.4 ± 1.5
Belt Material	4.2 ± 1.8
Chest Strap Fastener	4.8 ± 1.5

1 = Very Uncomfortable, 2 = Moderately Uncomfortable, 3 = Slightly Uncomfortable, 4 = Neither Comfortable nor Uncomfortable, 5 = Slightly Comfortable, 6 = Moderately Comfortable, 7 = Very Comfortable

Impact of the System on the Body

When test participants were asked if there was an overall negative impact on the body from wearing the system, 37.5% of test participants felt there was at least some negative impact on the body. When test participants were asked if the system caused any skin irritation or other discomfort, a majority (56.3%) of test participants responded that it did cause skin irritation or discomfort.

The following open-ended comments regarding impact on the body were given:

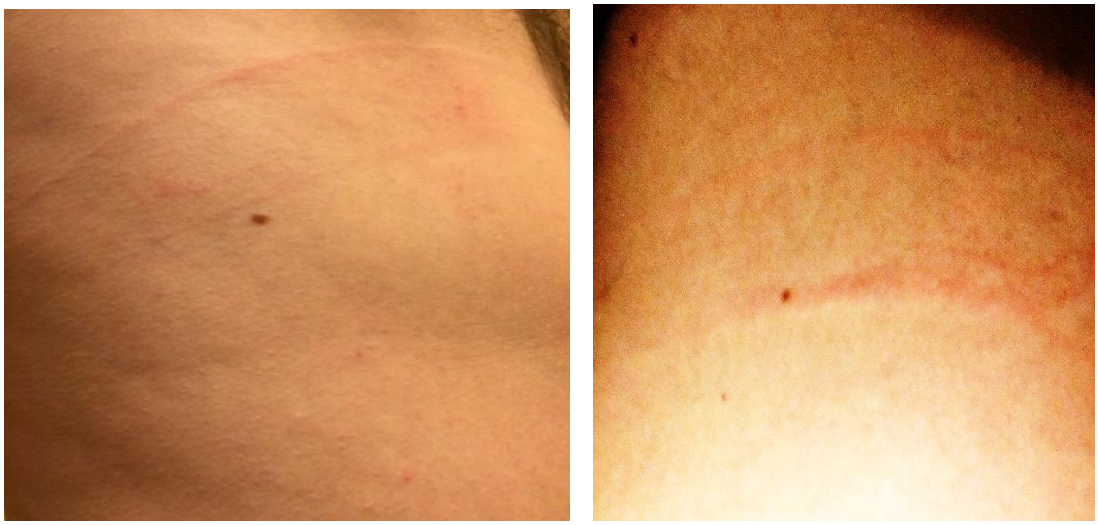
- "After sweating the chest strap stuck to the skin and started to itch." (*n* = 1).
- "The chest strap felt like it adhered to the skin. And then when you had to "peel" it off it causes discomfort." (*n* = 1).
- "The chest strap irritated both the chest and sides of the body which caused itchiness, and this was especially a problem in the hot weather." (*n* = 1).
- "After several hours, the chest strap caused itchiness and irritation." (*n* = 2).
- "On the chest there were scratches and irritated skin caused by the chest strap." (*n* = 1).

There was only one female test participant, and she was one of the 56.3% who responded that the chest strap caused skin irritation and discomfort. Her open-ended comment regarding this discomfort was:

- "There was discomfort in the underarm area, the chest, and in my breasts. The chest strap left three inch red lines where the system pressed into my chest." (*n* = 1).

A male test participant took a picture of himself and provided it unsolicited of the skin rash/irritation that formed after three hours of wear in a standard uniform with t-shirt (Figure 12). While this rash is not very severe, it began developing after a short time wearing the system without significant physical exercise or sweating that accompanies high activity rates. He was not wearing a backpack, body, armor, or CBRN PPE, all of which can exacerbate skin rashes and irritations.

Figure 12. Skin rash/irritation after approximately three hours of wear in standard uniform with t-shirt. Photos used with permission courtesy of Test Participant #5 taken of left and right sides of his chest.



Assessing the system by component (Table 4) to determine the most problematic area, it can be seen that the belt material was the most problematic. However, it should be noted that this problem rating was voiced by only two individuals, one who said it had an “Extreme Negative Impact” and the other that said it had a “Moderate Negative Impact” on the body.

Table 4. Impact of the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system and its various components on the body.

Impact on the Body	(Mean ± SD; *n* = 16)
Overall System	4.5 ± 0.9
Electrodes	4.9 ± 0.4
Area Under OBAN-PSM Hub	4.7 ± 0.8
Belt Material	4.2 ± 1.1
Chest Strap Fastener	4.8 ± 0.6

1= Extreme Negative Impact, 2 = Very Negative Impact, 3 = Moderate Negative Impact, 4 = Slight Negative Impact, 5 = No Negative Impact

Impact of the System on Military Performance

Time spent wearing CBRN PPE ranged from 0 hours to 8 hours. Twelve individuals indicated wearing CBRN PPE from 15 minutes to 8 hours with a mean time of 3.0 ± 3.4 hrs. Ratings on the impact on military performance are tabulated in Table 5, broken down by wearing CBRN PPE and not wearing CBRN PPE or anything else, for example, military protective equipment or carrying backpacks. Ratings included the impact of wearing the system without CBRN PPE and while wearing CBRN PPE. A 5-point scale was used to assess the impact, with "1" being "Extreme Negative Impact" to "5" being "No Negative Impact."

Acceptability

When test participants were asked "would the system be acceptable to wear for twenty-four hours or longer for military training" 87.5% responded that it would be acceptable. For the two individuals that responded it would not be acceptable, both said the reason is because of the skin irritation that the chest strap causes. They both said that if these problems were alleviated they believed that the system would be acceptable to wear for twenty-four hours or longer during military training or missions.

When test participants were asked if they would wear the system if it provided better medical care during training and actual missions, 93.8% said they would wear the system. For the one individual that said he would not wear the system, even if it provided for better medical care during training or actual missions he stated that the system is:

- "too annoying and irritating on the body to wear."

Table 5. Impact of the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system on military performance for various equipment configurations.

