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FORM FACTOR EVALUATION OF OPEN BODY AREA NETWORK (OBAN) PHYSIOLOGICAL STATUS MONITORING (PSM) SYSTEM PROTOTYPE DESIGNS

United States Army
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14. ABSTRACT

A new PSM development effort is jointly being undertaken by the U.S. Army Research Institute of Environmental Medicine (USARIEM) and the Massachusetts Institute of Technology – Lincoln Laboratory (MIT-LL). The Open Body Area Network (OBAN) system is the main product of this effort and has been developed to specifically meet the needs of the military. It will use a commercial off-the-shelf (COTS) chest strap with a custom-made hub. The test described in this report assesses proposed form-factor designs. Feedback using non-functional prototype systems was obtained from two experienced soldiers during and after simulated military activities. Assessed were two proposed hub designs and two proposed strap designs. One hub had a rounded top while the other was an inverted V-shaped design. Both straps consisted of a Polar (Polar Oy, Kempele, Finland) chest strap with custom-made shoulder straps. Results from this test showed that the rounded hub design was preferred as the inverted V-shaped design, The new (2017) Polar Pro chest strap with small silicone dots/nubs was also recommended as a replacement strap.

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EXECUTIVE SUMMARY

A new PSM development effort is jointly being undertaken by the U.S. Army Research Institute of Environmental Medicine (USARIEM) and the Massachusetts Institute of Technology – Lincoln Laboratory (MIT-LL). The Open Body Area Network (OBAN) system is the main product of this effort and has been developed to specifically meet the needs of the military. It will use a commercial off-the-shelf (COTS) chest strap with a custom-made hub. It is being engineered to 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 test described in this report assesses proposed form-factor designs. Feedback using non-functional prototype systems was obtained from two experienced soldiers during and after simulated military activities. This test follows recommended system engineering practices. Assessed were two proposed hub designs and two proposed strap designs for a total of four combination prototypes. One hub had a rounded top while the other was an inverted V-shaped design. Both straps consisted of a Polar (Polar Oy, Kempele, Finland) chest strap with custom-made shoulder straps. The only difference between the straps was that one strap was modified with a white sticky based backing to help reduce movement on the body. The following areas of user feedback were sought: ease of donning, fit, comfort, impact on military performance, impact of the systems on the body, durability of the system, and overall acceptability. Results from this test showed that the rounded hub design was preferred as the inverted V-shaped design caused discomfort when the person was in the prone position. The problem with that hub was the top of the hub (the top of the inverted V) could dig into the skin causing discomfort. There was excessive movement with both strap designs, and the shoulder straps and the adjustment buckles are likely to cause issues. In addition, the metal fastener could likely cause discomfort or injury if it became bent through use. A softer rubber or plastic connector was recommended. The new (2017) Polar Pro chest strap with small silicone dots/nubs was also recommended as a replacement strap.

INTRODUCTION

The dismounted warfighter is susceptible to excessive heat strain as a result of environmental and operational stressors. For example, the use of body armor adds weight to the individual. This, in turn, increases the metabolic rate for any given activity resulting in increases in the heat the body produces (4). The encapsulation effect of body armor also reduces the ability for the body to cool by adding insulation, hampering evaporative cooling of the body. These effects are even more pronounced when chemical, biological, radiological and nuclear (CBRN) personal protective equipment (PPE) is worn. The CBRN-PPE compromises thermo-regulation primarily by preventing evaporative cooling (3). Recent physiological status monitoring (PSM) systems are capable of monitoring work intensity and heat strain/body core temperature (10). Use of PSM technology can improve an individual's awareness of himself/herself, his buddy's thermal state, or those under his/her supervision by providing an objective measure of health state including thermal strain (10).

In 2007, real-time physiological monitoring with a commercial-off-the-shelf (COTS) product was demonstrated with Weapons of Mass Destruction – Civil Support Team (WMD – CST) personnel encapsulated in CBRNE-PPE (1). A usability evaluation of the Hidalgo Equivital™ EQ-01 PSM system (Hidalgo, Ltd., Cambridge, UK) completed during that evaluation (1) showed skin irritation due to the PSM system was an issue. This and previous usability evaluations with various groups of warfighters (1,7,8) identified three main issues with the Equivital™ EQ-01 PSM system: 1) discomfort when individuals wore body armor, 2) interference with mission-critical tasks such as shooting in the prone position and low crawling, and 3) interference with a person's ability to sleep. These issues were primarily a result of the size, weight, and location of the sensor electronics module (SEM) in the center of the body's torso below the pectoral muscles. The Equivital™ EQ-01 SEM is a triangular piece of hard plastic, weighs 85.8 g and is approximately 12.3 cm × 7.5 cm × 1.5 cm (width × height × depth). As a result of these issues, a new the Equivital™ EQ-02 system was developed that was less bulky with a smaller SEM (41.3 g, and is 7.7 cm × 5.3 cm × 1.1 cm). This new version is mounted just below the left axilla. This Equivital™ EQ-02 system resulted in a better fit, more comfort, less negative impact on the body or on job performance, and greater acceptability than the older EQ-01 design whether with or without body armor or CBRN-PPE (6,9).

