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# Increasing Spaceflight Analogue Mission Fidelity by Standardization of Extravehicular Activity Metrics Tracking and Analysis

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**Spaceflight analogues include human simulations that attempt to match as many variables of a real mission as possible, but here on Earth and at a fraction of the cost each having limitations. The goal of this Embry-Riddle Aeronautical University (ERAU) Spacesuit Utilization of Innovative Technology Laboratory (S.U.I.T. Lab) research is to improve simulation fidelity through Extravehicular Activity (EVA) data collection, analysis, and feedback, which will help humanity prepare for destinations such as the Moon or Mars. Investigated EVA metrics, physical and biomedical, are based on the identified NASA Human Research Roadmap research gaps related to the risk of injury and compromised performance due to EVA operations. Previous data acquired on 88 EVAs at the Flashline Mars Arctic Research Station in 2007, as well as historical Apollo data on EVAs, act as a baseline for data collection. Metrics tracked, collected, and analyzed from the Mars Desert Research Station (MDRS Crew 188, 2018) will aid in creating protocol recommendations for EVA simulations. Additional work was investigated with mission simulation analogues including the 2017 Hawai'i Space Exploration and Analog Simulation (HI-SEAS) and the AMADEE-18 (2018, Oman) missions. The investigation of human performance data with respect to energy expenditure will help identify physical limitations, thus providing explorers with a schedule that maximizes their potential on EVA. It is envisioned that the results of these studies will help prescribe systematic field operations and data collection standards that will prepare humankind for surface planetary expeditions. It is the intent of the ERAU S.U.I.T. Lab to act as a bridge between international efforts and as a repository of simulated mission EVA data for analysis and enhancement of human exploration.**

## Nomenclature

| | | |
|---|---|---|
| ATV | = | all-terrain vehicle |
| bpm | = | beats per minute (heart rate) |
| Cal | = | Calories, or kilocalories |
| EE | = | Energy Expenditure |
| ERAU | = | Embry-Riddle Aeronautical University |
| EV | = | extravehicular (crewmember) |
| EVA | = | extravehicular activity |
| FMARS | = | Flashline Mars Arctic Research Station |
| F-XI LDM | = | FMARS Crew 11 Long Duration Mission |
| HI-SEAS | = | Hawai'i Space Exploration and Analog Simulation |
| IRB | = | Institutional Review Board |
| IV | = | intravehicular (crewmember) |
| kg | = | kilograms |
| kJ | = | kilojoules |
| km | = | kilometers |
| MDRS | = | Mars Desert Research Station |
| mi | = | miles |
| mph | = | miles per hour |
| PI | = | Principal Investigator |
| S.U.I.T. Lab | = | Spacesuit Utilization of Innovative Technology Laboratory |
| TMG | = | Thermal Micrometeoroid Garment |

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## I. Introduction

Spaceflight analogues include human simulations that attempt to match as many variables of a real mission as possible, but here on Earth and at a fraction of the cost. Each analogue has unique environmental and human performance testing conditions, but they all have limitations. The goal of this Embry-Riddle Aeronautical University (ERAU) Spacesuit Utilization of Innovative Technology Laboratory (S.U.I.T. Lab) research is to improve simulation fidelity through Extravehicular Activity (EVA) data collection, analysis, and feedback, which will help humanity prepare for destinations such as the Moon or Mars. Investigated EVA metrics (e.g. times, distance, "task", biometrics, as well as many others) are based on the identified NASA Human Research Roadmap [Abercromby, 2016] research gaps related to the risk of injury and compromised performance due to EVA operations [Kobrick, 2017]. Previous data acquired on 88 EVAs at the Flashline Mars Arctic Research Station in 2007 [Battler, 2008], as well as industry data on EVAs, act as a baseline for data collection. Metrics tracked, collected, and analyzed from the Mars Desert Research Station (MDRS) Crew 188 (Jan-Feb 2018) will aid in creating protocol recommendations for EVA simulations. Lead author and Principal Investigator (PI) of the ERAU S.U.I.T. Lab Dr. Ryan Kobrick was the MDRS Crew 188 Commander on his sixth analogue mission, fifth at MDRS (Figure 1). Additional work was investigated with mission simulation analogues leading up to MDRS Crew 188 including the Hawai'i Space Exploration and Analog Simulation (HI-SEAS) Mission V [HI-SEAS, 2017] and the 2018 AMADEE-18 mission in Oman [ÖWF, 2017] that occurred simultaneously.