Impact on Military Performance	Mean ± S.D.
Effect While Wearing No Body Armor/No CBRN PPE/No Backpack	
Overall (n = 15)	4.9 ± 0.5
Ease of motion (n = 15)	5.0 ± 0.0
Ease of body movement (n = 12)	4.9 ± 0.5
Bending (n = 12)	4.9 ± 0.3
Effect While Wearing CBRN PPE	
Overall (n = 12)	4.9 ± 0.3
Ease of motion (n = 12)	4.9 ± 0.3
Ease of body movement (n = 12)	4.9 ± 0.3
Bending (n = 10)	5.0 ± 0.0

1 = Extreme Negative Impact, 2 = Very Negative Impact, 3 = Moderate Negative Impact, 4 = Slight Negative Impact, 5 = No Negative Impact; CBRN = Chemical, Biological, Radiological and/or Nuclear, PPE = Personal Protective Equipment

When test participants were asked if they would wear the system if the use of the system would allow for enhancements to training and actual mission performance, 87.5% said they would wear the system if it provided enhanced training or mission performance. When one of these two test participants who said they would not wear the system provided a written open-ended response (it was the same individual who responded negatively regarding better medical care), he responded similarly to this question regarding potential enhancement to training or missions, i.e., he said:

- "it is too annoying and irritating on the body to wear."

The second individual who said he would not wear the OBAN-PSM system even if it provided enhancements to training or mission performance said he did not believe that there would be a benefit in using this system because the way it needed to be used in real-time is for the leader or health care provider having to go down-range using the EUD to be in physical close proximity to the wearers' of the OBAN-PSM system. He said a leader or health care provider would never go down-range into a contaminated zone just to monitor a person's physiology and likely put himself/herself at risk of CBRN exposure or from overheating by being forced to be encapsulated in PPE himself or herself. This test participant believes that long range communications would be the only way to enhance training or mission effectiveness. His comment regarding why he would not wear the system was:

- "No data received at command location."

When test participants were asked if they would wear the system if it allowed medical or leadership to make better decisions regarding medical intervention and possibly preventing injuries from happening in the first place either in training or actual missions the same 87.5% said they would wear it. The same two individuals as above when asked why they would not wear it responded with the same answers as above regarding this preemptive medical use case example during training and actual missions.

The same 87.5% of test participants would recommend this system to others if it provided for enhanced or earlier medical care through the use of medical situational awareness or if it enhanced training or mission effectiveness. One test participant who said that he would recommend the system to others caveated his response with the comment "that problems with skin irritation need to be overcome." It is likely that the other participants who would not wear it assumed that these negative irritating and annoying effects they experienced could not be improved upon or that the longer range communications issues could not be fixed.

Affective Feelings When Wearing the System

Regarding affective feelings, the OBAN-PSM system was always rated above the neutral point (0 score) towards the positive adjective on each affective state scale (Table 6).

Table 6. Affective feelings of wearing the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system.

Affective State	(Mean $\pm$ SD; n = 16)
Worried/Confident	5.6 $\pm$ 4.6
Feel Device/Wear and Forget	3.5 $\pm$ 6.5
Causes Harm/Is Beneficial	5.6 $\pm$ 4.4
Feels Strange/Feels the Same	4.8 $\pm$ 5.5
Restricts Movement/Freedom to Move	6.9 $\pm$ 4.0
Secure/Insecure	6.1 $\pm$ 4.4

-10 to 0 Negative Affective State, 0 to 10 Positive Affective State

Durability of the System

Throughout the test, test participants and the testers noted if the system broke or came apart. No system broke. It was observed that all systems stayed intact.

USE OF THE PHONE TO MONITOR

The two safety officers reported that they spent 2 to 8 hours (the survey category) using the phone, while the EMT spent 30 min to 2 hour (the survey category) using the phone. When they were asked what type of device they would like to use as the EUD, one test participant said this phone, one said an iPhone and another said having both a phone (model not specified) and a computer. The individual who stated they wanted it on the iPhone stated that it would be easier for him because he is already very familiar with Apple (Apple, Inc., Cupertino, CA) products and operations like navigating would be easier. He stated that ideally, there would be a cross-platform App that would include an iOS (Apple product) and an Android (Google product; Google Inc., Mountain View, CA) to allow users to use their phone of choice rather than having a phone just dedicated to this PSM system.

With regard to function of the App on the phone all said that it worked without crashing and the speed of the program was fast enough. Two test participants stated that the App was "Very Easy" to use while the third test participant said that it was "Somewhat Easy to Use." All three test participants indicated that the screen was very easy to read without having to read through the clear plastic of the protective phone case, but reading the EUD phone through the case was difficult. The comments to the question: If the system was difficult to read please explain what conditions made it difficult. Here, all three test participants mentioned that reading through the clear plastic of the case made it difficult. Therefore, it is most likely that the two participants who provided their rating with an ease of reading were providing their ratings from viewing the phone directly. It is likely the third participant provided their rating taking into account viewing through the clear plastic of the protective case. Figure 13 illustrates how those evaluating the data of the OBAN-PSM system used the EUD phone. From the figure it may be observed that this test participant has the empty plastic case worn on his waist belt while viewing the data directly off of the phone.

All three test participants (i.e., the two safety officers and the EMT) stated that monitoring for Coast Guard Strike Force personnel operating in a CBRN environment would require a long range communication capability to push physiological data from team members wearing the system to a decision maker some distance away, ideally outside of the contaminated "hot zone." While, for this test, test participants saw the usefulness of the OBAN-PSM system in general (one said extremely useful while the other one said very useful), they stated that use of the phone without a long range communications capability would not meet the necessary concept of operations (CONOPS) of CBRN missions. All three test participants felt the use of the OBAN-PSM system if it were available to them, they would be very likely to use the system. One participant included the following comment in the open-ended comment section associated with the likely to use question. His comment was:

Figure 13. Use of the end user device (EUD) phone by the Safety Officer to monitor personnel wearing the Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system.

"I chose "Very Likely" because it is a great real time data set to have on your downrange personnel. Personnel safety is the top priority and this device aids in that area. To be truly effective and implemented the range of transmission would have to increase so medical personnel can monitor their downrange team from the support zone (Safety Zone)."

When test participants were asked to comment on "How You Would Use the Application?"; there were two responses:

- *"Emergency response with Level A and B suits."*

- *"The EMT or medical personnel would monitor the team from the Support Zone. When downrange member's level of concern for heat strain (8 or 9 on the HSI) the EMT would radio the downrange team and pass along the HSI and heart rate information and ask if the response team member feels safe and is willing to continue with their mission."*

When test participants were asked if other features would make the app more useful all three responded yes, there are other features that they desired. When asked what these features were, the following responses were given:

- Have alerts/alarms other than for HSI such as for low or no heart rate. (*n* = 1).
- Audible or vibration alerts/alarms. (*n* = 1).
- Customize for stress level operations. (*n* = 1).