While the Equivital™ system is an acceptable PSM system for some users, it is expensive, lacks the battery life needed to monitor for 72 hours or more - the typical length of time of military sustained operations, and is not tactically acceptable in certain operations. Communication with the Equivital™ system uses commercially available wireless technologies such Bluetooth, currently not approved for use in combat environments. As a result, 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 hub. It was engineered to be tactically acceptable by using a tunable narrow band (TNB) radio, and to function for 72 hours or more. This OBAN-PSM prototype system was tested both in the laboratory and 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). The tests of this system showed that the OBAN-PSM prototype system was generally functional, however, there were issues with its performance and its acceptability with soldiers and Marines (2,5). For example, the prototype hub was square with sharp edges and chafed the skin. Of the original 13 systems to be tested only six of the units functioned and collected accurate data. As a result of these tests, a new OBAN-PSM design using the basic technology from MIT LL is being developed by Odic, Inc. (Devens, MA). The purpose of this report is to assess proposed form-factor designs by obtaining feedback from experienced military personnel doing simulated military activities.

METHODS

TEST PARTICIPANTS

Test participants were two male (Age: 34.5 yrs, Height: 181.6 cm, and Weight: 89.5 kg) U.S. Army soldiers currently in the U.S. Army Reserve Unit 443 Civil Affairs, Charlie Company, Newport, RI. One participant was Ranger School qualified and has deployed four times with the 3rd U.S. Army Ranger Battalion (Ft. Benning, GA). He had deployed to both Iraq and Afghanistan, with each of his deployments lasting approximately four months. The other participant was deployed as part of the 831st Transportation Battalion out of Kuwait. His deployment was 12 months in duration to Afghanistan. Both participants were involved in contact with enemy combatants and participated in ground dismounted infantry maneuvers. They also had participated in many field infantry (dismounted fighting) training exercises. Attempts to recruit additional reserve soldiers from the above unit, active duty soldiers at Ft. Benning, or Marines at Camp Pendleton, CA, Quantico, VA, or Camp Lejeune/Camp Geiger, NC were not successful within the timeline required for the contractor to meet the obligations of their contract.

TEST ARTICLES

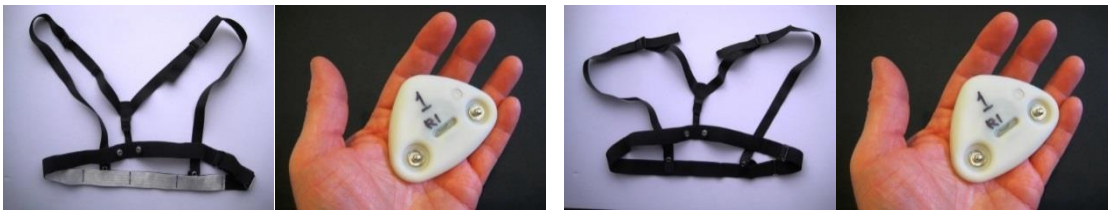
There were two versions of the hub and two versions of a commercial Polar chest strap (Polar Oy, Kempele, Finland) for a total combination of four prototypes tested of this OBAN-PSM system. The assigned prototype numbers are shown in Figure 1. Test order was counter-balanced using a Latin-Square design for four prototypes. Hence, the first two participants tested the four prototypes in the following order:

Test Participant 1: Prototypes 3, 1, 2 and 4.
Test Participant 2: Prototypes 2, 4, 1 and 3

Figure 1. Four prototypes tested.

Prototype 1 Prototype 2

Prototype 3 Prototype 4



Prototypes 1 and 2 had the round topped hub, whereas Prototypes 3 and 4 had an inverted V-shaped hub. Prototypes 1 and 3 have the same Polar strap (belt) with a white sticky material backing on each strap added; whereas Prototypes 2 and 4 have the same strap as Prototypes 1 and 3 but without the white sticky material.

TEST PROCEDURES

Test participants completed four iterations of testing on back-to-back test days. Duration of test iterations was between three and four hours. Testing was performed at Hanscom Air Force Base, MA and on the Minuteman Trail in the towns of Lincoln, Bedford, and Lexington, MA. Testing occurred in overcast and partly cloudy conditions with temperatures ranging between 30° and 50° F. On the first day of testing, participants were given an information sheet that described the test. They were informed that the test protocol summarizing the test had been approved by the U.S. Army Research Institute of Environmental Medicine, Natick MA. They were also told that they were voluntarily participating and that they could withdraw their participation at any time without prejudice. Both soldiers decided to voluntarily participate.

After the initial briefing, test participants were given the system donning procedure information sheet (Appendix A) to see if they could put the system on correctly without further instruction. Both test participants were able to put the system on correctly with the use of the information sheet. The tester ensured that the system

was on correctly and that the straps were lying flat and the hubs were properly secured prior to beginning the test.

The military training was established by the Army Reserve Unit's training leader, with the only requirements that each of the four iterations be similar in length and have similar activities performed. Additionally, training must include wearing body armor for at least part of the time, and that the training be realistic with respect to what unit typically does.

Training performed during each iteration began with a 9.7 km road march while carrying a rucksack. One test participant carried approximately 20.4 kg in his rucksack and wore standard military combat equipment, including a Kevlar helmet. The other participant wore a standard military blouse, civilian cargo pants and a military stocking cap. For the first two iterations (Day 1 of testing), body armor consisted of only a front plate in a body armor carrier. On Day 2, the complete Improved Outer Tactical Vest (IOTV) with front and back plates were worn. No weapon or anything else was carried in the hands during training. During the march, tactical training activities such as taking prone shooting positions, site and area assessments for vehicle passage, and simulated reaction to hostile threats were performed. Bound and cover exercises were performed where test participants simulated taking a hill by short bursts of running, hitting the ground in a prone position, and rapidly simulating firing positions in upright, on one knee, and while lying prone.

Upon completion of the road march, additional military training exercises took place. This supplemental training took place inside a gym, and consisted of rope work techniques (such a belaying etc.) and stretching exercises. Systems were also worn while sitting and eating lunch and planning of military missions based on simulated mission orders obtained from simulated command headquarters.