USE OF THE CHARGING DOCK

The hubs being charged were not all either fully charged OR the indicator light that signified those particular hubs had been properly charged did not work despite being charged for over 15 hours. On Day 1 two hubs (Test Participants' #5 and #10 (no Test Participant #10 was used)) had indicator lights that remained red and on Day 2, one hub had an indicator light that remained red (Test Participant #5) (Figure 14).

Figure 14. Hubs charging in charging dock after 15 hours of charging. On left – Day 1; two hubs with red lights and on right – Day 2; one hub with red light on.

In Figure 15 it is seen that after shipping, a charging dock cracked during transport by airplane while packed in a 1510 Pelican Case (Pelican Products, Inc., Torrance, CA). This Pelican Case did not have custom-fitted foam padding for the charging dock, but the charging dock was secured inside the Pelican case. In addition, in Figure 15 it may be seen that the USB connect was pushed into the body of the docking station. The plastic nut holding the connector in place broke off. A temporary fix by research staff was done to replace the broken plastic nut with a metal nut to secure it (Figure 16). It is hypothesized that the docking station shifted inside the Pelican Case while being shipped as it was undamaged when packed but broken when unpacked. At least two USB connects have been shown to break during normal use and during shipping of the charging dock. In both cases the charging dock had been damaged while in normal office or shipping conditions, not harsh conditions that might be expected in the field during military use. This shows that the charging dock as currently designed and manufactured is too fragile for normal military use. When the equipment was fitted inside custom-fitted foam inside a Pelican case no damage occurred during shipping.

Figure 15. Damage in red circles to the charging dock USB connector and the plastic frame itself.

Figure 16. Fix with a metal nut to the pushed-in (broken) USB connector with a metal nut.

SOFTWARE

The version of the OBAN-PSM software used was compatible with Microsoft Windows 7 operating system. All U.S. Army computers are moving to have Microsoft Windows 10 operating systems or higher and the next version of the OBAN-PSM software must operate on these operating system versions. In addition, all Security Technical Implementation Guidelines or STIGs need to be met for the software to be Defense Information Systems Agency (DISA) (Ft. Meade, MD) compliant. The purpose is to prevent vulnerabilities to the software of the system and the OBAN-PSM software itself from outside malicious attacks. The software used on the current test used one government computer that was non-networked. Newly developed software that is Windows 10 or later compatible must have all STIGs met or an approved mitigation strategy to prevent vulnerabilities in the OBAN-PSM system software or the operating system that the computer is running on.

Downloading and Processing Data

The current OBAN-PSM post-processing software parses the down-loaded data and creates files which include two Microsoft (Redwood, WA) Notepad files. The first of these is a system information file that is mostly unreadable for a non-user, although it does include certain information at the top such as creation date, radio mode (BLE or TNB), component identification number, etc. The second file is a short easily readable file that displays information for the user about the system. For example, the hub serial

number, the test participant it was assigned to, radio mode etc. The other three files are csv files which can be viewed with Microsoft Excel, that contain the data organized by variables across the columns and time entries in the first column, with data continuing down the rows as data is accumulated over time. The first data file is for accelerometer measurements (not examined in detail in this report), the second data file is one that contains heart rate and associated HSI (See Figure 17). The third data file contains skin temperature. All data files use a UNIX time stamp as can be seen in Figure 17.

Three improvements that would make the data files easier to use for operational users would be to first combine all three Excel files into a single file. This would allow direct comparison of the various physiological and status parameters (heart rate, skin temperature and body motion/body position) and how they may be associated with changes in one measure compared to another at a glance. The second improvement would be to change the time stamp into actual date-time (e.g., Date: Hour: Minute: Second). The downloading parser program should have a function that includes this time conversion and grouping data into a single Excel file with a single command, eliminating the need for the end-user to do a number of post-processing steps. Finally, within the Excel file it should have the hub number or test participant number rather than have to cross-reference the Notepad file.

Figure 17. Example of processed data from Open Body Area Network – Physiological Status Monitoring (OBAN-PSM) system hub.

Time	HR	HSI
1534941833	80	0
1534941838	84	0
1534941843	84	0
1534941848	80	0
1534941853	77	0
1534941858	75	0
1534941863	74	0
1534941868	74	0
1534941873	73	0
1534941878	72	0

DISCUSSION

The results of this test show that the heart rate data obtained from the OBAN-PSM system is most likely reliable and valid. These results are to be expected because the heart rate sensor used Polar Oy heart rate technology which has been proven to be reliable and valid for years (6, 8, 17). Regardless, the OBAN-PSM system as a whole should undergo a scientifically-based reliability and validity test comparing the OBAN-PSM technology to gold standard sensor system (for validity of measures) while using a

test-retest design (for reliability of measures). That reliability/validity test using this current system should entail a range of activities with corresponding heart rates (i.e., sleeping to extreme vigorous exercise in young adults) is necessary. With respect to skin temperature, there were a number of spurious readings and excessive variability in measures that were not physiological possible. An examination of the sensor itself or a software fix to the system to adjust these skin temperature measurements into physiological reasonable measures is necessary. Like the heart rate sensor system, a reliability and validity of measures test over the course of likely skin temperatures while a human is wearing the system is needed.

The form and fit aspect of the test showed that the current system provoked skin irritation in some but not all individuals. For short term training and missions like those undertaken by CBRN personnel the OBAN-PSM system is probably acceptable. In general, this OBAN-PSM system was less comfortable than the Equivital™ EQ-02 system. The same questions and rating scales used on this test were used on a test with the Equivital™ EQ-02 system with personnel similarly encapsulated in CBRN PPE was used (13). There were indications that extended wear of this OBAN-PSM system, one of its intended uses, could be an issue. Compliance with wearing a system that is uncomfortable is likely to be a problem. Continued efforts to find belt systems that are more comfortable is warranted. Ideally, working the OBAN-PSM technology into wearable clothing and or watches or other accessories should be advocated. However, data accuracy is paramount for these systems to be used as intended within the CBRN community in particular and military communities in general (14, 16).

The CONOPS used by the Coast Guard Strike Teams will not allow the use of a EUD that needs to be within 20 meters of those that are being monitored. While the data from the OBAN-PSM system was thought to be valuable in decision making, without changing the communication protocol the system uses, OBAN-PSM would not be adopted. The CONOPS for CBRN operations requires downrange personnel to be encapsulated in CBRN PPE when they enter the contaminated area or hot zone. These downrange personnel are then monitored via radio with physiological and other pertinent information telemetered to medical and/or leadership personnel positioned in the clean/ cold zone for decision making. The CONOPS used by the Coast Guard Strike Teams are similar to that used by the WMD-CSTs (3) and other CBRN operators. Incorporation of OBAN-PSM into the U.S. Army's Android Tactical Assault Kit (ATAK), Nett Warrior, Leaderboard (9), or other central communications network for central viewing by medical or leadership personnel is recommended to meet the CONOPS of CBRN training and missions. The required range of between 200 and 1000 meters from the wearer of the system in the hot zone to the decision maker, typically a medical person or leader, positioned at a command post in the cold zone is needed.

The use of the HSI color-coded display was enthusiastically embraced by the safety personnel during this exercise. The easy-to-use 1 to 10 scale allowed for quick decision making on whether there is 1) little concern about the participant's health status (green indicator), 2) the need to take a look at the participant is warranted (yellow indicator), or 3) the need to examine and make a decision about a participant's

continued mission execution is necessary (red indicator). The health care providers expressed the need for simple and accurate information for quick decision making. They felt the OBAN-PSM system met that need.

Use of the phone EUD was well accepted, however the phone could not be used effectively while in its protective case. The current case is probably acceptable for protecting the phone while the user is just carrying it. However, expecting medical personnel and leaders to use the phone through the clear plastic case would not be feasible. If the phone is needed to be protected while actually being used, a more form-fitting case that is easier to manipulate through the screen is necessary.

During a briefing (personal communication with W.J. Tharion; 27 February 2019, Ft. Benning, GA) the 75th Ranger Regiment commanders (incoming: COL Peter Schull and outgoing: COL Brandon Tegtmeier) two key recommendations were made by these commanders for the OBAN-PSM system. The first recommendation was that the system has to have a forward prediction capability of who will become a heat casualty with enough time to allow for appropriate intervention. This concept has been developed with use of real-time PSM data (7) and could be incorporated immediately with the current system using the estimated core temperature algorithm (1). The commercial competitive PSM system, the Equivital™ Black Ghost system, has an estimated HSI fifteen minutes into the future function (3) using USARIEM's estimated core temperature prediction algorithm (1). A similar function could and should be made available to the OBAN-PSM system. The second recommendation was to have a gauge similar to that of a battery life indicator on how physically ready a soldier is based on his or her physiology. For example, is the soldier 100%, 70%, or 50% likely to be able to do their mission? This concept is beyond the scope of this current system because there are many aspects that go into a soldier's physical and/or overall readiness to do their mission. However, this concept is a key aspect of the Health Readiness and Performance System (HRAPS) requirements. Currently, the OBAN-PSM is targeted for inclusion as part of the HRAPS sensor system.

CONCLUSIONS AND RECOMMENDATIONS

- A reliability and validity study should be done with humans that have a range of heart rates, skin temperatures, and movements. This study should examine test - retest reliability. It should also compare values from the test device against gold standard measurements. For example, using heart rate, the heart rate from the hub should be compared against a Holter monitor like-system to determine validity of measurements.

- Skin irritation with the Polar Pro belt is an issue for some individuals. A system that is to be used for sustained operations (72 hours or more) cannot cause skin irritation if it is expected to be adopted. Effort to find a more comfortable sensor system to obtain heart rate and skin temperature signals is needed, whether it is

through a belt, clothing, or some other type of wear and forget system needs to be pursued. A sensor system needs to produce both accurate data and a willingness to be worn. A system that is comfortable to wear but outputs faulty data is not useful. A system that provides accurate, reliable and valid data but is uncomfortable will not be worn and is similarly not useful.

- The use of the HSI 1 to 10 color-coded scale was determined to be very useful and should be adopted for easy and fast decision making by medical and/or leadership personnel.

- The OBAN-PSM system needs to have a long-range communication system (threshold of 200 meters and objective of 1000 meters) to fit the CONOPS of CBRN missions.

- The protective case over the EUD phone was not acceptable for reading and manipulating the screen. A new protective case is required. It should possess the same level of protection for the EUD phone, but be easier to read through and manipulate the screen.

- The charging dock needs to be ruggedized for use in the field by military personnel.

- Software developed must be DISA compliant to be loaded onto Department of Defense (DoD) computer systems.

- When downloading data, ideally during the download, the process would automatically create a csv file that would include system information (e.g., hub number, participant number, etc.) and data (date, time, and physiological information). It would be preferable if this downloaded data did not have to be parsed into different files. However, if it does need to be parsed, the file with the physiological data should have actual date and time (date: hour: minute: second) and the associated physiological data at those time points all in one file (HSI: Heart Rate: Skin Temperature: Estimated Core Temperature: Body Motion/Body Position). This data should be synched by time to more easily allow direct comparisons of the different physiological measures at any given point in time.

- Finally, a forward prediction of thermal strain state by 10 minutes of who is likely to become a heat casualty is needed to allow time for an appropriate intervention.

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APPENDIX A

ACTIVITY LOGS

Activity Log For Day 1: 21 August 2018
First Entry

Time	Activity
10:26	Test Participants 3, 4, 5, and 7 walking to Test Building from staging area. One test participant (*not recorded)* pulls equipment wagon.
10:28	All test participants unload equipment wagon at bottom of stairs of Test Building.
10:29	Test participants walk up the stairs of test building.
10:30	Initial screening at door of first test room with gas meter by Test Participant 5
10:36	Enter room 210, begin clocking room to screen with gas meter.
10:38	Test Participant 5 enters closet in room 210 to continue screening with gas meter.
10:39	Test Participant 4 conducts chemical screening with Bio-check in a closet.
10:40	Test Participant 5 screening lab setup in main room with 5 gas meter.
10:43	Test Participant 4 collecting a suspicious substance sample in closet
10:54	Test Participants 4, 5, and 7 screening lab setup in main room. Test Participant 3 calling in results on radio.
11:01	All test participants standing in main room discussing next steps.
11:04	Test Participants 4 and 7 move closer to main room door to retrieve Hazardous Material (HazMat) Identification (ID) and First Defender chemical ID equipment.
11:07	All test participants conducting sample analyses with HazMat ID and First Defender chemical ID on far right side of room (as you look from entrance).
11:11	All test participants depart room 210 and walk down the stairs.
11:13	All test participants back at staging area near Coast Guard trailers
11:23	All test participants walking back to test building.