Immediately upon completion of each training iteration test participants filled out a survey (Appendix B) for each prototype worn. These surveys assessed subjective ratings of comfort, fit, durability of the system, impact on the body, impact on military performance, and overall acceptability. Questions are in the form of Likert rating scales and open-ended questions. This survey has been adapted from a survey that assessed the form, fit, and function of commercial PSM systems (6,7).

Upon completion of the final testing/training iteration and after the survey was filled out, an After Action Review (AAR) was conducted to obtain general impressions of the systems and provide test participants an opportunity to give any feedback on the systems they felt was important that was not specifically asked for on the survey. Two questions that were specifically asked during the AAR were for test participants to 1) rank order the overall acceptability/preference of the four prototypes and 2) assess the ease of donning this PSM system. These AARs were not video- or audio-recorded, but written notes were taken on what was said.

DATA ANALYSIS

Means and standard deviations (SD) were calculated from the subjective rating scales. Frequencies of responses with proportions of various responses were tabulated.

RESULTS

EASE OF DONNING

Test participants were asked about how easy it was to don the system based on the instruction sheet shown in Appendix A. There is no difference between prototypes with regard to donning the system so only an overall ease of donning on a 10-point scale was asked with "1" being "Extremely Difficult to Don" and a "10" being "Extremely Easy to Don." An average rating of "6" was given, with one participant rating the donning procedure as a "7" and the other as a "5".

The greatest difficulty, although not a major one, was ensuring the shoulder straps laid flat on the body. In addition, based on the instructions, test participants felt that there was not a clear illustration that shows how to put the system on, only what it should look like once it was on. A recommendation was made that having a picture or graphic to show how to put the system on most efficiently, easily, and correctly could aid in greater understanding to a naïve user. Finally, one participant mentioned that putting labels of "front and back" and "toward body and away from body" printed on the strap could help the ease of donning.

FIT

All participants reported that all four prototypes of the OBAN-PSM system fit them comfortably. When participants were asked to rate the fit of the system, the overall fit, and the fit in specific anatomical areas, all ratings were: "Like Moderately" or better except for the Chest rating on Prototype 3 which was rated between "Neither Like nor Dislike and Like Slightly" (see Table 1).

Table 1. Fit ratings of the OBAN-PSM system on various body area regions.

Body Area of Fit	Prototype 1	Prototype 2	Prototype 3	Prototype 4
Overall	6.5 $\pm$ 0.7	6.0 $\pm$ 0.0	6.0 $\pm$ 0.0	6.5 $\pm$ 0.7
Chest	6.0 $\pm$ 1.4	6.0 $\pm$ 0.0	4.5 $\pm$ 2.1	6.0 $\pm$ 0.0
Shoulders	7.0 $\pm$ 0.0	7.0 $\pm$ 0.0	6.5 $\pm$ 0.7	6.5 $\pm$ 0.7
Neck	7.0 $\pm$ 0.0	7.0 $\pm$ 0.0	6.5 $\pm$ 0.7	6.5 $\pm$ 0.7
Back	7.0 $\pm$ 0.0	6.0 $\pm$ 0.0	6.5 $\pm$ 0.7	6.5 $\pm$ 0.7

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 being too loose on the body.

Table 2. Tightness-looseness ratings of the OBAN-PSM system.

Body Area of Fit	Prototype 1	Prototype 2	Prototype 3	Prototype 4
Overall	4.5	4.5	4.5	5.0
Chest	3.5	3.5	3.5	3.5
Shoulders	5.5	4.5	5.5	5.5
Neck	5.5	5.0	5.5	5.5
Back	5.5	5.0	5.5	5.5

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

The following comments concerning fit were obtained from the open-ended comments section of the survey and are strap specific as the same strap was used in Prototypes 2 and 4. Comments were:

- Prototype 2: System shifted down from the chest during movement, it felt like the system loosened up on me over time after an initial good fit (*n* = 2).

- Prototype 4: The system felt like it was slipping down my chest during the march (*n* = 2).

COMFORT

When test participants were performing their training, some comments about the system were made verbally. The following comments were captured during the test session and are paraphrased below:

- Both test participants stated that all prototypes did not cause any major issues, but on the other hand, the systems were not wear-and-forget either (*n* = 2).

- When taking a prone position while wearing Prototype 2 a test participant stated that it was not a significant issue for the short time that he was in the prone position but he hypothesized that over time it would become an issue. He did not specify if it was the hub or the chest strap that was the source of the discomfort (*n* = 1).

- A participant noted while wearing Prototype 3 that the inverted V-Shape of the hub was pushed by the body armor plate into the chest. In his case, he was only wearing one plate in a plate carrier that did not have any soft body armor with it. He said it felt like a thick necklace or multiple dog tags being worn that got all bunched up and digging into his body. He stated it was tolerable but distracting. (*n* = 1). The tester questioned if it was ever practical to wear this equipment configuration. The test participant said that this equipment configuration while not ideal was a possible configuration. He said there are times when equipment is missing, the unit will do the best they can with what equipment they have to outfit as many soldiers as possible with as much protection as possible.

The following comments concerning comfort were obtained during the AAR. They are paraphrased below:

- When wearing soft body armor in combination with the hard body armor plates, the soft body armor helps to cushion and buffer the plate from pushing on the hub and causing discomfort. The test participant did not specify a particular hub prototype (*n* = 1).

- When you begin to take a knee during particular training activities, or you begin to get in the prone position with these prototypes, that is when these PSM systems are most uncomfortable. The systems seem to slightly change their position on your body and they can then dig into your skin causing discomfort. When you get to your final tactical position you can adjust your position so that the PSM system doesn't bother you. But, it is the change from the upright position (i.e., standing, walking, running) to a bending over position that causes the distraction or sometimes even an irritation to the body (*n* = 2).

- The body armor plate can act as a fulcrum on the hub (i.e., pushing it unevenly), where the top of the hub then gets repositioned and begins to dig into the body. This problem is worse with the inverted V-shaped hub (Prototype 3 and Prototype 4 designs). One test participant mentioned this and the other test participant agreed (*n* = 2).

- Generally, wearing this PSM system is a nuisance. But there are many pieces of equipment that a soldier has to wear or carry that are nuisances to wear or carry. Carrying a radio is a nuisance, but all soldiers that are required to carry a radio usually don't complain about it because they easily see its utility. Therefore, the utility of the system has to be properly understood. If the system works as stated with high reliability, and through proper new equipment training (NET), it should be easy to understand its usefulness. The small amount of discomfort it causes, any soldier should be able to put up with. However, data supporting its usefulness needs to be communicated to prospective leaders. The

leaders need to buy-in to this technology. The leaders need to then communicate how important this technology is to enhancing mission effectiveness and soldier safety. Soldiers will then know how important this system is and acceptability should be high. If the NET provided is clear and effective, soldiers will wear any of these prototypes; even as is, if the system works, That is, even the worst rated prototype system from a comfort standpoint would be worn. The focus needs to be on developing the functionality of the system. The utility of the system needs to be properly communicated to the specific user group on why having this technology is so important. The PSM system will need to work as stated and it needs to be reliable. If all that is done, any of these prototypes are good enough to wear. If it is not done, no matter how comfortable you make these systems, they will not be acquired through the complicated acquisition process (*n* = 2). These comments include statements by both participants; but both agreed with the overall comment when it was read back to them.

- Test participants (*n* = 2) thought the design of the hub, especially the inverted V-shaped hub in Prototype 3 and Prototype 4 should be more rounded if possible if that design was to be used. The hub (either design tested) should be made smaller, and if possible made as similar in size to the Polar heart rate electronic sensor unit that snaps into the center of the Polar strap/belt on the chest (*n* = 1). The tester commented that the size of hub likely needed to be larger than the Polar electronic sensor unit to accommodate the firmware necessary, and in general about the size of the prototypes used in this test. He also mentioned that one approach taken with a commercial system, the Equivital™ EQ-02 system (Equivital™, Ltd., Cambridge, UK), was to move the hub (called the sensor electronics module (SEM) in the Equivital™ system) to under the arm and positioned above the body armor. Both participants (*n* = 2) felt that solution could be considered for this OBAN-PSM system. But, they also said if the hub could be made smaller and in general the size of the Polar sensor unit perhaps it could be worn in the center of the chest in the same location as the Polar unit is worn. Both participants thought the Polar sensor unit would be acceptable to wear regarding size and location in the center of the chest.

When asked if there were particular activities when the system was uncomfortable to wear the following responses were obtained:

Prototype 1: Both participants said yes (*n* = 2). The activities stated were:

- Prone activities and bounding to a hill.
- Moving into the prone position in body armor.

Prototype 2: Both participants said yes (*n* = 2). The activities stated were:

- Prone activities.

- Moving in and out of the prone position and while getting in and out of the rucksack.
- The system digs into my chest while bending to tie boots.
- Lying in the prone position was uncomfortable.

Prototype 3: Both participants said yes (*n* = 2). The activities stated were:

- Prone activities.
- In the prone position while in body armor.
- During the march the system was not a distraction, but as soon as I did any core movement, the chest strap became a distraction, that is getting in the prone position or removing the pack.

Prototype 4: Both participants said yes (*n* = 2). The activities stated were:

- Prone activities.
- Moving into the prone position. Hub would press into the chest due to the body armor plates.

The overall comfort and the comfort levels that could be impacted by specific system components were rated in general higher for Prototypes 3 and 4, and are shown in Table 3. The lowest rated, most problematic areas are the electrodes and the area under the hub.

Table 3. Comfort ratings of the OBAN-PSM system components.

Comfort of System Component	Prototype 1	Prototype 2	Prototype 3	Prototype 4
Overall System	4.0	4.5	6.0	5.5
Electrodes	4.5	3.0	4.5	4.0
Area Under the Hub	3.0	5.0	4.0	4.0
Belt Material	6.5	5.5	6.5	4.0
Belt Adjustment Fastener	6.5	6.0	7.0	6.0
Shoulder Straps	6.5	5.5	7.0	6.0

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 SYSTEMS ON MILITARY PERFORMANCE

Time spent wearing each of the prototypes is tabulated in Table 4. Ratings on the impact on military performance are tabulated in Table 5, broken down to various types of activities that serve as building blocks to military training tasks. Ratings included the impact of wearing the prototypes with and without body armor and while carrying a rucksack/backpack. A 5-point scale was used to assess the impact, with “1” being “Extreme Negative Impact” to “5” being “No Negative Impact.”

Table 4. Time in minutes spent (total time, time wearing body armor, and time wearing a rucksack) while wearing each of the prototypes.

Time (In Minutes) Wearing Each Prototype	Prototype 1	Prototype 2	Prototype 3	Prototype 4
Overall Time Worn	188	235	180	180
Time Wearing Body Armor	188	180	155	155
Time Wearing a Rucksack	165	160	135	135

IMPACT OF THE SYSTEMS ON THE BODY

Test participants were asked to rate whether the systems caused skin irritation or other physical discomfort. When specifically asked about the impact on the body, the same 5-point scale was used as was used for determining the impact of the systems on military performance (Table 6). When participants were asked to identify the system component that had an effect on the body; the area under the hub was the most often cited has having the greatest negative impact, especially for Prototypes 3 and 4 (Table 7). Table 8 summarizes specific skin irritation ratings of the four prototypes.