11:24	Walking up the stairs of test building and back into room 210.
11:26	All test participants analyzing samples with HazMat ID and First Defender chemical ID.
11:33	Test participants complete tasks in room 210.
11:34	All test participants walking down the stairs.
11:36	All test participants standing around at bottom of stairs.
11:38	All test participants walking back up the stairs.
11:39	All test participants involved in screening outside door to room 207 with gas meter.
11:40	Crack door and continue screening with gas meter.
11:41	Enter room 207, check room to screen with gas meter and radiation meter.
11:52	Move to second room, check this room to screen with gas meter and radiation meter.
11:53	Move to third room, check this room and screen with gas meter and radiation meter.
11:58	Test Participants 3 and 4 move back to second room.
11:59	Test Participants 3 and 4 move back to third room.
11:59	Test Participants found hidden closet room. Test Participants 5 and 7 enter hidden closet room.
12:01	Test Participants 5 and 7 leave hidden closet room.
12:04	All test participants leave room 207 and walk down the stairs.
12:05	All test participant enter room 100 and leave room 100 and the test building.
12:12	All test participants walk back to staging area at Coast Guard trailers.

Activity Log for Day 1: 21 August 2018
Second Entry

Time	Activity
1313	Test Participants 2, 8, 15, and 16 Walk up the stairs in the Test building.
1316	Screening door at room 210 with gas meter by Test Participant 8
1317	All Test Participants enter room 210.
1318	Clock room 210 is screened with gas meter. Test Participant 8 operates the gas meter. Test Participant 15 does chemical screening using the Bio-check. Test Participant 16 operates the radio.
1324	Test Participant 8 in closet with small lab setup. Other test participants in main room.
1325	Test Participant 8 out of closet.
1327	All test participants in main room discussing next steps.
1328	Test Participant 2 left room 210 and went down the stairs to retrieve additional Bio-check kits from equipment wagon
1329	Test Participants 8 and 15 test samples at table in main room.
1330	Test Participant 8 enters closet.
1340	All test participant are testing samples at table in main room and reporting label information over the radio. Test Participant 16 operates the radio.
1350	Assessing lab on table in main room is completed. All test participants move out of room 210 and proceed down the stairs.
1351	Test participants conduct radiation testing with radiation equipment checks at equipment wagon at bottom of stairs.
1356	All test participant walk back up the stairs.
1357	Test participant conduct screening at door to room 207 with radiation meter.
1358	Test participant crack door to room 207 and continue screening with radiation meter.
1359	All test participants enter first room inside room 207.
1401	Checking first room and screening with radiation meter.

1402	All test participants move to second room.
1406	All test participants checking room, screening with radiation meter and radioing in (Test Participant 16) label information.
1406	Test Participant 8 and 15 move to third room.
1407	Test Participants 2 and 16 move to third room.
1408	Test Participant 15 at closet door in third room screening with radiation meter.
1409	Test Participants 2 and 15 at closet door in third room.
1414	Test participants find hidden room in closet. All test participant enter hidden room.
1422	Test Participants 2 and 8 come out of hidden room and closet, and proceed back to the main third room.
1423	Test Participant 15 and 16 come out of hidden room and closet, and proceed back to the main third room.
1423	All Test Participants move back through second room and into first room.
1424	All test participants exit room 207 and back outside.
1426	All test participant walking down the stairs and back to staging area near Coast Guard trailers.

Activity Log for Day 2: 22 August 2018
First Entry

Time	Activity
1226	Test Participants 2 and 15 – in Level A personal protective equipment (PPE) completely put on, but unzipped.
1232	Test participants on air and PPE is completely zipped up.
1234	Test participants walking to Test Building; Test Participant is pulling the equipment wagon.
1235	Test participants at the door of Test Building. Test Participant 15 reporting description of room using the radio. Test Participant 2 is drawing a diagram of the room.
1237	Test Participant 15 screens door area with gas meter.
1239	Test Participant 15 cracks door and checks area with gas meter.
1240	Test Participant 15 opens door and both test participants enter Test Building lobby area.
1242	Test participants are standing in the lobby with Test Participant calling in information on radio.
1244	Test participants walk along hallway on northwest side of building, coordinating location with map of building they have been provided and are carrying. Test Participant 15 conducting screening checks with gas meter.
1246	Test participants walk along hallway on southwest side of building, coordinating location with map of building they have been provided and are carrying. Test Participant 15 conducting screening checks with gas meter.
1247	Test participants stopped at far south corner of the building to inspect two 55 gallon drums. Test Participant 15 uses radio to call in descriptive information.
1250	Test participants take readings of the 55 gallon drums and radiation meters. Test Participant 15 operates the two meters, Test Participant 2 is drawing a map of the location on a sketch pad.
1253	Test participants walk past the drums and around the south corner of the building.
1254	Test participants walking along the hallway on the southeast side of the building. Test Participant 15 conducting screening checks with gas meter.

1258	At a table in the lobby near the east corner of the building, Test Participants take gas reading of a spray bottle that was located.
1300	Both test participants move to entrance door of the Test Building and exit the building to retrieve evidence bags from the equipment wagon that they left just outside of the building.
1301	Both test participants re-enter the building lobby and move to the last location where the table with the spray bottle was located. Gather evidence.
1304	Both test participants walk to the entrance of the building and proceed to the decontamination line, set up about 25 meters away.
1305	Both test participants arrive at the decontamination line.
1307	Test Participant 2 sits down at the decontamination line to way for proper contact time of the decontamination solution on the suit.
1308	Test Participant 15 sits down at the decontamination line to way for proper contact time of the decontamination solution on the suit.
1315	Both test participants continue down the decontamination line.
1317	Both test participants unzip their Level A suits.
1320	Both test participants off air tanks.
1324	Both test participants in post-test medical monitoring.