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

- Prototype 1: Overall the system did not cause any issue, however, the system was noticeable and somewhat distracting due to the irritation and itchiness from the strap across the chest.

The following open-ended comments regarding skin irritation or discomfort were given:

Prototype 1:

- Itchy with slight irritation when bending or moving.
- Overall the system did not cause any issue, however, the system was noticeable and somewhat distracting due to the irritation and itchiness from the strap across the chest.

Prototype 2:

- Somewhat uncomfortable including itchiness in center of chest under the hub.

Prototype 3:

- Slight irritation in front of the chest.

Prototype 4:

- Chest pain due to the hub.

- Slight irritation in front of the chest after 30 minutes of wear.

Table 5. Impact on military performance of the four prototypes for various equipment configurations.

Impact on Military Performance	Prototype1	Prototype 2	Prototype 3	Prototype 4
No Body Armor/No Rucksack				
Overall	5.0	5.0	4.5	4.5
Ease of motion	5.0	5.0	4.5	5.0
Ease of body movement	5.0	5.0	4.5	5.0
Rolling	4.0	5.0	4.0	4.0
Jumping	5.0	5.0	5.0	5.0
Landing	5.0	5.0	5.0	5.0
Running	4.5	5.0	5.0	4.5
Bending	5.0	5.0	4.0	5.0
Assuming a prone firing position	4.0	4.5	4.5	5.0
Assuming an upright firing position	5.0	5.0	5.0	4.0
Other activities in a prone position	4.0	4.5	4.0	4.0

Impact on Military Performance	Prototype1	Prototype 2	Prototype 3	Prototype 4
Effect of Body Armor				
Overall	4.0	4.0	4.0	4.0
Ease of motion	4.5	5.0	4.5	4.5
Ease of body movement	4.5	5.0	4.5	4.5
Rolling	3.5	4.5	3.0	4.0
Jumping	4.5	5.0	4.0	4.5
Landing	4.5	5.0	4.0	4.5
Running	4.0	5.0	4.0	4.0
Bending	4.5	4.5	4.0	4.0
Assuming a prone firing position	3.5	4.0	3.5	3.5
Assuming an upright firing position	5.0	5.0	4.5	4.5
Other activities in a prone position	3.0	4.0	3.0	3.0

Impact on Military Performance	Prototype1	Prototype 2	Prototype 3	Prototype 4
Effect of Rucksack				
Overall	4.5	4.0	4.0	4.0
Ease of motion	4.5	5.0	4.5	4.5
Ease of body movement	4.5	5.0	4.5	4.5
Rolling	3.0	4.0	4.0	4.0
Jumping	4.0	5.0	4.0	4.0
Landing	4.0	5.0	4.0	4.0
Running	4.0	5.0	4.5	4.0
Bending	4.0	4.5	4.0	4.0
Assuming a prone firing position	3.5	4.0	3.5	3.5
Assuming an upright firing position	4.5	5.0	4.5	4.5
Other activities in a prone position	3.0	4.0	3.0	3.0

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

Table 6. Impact of the system on the body of the four prototypes.

	Prototype 1	Prototype 2	Prototype 3	Prototype 4
Impact on the body	4.5	4.5	4.0	5.0

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

Table 7. Impact by system component on the body of the four prototypes.

Component	Prototype 1	Prototype 2	Prototype 3	Prototype 4
Overall system	4.5	4.5	4.0	4.5
Electrodes	4.0	4.5	4.0	4.5
Area under the hub	4.5	4.5	3.5	4.0
Belt material	4.5	5.0	5.0	5.0
Belt adjustment fastener	5.0	5.0	5.0	5.0
Shoulder straps	5.0	5.0	5.0	5.0

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

Table 8. System causes skin irritation or discomfort of the four prototypes.

	Prototype 1 (Yes/No)	Prototype 2 (Yes/No)	Prototype 3 (Yes/No)	Prototype 4 (Yes/No)
Overall	(1/1)	(0/2)	(1/1)	(1/1)
In prone position	(1/1)	(2/0)	(1/1)	(2/0)

DURABILITY OF THE SYSTEM

Throughout the test, test participants and the tester noted if the system broke or came apart. No system broke. However, for one test participant, Prototype 2 and Prototype 4 (systems with the non-stick black backing) came apart. The test participant recommended:

- “a more robust strap/clip for the front clip.”

Since Prototypes 1 and 3 did not cause an issue for this test participant or the other test participant, it may be that use of the white sticky backing material bolsters the strap and could be recommended to alleviate this problem.

ACCEPTABILITY

Participants were asked “would the system be acceptable to wear for twenty-four hours or longer for military training?” Both test participants believed all four prototypes would be acceptable for extended wear of up to 24 hours if the system provided the claimed utility of better mission management and soldier safety.

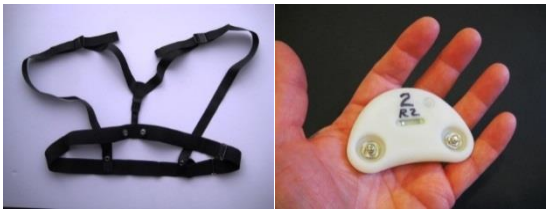
When test participants were asked to rank order the most acceptable to the least acceptable, both participants were in agreement with the following order (Figure 2):

Figure 2. Rank order of the four prototypes tested.