Activity Log for Day 2: 22 August 2018
Second Entry

Time	Activity
1440	Test Participants 2 and 15 depart staging area.
1441	Test Participants 2 and 15 arrive at the entrance of Test Building.
1443	Test Participants 8 and 17 arrive at the entrance of Test Building.
1444	All four test participants enter Test Building.
1447	All four test participants are in the lobby of the Test Building near building entrance. Test participants are conducting screening with gas and radiation meters.
1448	Test participants spit up and go separate ways to conduct screening of rooms in the Test Building. Test Participants 2 and 15 gather on the hallway on the east corner of the test building. Test Participants 8 and 17 enter the hallway on the southern end of the main building.
1450	Test Participants 2 and 15 screening with gas and radiation meters in hallway. Move to room off of hallway and continue screening just inside the room.
1453	Test Participants 8 and 17 conduct screening in rooms on the south end of the building (*data collector only periodically checked on these participants as she primarily was following activities of the other team, Test Participants 2 and 15).*
1455	Test Participants 2 and 15 leave room and proceed down the hallway continuing gas and radiation checks.
1500	Test Participants 2 and 15 arrive at the end of the hallway.
1501	Test Participants 2 and 15 enter a second room at the end of the hallway and continue with gas and radiation checks.
1503	Test Participants 2 and 15 exit room and proceed down a different hallway on the southeast side of the Test Building continuing with gas and radiation checks.
1505	Test Participants 2 and 15 enter a third room and conduct continue to conduct gas and radiation checks. There are two 55 gallon drums with liquid in them in this room.
1510	Test Participants are screening the two 55 gallon drums in detail.
1514	Test Participant 15 on radio and calls in descriptions of the labels on the two 55 gallon drums.

1518	Test Participants 2 and 15 move to fourth room across the hallway from the third room to conduct gas and radiation checks.
1521	Test Participants 8 and 17 are in another location on the southwest side of the building conducting gas and radiation checks.
1530	Test Participants 8 and 17 exit the room they were monitoring and head to hallway. They are notified by command staff that their mission is complete and to exit the building and proceed to the decontamination line.
1535	Test Participants 8 and 17 arrive at the start of the decontamination line.
1539	Test Participants 2 and 15 exit Test Building.
1540	Test Participants 2 and 15 arrive at the start of the decontamination line.
1548	Test Participants 8 and 17 complete removal of their PPE.
1552	Test Participants 2 and 15 complete removal of their PPE.

APPENDIX B

Open Body Area Network Personal Physiological Status Monitoring (OBAN-PSM) System – User Survey

*Identification Number:*_____

This monitoring device is a wearable system that has been made to send health data to a medic or your buddy to help prevent injuries in training and also to send information in a time of emergency. The system measures heart rate, skin temperature, body position and activity. The system may allow injuries to be prevented and quicker treatment and aid sent to wounded Warfighters more quickly.

We would like to know your opinions about the comfort and fit of this device during your training exercise. By answering the questions below you will help us create a better product.

1. The fit of the system to my body was:

	Extremely Poor **1**	Quite Poor **2**	Neither Good nor Poor **3**	Moderately Good **4**	Extremely Good **5**
Overall Fit	○	○	○	○	○

1a. Please explain why it did not fit you properly.

_____

_____

_____

2. Using the following scale please rate how acceptable the fit of the monitoring system for the following areas:

	Very Unacceptable **1**	Moderately Unacceptable **2**	Slightly Unacceptable **3**	Neither Acceptable nor Unacceptable **4**	Slightly Acceptable **5**	Moderately Acceptable **6**	Very Acceptable **7**
a. Overall	○	○	○	○	○	○	○
b. Chest	○	○	○	○	○	○	○
c. Back	○	○	○	○	○	○	○

3. Using the following scale please rate, how tight or loose, the fit of the monitoring system was for the following areas:

	Very Tight **1**	Moderately Tight **2**	Slightly Tight **3**	Neither Tight nor Loose **4**	Slightly Loose **5**	Moderately Loose **6**	Very Loose **7**
a. Overall	○	○	○	○	○	○	○
b. Chest	○	○	○	○	○	○	○
c. Back	○	○	○	○	○	○	○

4. Were you able to put the system on without any help from the test staff?

○ Yes

○ No ⟶ If No: **4a.** How did they help you?

_____
_____
_____
___

Please rate how comfortable or uncomfortable you found the system during your training exercise. Rate the system overall and for the individual parts of the belt listed for the question:

5. COMFORT	Very Uncomfortable **1**	Moderately Uncomfortable **2**	Slightly Uncomfortable **3**	Neither Comfortable nor Uncomfortable **4**	Slightly Comfortable **5**	Moderately Comfortable **6**	Very Comfortable **7**
a. Overall	○	○	○	○	○	○	○
b. Electrodes	○	○	○	○	○	○	○
c. Area Under OBAN-PSM Hub	○	○	○	○	○	○	○
d. Belt Material	○	○	○	○	○	○	○
e. Chest Strap Fastener	○	○	○	○	○	○	○

If certain areas caused discomfort, please briefly describe why they were uncomfortable.

_____
_____
_____
_____

6. While wearing the system during your training approximately how long did you spend in the following activities:

6a. Sleeping or trying to sleep? _____ hours
6b. Wearing body armor? _____ hours
6c. Carrying a backpack _____ hours
6d. Wearing Personal Protective Equipment (PPE) _____ hours

7. Was there a particular activity or activities during your training when you found the system to be more uncomfortable to wear?

○ No

○ Yes → If Yes: **7a.** What was the activity(s)?