Rank 1: Prototype 1

Rank 2: Prototype 3

Rank 3: Prototype 2



Rank 4: Prototype 4

In the rank ordering of the prototype systems as well as in comments obtained in the AAR, both test participants put greater emphasis on the strap/belt with regard to acceptability. One participant mentioned (and the other agreed) that the strap with the non-sticky backing (black strap) shown in Prototypes 2 and 4 produced more of a chronic problem with it moving around, and it was this strap that came apart. In contrast, they stated that the inverted V-shaped hub with the "#1" on it in Figure 2 was more of an acute problem of it pressing against the chest. This was especially true as one moved into a prone position. Once a prone position was established and adjusted for comfort, then both hubs produced the same amount of "little" discomfort. However, both participants mentioned both hubs causing a distraction or discomfort even when one adjusted their position. They stated that the hubs should not cause any discomfort and they should be "wear and forget."

When the test participants were asked if they would wear the system during training or actual missions if the system would allow them to receive better medical care or help them accomplish their mission more effectively, both soldiers said they would wear the system (any of the four prototypes). Both test participants also would recommend this system (any of the four prototypes) to other ground warfighting personnel if it did what it was purported to do.

The following open-ended comments were added when asked for any other comments during the AAR:

- Both test participants when asked about the concepts of operations (CONOPS) for this system for use in units that they have been or are currently in, said that the system should send information to the medic. The medic should not have to be right next to the individual to obtain the information, but rather within say 100 m of a solider they are responsible for. The medic should be able to get as much detailed information as the system can provide. The medic would then advise the tactical mission leader, typically the platoon leader but it could be a team leader, squad leader, commander etc. of the medical readiness of the various soldiers they are monitoring. These test participants said that in their experience, the various mission leaders; team, squad, or platoon leaders do not have the time to monitor the health status of their soldiers. But, they said that the medic would have the time and that task is within his/her job responsibilities. They said, he/she could provide updates as requested to the tactical leader or if a soldier's status is becoming more of a risk (amber or red alerts from the PSM system) regarding the health of the soldier. Alternatively or additionally, if the health state of a soldier they were monitoring could compromise the mission, the medic would alert the appropriate leader of that change in status.

- Both test participants have had U.S. Army acquisition training and experience. One test participant currently works in an acquisition position for the U.S. Air Force as a civilian. He stated that to get this PSM system to the point of being an acquired item a focused effort is needed to work with units that will want this system. He stated that the end user needs to have requirements generated and

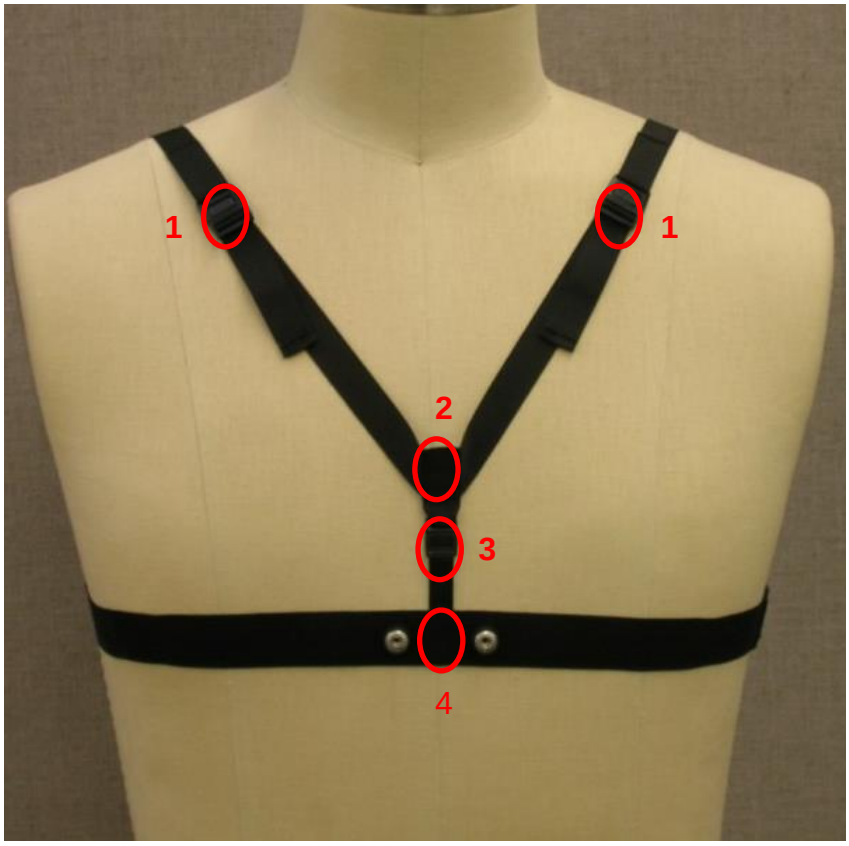
they should be an active partner in providing focused feedback on the system so that the system is built to meet their particular needs. This individual was a former member of the U.S. Army Ranger Battalion. He said that as an example, most Ranger Battalions most likely could use a system like this but that they should be involved early in the development of the system to ensure that it meets their specific requirements. The other individual who spent significant time with a transportation company, said when a unit like his, having many vehicles as part of their mission equipment, a PSM system like this would not be as valuable or needed. He said, for example, those engaged in dismounted patrols could find a reliable working PSM system to be quite beneficial. He suggested approaching the Special Forces as a target group. Both test participants agreed that the two key stakeholders that need to be convinced of a PSM system's utility are the commander of the unit and the top medical person of the unit. Both test participants suggested that if a unit with documented heat injuries in their training or mission was provided a PSM system, shown how it can work, and then provided input into its development to meet their requirements, it will be met with greater acceptability and would likely be a valuable technology for those particular customers.