_____

Questions 8 through 11. Please rate whether the system had an impact on your overall performance and for the other activities listed:

8. No Body Armor and No Backpack	Not Applicable	Extreme Negative Impact **1**	Very Negative Impact **2**	Moderate Negative Impact **3**	Slight Negative Impact **4**	No Negative Impact **5**
a. Overall impact on performance		○	○	○	○	○
b. Ease of motion		○	○	○	○	○
c. Ease of movement		○	○	○	○	○
d. Rolling	○	○	○	○	○	○
e. Jumping	○	○	○	○	○	○
f. Landing	○	○	○	○	○	○
g. Running	○	○	○	○	○	○
h. Assuming a prone firing position	○	○	○	○	○	○
i. Assuming an upright firing position	○	○	○	○	○	○
j. Throwing a grenade or other object	○	○	○	○	○	○
k. Bending	○	○	○	○	○	○
l. Lying on back	○	○	○	○	○	○
m. Lying on stomach	○	○	○	○	○	○
n. Lying on side	○	○	○	○	○	○

9. With Body Armor	Not Applicable	Extreme Negative Impact 1	Very Negative Impact 2	Moderate Negative Impact 3	Slight Negative Impact 4	No Negative Impact 5
a. Overall impact on performance		○	○	○	○	○
b. Ease of motion		○	○	○	○	○
c. Ease of movement		○	○	○	○	○
d. Rolling	○	○	○	○	○	○
e. Jumping	○	○	○	○	○	○
f. Landing	○	○	○	○	○	○
g. Running	○	○	○	○	○	○
h. Assuming a prone firing position	○	○	○	○	○	○
i. Assuming an upright firing position	○	○	○	○	○	○
j. Throwing a grenade or other object	○	○	○	○	○	○
k. Bending	○	○	○	○	○	○
l. Lying on back	○	○	○	○	○	○
m. Lying on stomach	○	○	○	○	○	○
n. Lying on side	○	○	○	○	○	○

10. With Carrying a Backpack	Not Applicable	Extreme Negative Impact 1	Very Negative Impact 2	Moderate Negative Impact 3	Slight Negative Impact 4	No Negative Impact 5
a. Overall impact on performance		○	○	○	○	○
b. Ease of motion		○	○	○	○	○
c. Ease of movement		○	○	○	○	○
d. Rolling	○	○	○	○	○	○
e. Jumping	○	○	○	○	○	○
f. Landing	○	○	○	○	○	○
g. Running	○	○	○	○	○	○
h. Assuming a prone firing position	○	○	○	○	○	○
i. Assuming an upright firing position	○	○	○	○	○	○
j. Throwing a grenade or other object	○	○	○	○	○	○
k. Bending	○	○	○	○	○	○
l. Lying on back	○	○	○	○	○	○
m. Lying on stomach	○	○	○	○	○	○
n. Lying on side	○	○	○	○	○	○

11. Other Activities (e.g., Wearing PPE) _____	Not Applicable	Extreme Negative Impact **1**	Very Negative Impact **2**	Moderate Negative Impact **3**	Slight Negative Impact **4**	No Negative Impact **5**
a. Overall impact on performance		○	○	○	○	○
b. Ease of motion		○	○	○	○	○
c. Ease of movement		○	○	○	○	○
d. Rolling	○	○	○	○	○	○
e. Jumping	○	○	○	○	○	○
f. Landing	○	○	○	○	○	○
g. Running	○	○	○	○	○	○
h. Assuming a prone firing position	○	○	○	○	○	○
i. Assuming an upright firing position	○	○	○	○	○	○
j. Throwing a grenade or other object	○	○	○	○	○	○
k. Bending	○	○	○	○	○	○
l. Lying on back	○	○	○	○	○	○
m. Lying on stomach	○	○	○	○	○	○
n. Lying on side	○	○	○	○	○	○

12. During your training did the system cause any skin irritation, or other discomfort?

○ No

○ Yes → If Yes: **12a.** What was/were the problem/s? Describe nature of the discomfort and exact location on the body (chest, back, side etc.)

_____

_____

_____

13. Please rate overall the impact of wearing the system on your body, i.e., any pains or discomfort felt.

Extreme Negative Impact	Very Negative Impact	Moderate Negative Impact	Slight Negative Impact	No Negative Impact
1	**2**	**3**	**4**	**5**
○	○	○	○	○

14. For each of the system components listed below, please rate if there was any negative impact on your body.

	Extreme Negative Impact **1**	Very Negative Impact **2**	Moderate Negative Impact **3**	Slight Negative Impact **4**	No Negative Impact **5**
a. Overall	○	○	○	○	○
b. Electrodes	○	○	○	○	○
c. Area Under OBAN-PSM Hub	○	○	○	○	○
d. Belt Material	○	○	○	○	○
e. Chest Strap Fastener	○	○	○	○	○

For questions 15 to 20, rate each of the following statements. Place a circle around the number on the scale that best represents your feelings. For example, if you feel bad or have negative feelings you would circle a negative number that best represents the intensity of your negative feelings, if you feel good or have positive feelings you would circle a positive number that best represents the intensity of your positive feelings.

15. Rate how you feel you look when wearing this device. If you feel tense or on edge regarding how you look wearing the device that would indicate you are worried about your appearance, if you feel good or at ease about how you look wearing the device that would indicate you are confident about your appearance.

Worried **Neutral Feelings** **Confident**

-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10

16. I can feel the device on my body. I can feel the device moving or is it a wear and forget device.

Feel the Device **Neutral Feeling** **Device is Wear & Forget**

-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10

17. The device can cause some harm or is beneficial.

Causes Harm **Neutral Feelings** **Is Beneficial**

-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10

18. Wearing the device makes me feel physically different or feel the same. I feel strange wearing the device or I feel like it is just another piece of equipment worn.

Feel Strange									Neutral Feelings									Feel Normal		
-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10

19. The device affects or does not affect the way I move. The device inhibits/restricts my movement or I have complete freedom of movement.

Restricts Movement									Neutral Feelings								Freedom of Movement			
-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10

20. I do not feel secure or I feel secure wearing the device.

Feel Insecure									Neutral Feelings									Feel Secure		
-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10

21. Did the system come apart or break?

- ○ No
- ○ Yes ⟶ If Yes: **21a.** Please explain how the system broke or came apart, and how you fixed the problem.

_____

_____

_____

_____

22. Is the system acceptable to wear for an extended period of eight hours or more?

- ○ Yes
- ○ No ⟶ If No: **22a.** Please explain why the system is not.

_____

_____

_____

23. If this system were able to provide you with better medical care would you wear this system during infantry or Chemical-Biological training and actual operations/missions?

23a. Training

- ○ Yes
- ○ No → If No: **23b.** Please explain why you would not wear the system.

_____

_____

_____

23c. Actual Operations or Missions.

- ○ Yes
- ○ No → If No: **23d.** Please explain why you would not wear the system.

_____

_____

_____

24. If this system was able to assist your leaders with making better tactical decisions to prevent medical injuries from happening in the first place would you wear this system during infantry training or Chemical-Biological training or actual operations/missions?

24a. Training

○ Yes

○ No ⟶ If No: **24b.** Please explain why you would not wear the system.

_____

_____

_____

24c. Actual Operations/Missions

○ Yes

○ No ⟶ If No: **24d.** Please explain why you would not wear the system.

_____

_____

_____

25. Please list suggested operating guidelines courses of action you as a leader would possibly take for Green, Amber, and Red indicators of Heat Strain Index (HSI) based on your groups' concepts of operations for both the wearer of the system and the leader or viewer of the information.

Wearer of the PSM System

25a. Green Indicator:

25b. Amber Indicator:

25c. Red Indicator:

Leader or Viewer of the Information of the PSM System

25d. Green Indicator:

25e. Amber Indicator:

25f. Red Indicator:

26. Have you previously worn any type of heart rate monitor, such as the Polar Heart Rate Monitor or other Sports Monitors?

○ Yes
○ No

27. Would you like your heart rate and other vital signs displayed for your own use?

○ Yes ⟶ If Yes **27a.** Please explain where (on wrist watch or wearable sensor on your body?)

_____

○ No

28. Do you think any other measures other than heart rate and heat strain index should be displayed on your leader's or medic's handheld device?

○ Yes ⟶ If Yes **28a.** Please explain what other measures would be important to aid the leader or medic in making good decisions for your welfare.

_____

○ No

29. Would you recommend this system as a medical monitoring system to other ground warfighting personnel?

○ Yes
○ No ⟶ If No: **29a.** Please explain why you would not recommend.

_____

_____

_____

30. Any other comments please feel free to write them below or on the back of this form.

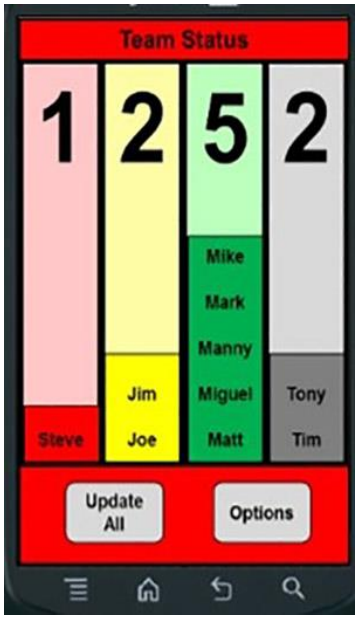
APPENDIX C

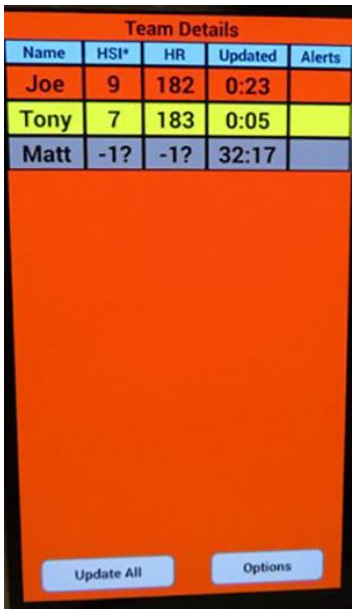
Open Body Area Network Physiological Status Monitoring (OBAN-PSM) End User Device - Satisfaction Survey

Identification Number: _____

End User Device Display

Summary Status View Screen





Detailed Status View Screen

The OBAN-PSM system was developed to assist leaders, instructors, and medical personnel to provide situational awareness and health information to aid in mission decision making. This questionnaire seeks feedback from you to ensure that we can make improvements to the OBAN-PSM end user device so it meets your needs. Please answer all questions after you have had a chance to use the OBAN-PSM end user device.

Information about you.

1. What is your job position (e.g., Squad Leader, Instructor, Medic, Physician)?

_____

2. How long have you had that job (Years and Months)? _____

3. How long did you observe or use the OBAN-PSM end user device?

- ○ Less than 10 Minutes
- ○ 10 to 30 Minutes
- ○ 30 minutes to 2 hours
- ○ 2 hours to 8 hours
- ○ 8 hours to 24 hours
- ○ More than 24 hours
  (Please specify how long) _____ Hours _____ Minutes

4. What type of device would you like to use as an OBAN-PSM end user device?

- ○ This Smart Phone
- ○ Another Smart Phone Device _____ (Please Specify)
- ○ As a Computer Program or Application
- ○ As a Tablet Program or Application
- ○ Other _____

4a. If you selected any other device other than this Smart Phone please describe why?

_____
_____

5. Did the application work without crashing?

- ○ Yes
- ○ No **5a.** If no please explain what happened, how did it crash, did you get it working again, what did you do? Provide details surrounding the application's crash.

_____

_____

_____

6. Did the program work fast enough?

- ○ Yes
- ○ No

7. Please rate ease of use for the following questions concerning the use of the OBAN-PSM End User Device.

	Very Difficult	Moderately Difficult	Somewhat Difficult	Neither Difficult nor Easy	Somewhat Easy	Moderately Easy	Very Easy
	1	**2**	**3**	**4**	**5**	**6**	**7**
a. How easy/difficult is the screen to read?	○	○	○	○	○	○	○

7a. If the system was difficult to read, 1-3 ratings, please describe under what conditions was it difficult to read?

_____

_____

8. Please rate how useful you think OBAN-PSM end user device might be to you to aid in your job as a Squad Leader, Instructor, Medic, Physician, etc.

Not Useful	Somewhat Useful	Moderately Useful	Very Useful	Extremely Useful
0	**1**	**2**	**3**	**4**
○	○	○	○	○

8a. If you rated the application as not useful, please explain why it is not useful?

._____

_____

_____

9. How likely would you be to use the OBAN-PSM end user device in your training and or actual missions?

	Very Unlikely	Moderately Unlikely	Somewhat Unlikely	Neither Unlikely nor Likely	Somewhat Likely	Moderately Likely	Very Likely
	1	**2**	**3**	**4**	**5**	**6**	**7**
Actual Missions	○	○	○	○	○	○	○
During Training	○	○	○	○	○	○	○

9a. Please comment on **WHY** you would (or would not) use the application. If you gave a rating of 4 or less on Question 9 please answer this question?

._____

_____

_____

9b. Please comment on **HOW** you would use the application (ratings 5 to 7 from Question 9)?

._____

_____

_____

10. Are there any other features that would make this application more useful?

- ○ No
- ○ Yes

If yes, please explain: _____

_____.

11. If you have any other comments regarding the OBAN-PSM end user device please write in the space below.

Thank You!