DISCUSSION

The results from this test show that these strap/belt designs tend to move around on the body and use of shoulder straps or a center chest belt design with a material that grips to the skin such as the belt material in Prototypes 1 and 3 would be required. Perhaps a material such as the white backing material on the Equvital™ systems should or could be considered. These results show that the hub designs of either system do not cause issues when the person is in an upright posture but when in the prone position cause comfort issues with the hub pressing into the chest. The more rounded design used in Prototypes 1 and 3 was the more preferred design but still not ideal. It was advocated to try and move the hub design to as close to the design used in the commercial Polar heart rate chest strap sensor unit as possible.

The authors of this report also identified potential issues with the system that were not mentioned by the test participants. From Figures 3 and 4 it may be seen that there were seven issues and potential solutions identified.

Figure 3. Chest strap with potential problem areas identified.



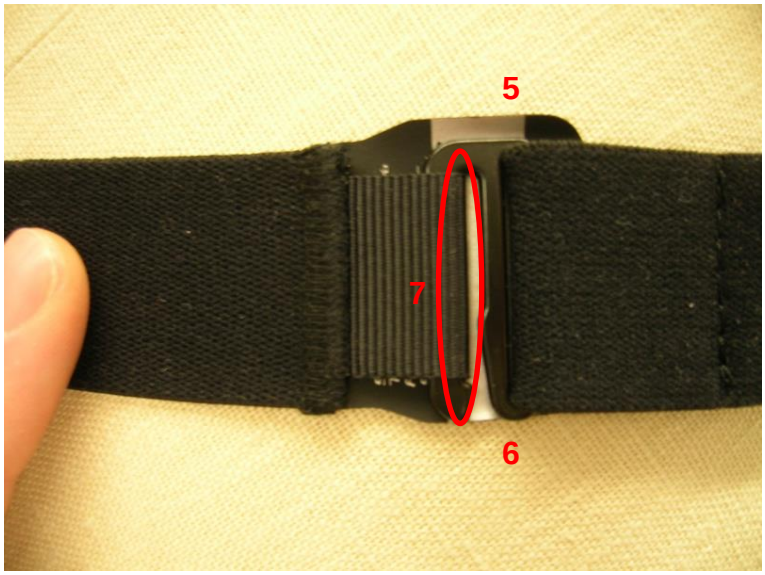
Issue: *Location 1* - Plastic shoulder strap adjustment buckle fastener is a potential problem because of 1) the size of the buckle and 2) the nylon strap can get turned within the fastener resulting in the strap not lying flat. Direct pressure on the plastic fastener can put pressure on the skin, with the risk of skin irritation increased when the skin is wet from sweating.
Potential Solution(s): Plastic buckle should be reduced in size or use another shoulder adjustment technology/approach.

Issue: *Location 2* - The bulk of the material at the Y location especially with the raised stitching on the underside is likely to cause skin irritation over time.
Potential Solution(s): Remove stitching from underside through laser laminating the connection straps, gluing the connecting straps, coating with soft fabric without stitching, have stitching recessed or have single strap that is cut in the Y shape. Any solution that reduces the bulk of material and/or the raised stitching on the underside would be an improvement over the current design.

Issue: *Location 3* – While this adjustment buckle is small, it is in a strategic location of where body armor, or lying prone can push this buckle into the skin (in addition to the hub) causing discomfort.
Potential Solution(s): Use of a series of small low-profile snaps to allow for various levels of adjustment could be considered as a replacement for the buckle.

Issue: *Location 4* – The shoulder straps are optional, and as such if they are not used the flap of strap that attaches to the chest belt is left loose. It is possible that it could double over and cause discomfort if bunched up underneath the center chest strap.
Potential Solution(s): If a series of small low-profile snaps as suggested above to address the previous issue were used all the way from the chest belt to the Y part of the shoulder strapping intersection it could reduce this issue. If a longer strap is needed, extender strapping could be used to eliminate the need for a strap that may have a flap that doubles over on those individuals with smaller chest sizes.

Figure 4. Belt connector.



Issue: *Location 5* – Edge is metal and sharp, potentially causing skin irritation or abrasions.
Potential Solution(s): Use a softer plastic or rubber connector with contoured edges.

Issue: *Location 6* – Edge is metal and sharp.
Potential Solution(s): Use a softer plastic or rubber connector with contoured edges.

Issue: *Location 7* – The metal hook can possibly slip out of the nylon sleeve and dig into the skin. In addition it is possible for it to get bent causing even more skin damage if it digs into the skin.

Potential Solution(s): Use a softer plastic or rubber connector with contoured edges or a flat connector that clips in or a turn and fit flat connector.

There are limitations to the findings in this report as they come from only two test participants. However, it should be noted that these two participants were both very experienced soldiers that have dealt with the fielding of many products. Both soldiers have experience in leadership positions and with the military acquisition system. The results from this report were provided to Odic, Inc., the contractor, prior to completion of this report to incorporate into design decision making of the OBAN-PSM system. Regardless of the final design, the key points obtained from these soldiers were that leaders and medical personnel need to understand the usefulness of these systems, otherwise they will not be adopted. A user-group that is experiencing heat injuries will likely embrace these concepts but should be engaged prior to the final product roll-out to ensure it will truly meet their needs.

CONCLUSIONS

The rounded hub design was recommended for the hub. While the current size was acceptable, effort to reduce the size to as thin as possible is recommended. Regarding the strap design, neither strap design was recommended. A new (2017) product the Polar Pro chest strap with small silicone dots/nubs to provide a gripping material to reduce movement is a recommended alternative to the Polar straps tested during this evaluation.

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APPENDIX A

Open Body Area Network - Physiological Status Monitoring System (OBAN-PSM) System Instruction Sheet

FRONT

BACK

1. Adjust both shoulder straps to their maximum length.
2. Release the center ½" buckle.
3. Unhook the chest strap.

4. Using the chrome slider, adjust the chest strap for a snug but not too tight fit. The shoulder straps may need to be repositioned in the back.

5. Slide the tang of the g-hook through the fabric loop at the end, verifying the serial number label is flat.

6. Connect the center ½" buckle.
7. Pull down on the shoulder straps as shown above.

To remove: Release the center ½" buckle, unhook the chest strap at the side, and pull off over your head.

APPENDIX B

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

Test Participant # _____ **Prototype #** _____

This chest belt with an attached plastic hub device is non-functional version of a physiological status monitoring (PSM) system. This survey will assess your views of the prototype you just wore and if it is acceptable to wear for extended periods of time. The functioning system is intended to send health data to a leader or medical person to better manage missions and to help prevent injuries in training or actual missions. A functioning system will measure heart rate, skin temperature, body position and activity.

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. Did the system fit you properly?

○ Yes

○ No → If No: **1a.** Please explain why it did not fit you properly.

_____

_____

_____

_____

2. Using the following scale please rate how much you like or dislike the fit of the system for the following areas:

	Dislike Very Much **1**	Dislike Moderately **2**	Dislike Slightly **3**	Neither Like nor Dislike **4**	Like Slightly **5**	Like Moderately **6**	Like Very Much **7**
a. Overall	○	○	○	○	○	○	○
b. Chest	○	○	○	○	○	○	○
c. Shoulders	○	○	○	○	○	○	○
d. Neck	○	○	○	○	○	○	○
e. 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. Shoulders	○	○	○	○	○	○	○
d. Neck	○	○	○	○	○	○	○
e. Back	○	○	○	○	○	○	○

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.

4. 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 Hub	○	○	○	○	○	○	○
d. Belt Material	○	○	○	○	○	○	○
e. Belt Adjustment Fastner	○	○	○	○	○	○	○
f. Shoulder Straps	○	○	○	○	○	○	○

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

5a. Wearing body armor? _____ hours: minutes

5b. Carrying a rucksack? _____ hours: minutes

5c. Wearing Chemical, Biological, Radiological And Nuclear (CBRN) Personal Protective Equipment _____ hours: minutes

6. 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: **6a.** What was the activity(s)?

_____

_____

Questions 7 through 10. Please rate whether the system had an impact on your overall performance and for the other activities listed:

7. No 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 stand-up firing position	○	○	○	○	○	○
i. Bending	○	○	○	○	○	○
h. Assuming a prone firing position	○	○	○	○	○	○
i. Other activities in the prone position	○	○	○	○	○	○

8. 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 stand-up firing position	○	○	○	○	○	○
i. Bending	○	○	○	○	○	○
h. Assuming a prone firing position	○	○	○	○	○	○
i. Other activities in the prone position	○	○	○	○	○	○

Not

9. During Carrying or Wearing Rucksacks	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	[redacted]	○	○	○	○	○
b. Ease of motion		○	○	○	○	○
c. Ease of movement		○	○	○	○	○
d. Rolling	○	○	○	○	○	○
e. Jumping	○	○	○	○	○	○
f. Landing	○	○	○	○	○	○
g. Running	○	○	○	○	○	○
h. Assuming a stand-up firing position	○	○	○	○	○	○
i. Bending	○	○	○	○	○	○
h. Assuming a prone firing position	○	○	○	○	○	○
i. Other activities in the prone position	○	○	○	○	○	○

10. While Wearing Chem-Bio Personal Protective Equipment	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	[redacted]	○	○	○	○	○
b. Ease of motion		○	○	○	○	○
c. Ease of movement		○	○	○	○	○
d. Rolling	○	○	○	○	○	○
e. Jumping	○	○	○	○	○	○
f. Landing	○	○	○	○	○	○
g. Running	○	○	○	○	○	○
h. Assuming a stand-up firing position	○	○	○	○	○	○
i. Bending	○	○	○	○	○	○
h. Assuming a prone firing position	○	○	○	○	○	○
i. Other activities in the prone position	○	○	○	○	○	○

11. Please rate the impact of wearing the system on your body.

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

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 (write in space below)?

12 b. During training specifically while in the prone position did the system cause any skin irritation, or other discomfort?

○ No

○ Yes ⟶ If Yes: **12c.** What was/were the problem/s (write in space below)?

_____

_____

_____

_____

_____

13. For each of the system components listed below, please rate if there was any negative impact.

	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 the Hub	○	○	○	○	○
d. Belt Material	○	○	○	○	○
e. Belt Adjustment Fastner	○	○	○	○	○
f. Shoulder Straps	○	○	○	○	○

14. Did the system come apart or break?

- ○ No
- ○ Yes → If Yes: **14a.** Please explain how the system broke or came apart, and how you fixed the problem.

_____

_____

_____

15. Is the system acceptable to wear for an extended period of 24 hours or more?

- ○ Yes
- ○ No → If No: **15a.** Please explain why the system is not

_____

_____

_____

16. If this system were able to provide you with better medical care or help you to complete your mission more effectively and safely would you wear this system during actual missions?

- ○ Yes
- ○ No → If No: **16a.** Please explain why you would not wear the system.

_____

_____

_____

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

- ○ Yes
- ○ No

18. Would you recommend this system as a monitoring system to other Soldiers or Marines?

○ Yes

○ No → If No: **18a.** Please explain why you would not recommend

_____

_____

_____

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