**Figure 1: MDRS Crew 188 Commander Dr. Ryan Kobrick investigates a rock sample during the first EVA of the mission.**

This investigation took many different variants as the S.U.I.T. Lab was preparing for MDRS. The group collectively felt that it would be best to acquire as much pilot data as possible to formulate a long term plan. Lessons learned are presented throughout this paper, and work is already underway for follow-on proposals in analogue mission data collection. The MDRS Crew 188 mission acted as "re-orientation" as the Principal Investigator Dr. Ryan Kobrick had last been on a Mars simulation in 2007 during a 100-operational-day mission at the Flashline Mars Arctic Research Station (FMARS) Crew 11 Long Duration Mission, or F-XI LDM. The S.U.I.T. Lab's goals remain: to provide students hands-on experiential experiences; and to contribute to industry as a research and development testbed.

## II. Background & Methodology

Recapping a previous paper by Kobrick [2017], this work directly aligns with NASA's ongoing human exploration mission, whether it be the Moon or Mars, to help address critical "EVA Gaps" identified by the Human Research Program [Abercromby, 2016; NASA, 2015; NASA, 2016; and HRP, 2016]. Several Gaps can be mapped to spacesuit mobility, design, and astronaut safety, including parts of EVA Gaps 6 through 11, 13, and 14. Specifically, EVA Gap 9 ("What is the effect on crew performance & health of variations in EVA task design and operations concepts for exploration environments?") inspired this investigation with EVA metrics data collection at MDRS Crew 188 including workload, duration, and future plans to examining fatigue before and after EVA.

### A. HI-SEAS Proposal Exercise: Physical Metrics

Based on the identified NASA EVA research gaps, the ERAU S.U.I.T. Lab developed two studies in the Spring 2017 semester to be investigated at mission simulations [Lones, 2017]. This was an exercise in spaceflight operations planning and laid the foundation for future mission collaborations. These investigations were shared as an unsolicited proposal with the mission management team at HI-SEAS (during Mission V, 2017) in coordination with one of the crewmembers, an ERAU alumni. The first study (Table 1) investigated EVA system data or "Physical

Metrics" and how they map to NASA's EVA Gaps (the second study investigated spacesuit range of motion: Kobrick, 2018). This preliminary meta-study for EVA operations was focused on adding value to simulations while attempting to avoid a duplicated effort. This provided the foundation for data collection, evaluating which variables are reasonable to request or potentially already collected. The HI-SEAS crew did not participate in data collection with ERAU but provided feedback on these potential variables. The HI-SEAS crew participated in a NASA Johnson Space Center led study that collected EVA journal information to investigate the relationship between extravehicular (EV) and intravehicular (IV) crewmembers with PI Kelsey Young, which could be used for future data mining. The previous EVA metrics work during F-XI LDM [Battler, 2008] with personal communications with Dr. Melissa Battler and Dr. Jonathan Clarke (as well as their papers as resources), an updated version of the F-XI LDM was created in the S.U.I.T. Lab for MDRS Crew 188. The Excel spreadsheet was updated with more general language for capturing EVA data and made as user friendly as possible with examples from F-XI LDM in the first few rows. The EVA Log was comprised of 37 column entries per EVA, but some were calculated time differences from phases, growing to 62 with advanced calculations post mission for this analysis. The log was designed so that a crewmember could take the "Hab-comm" or IV crewmember's notes and enter key data, while also recording equipment used and a generic overview of site location and EVA objectives.

Data was collected by authors Kobrick and Tomiyama during all MDRS Crew 188 EVAs ensuring that the IV member of the crew (or Hab-comm) would record timestamps of key operational moments as previously described. The authors used photos with timestamps, GPS data, or videos recorded to retrieve missing data. For every EVA, two documents are required by The Mars Society. An EVA request the night before and then the EVA Summary Report the evening of the event to be posted on the MDRS website. These documents provide a narrative from one of the EV crewmembers, which could be useful for post-processing and long-term goals of data collection. The draft of EVA metrics originally created for HI-SEAS (Table 1) will help construct the next iteration of metrics focused on time, task, and distance as the specific figures of merit where the older table will formulate an operational checklist.

**Table 1: EVA System Data Metrics for Analogue Research**

| TASK ID | METRIC | METRIC DETAILS | EVA GAPS |
|---|---|---|---|
| A1 | Type | Science (Geology, Biology, etc.)<br>Scouting (Navigation, Sample site discovery, exploration, etc.)<br>Engineering/Maintenance<br>Other (to be sorted with developing hierarchy) | 6, 9 |
| A2 | Pre/Planning | Time: briefing, equipment gathering, tool preparation (batteries charged, radios working, visual equipment ready, etc.) | 9 |
| A3 | Don | Time: Suiting up | 9 |
| A4 | Airlock Depart | Time: in airlock (usually 5 min) | 9 |
| A5 | Duration | Time: from airlock depressurization to start EVA to airlock pressurization start at end of EVA | 9 |
| A6 | Airlock Return | Time: in airlock (usually 5 min) | 9 |
| A7 | Doff | Time: Suit/Equipment off | 9 |
| A8 | Clean Up | Time: clean up equipment, charge equipment | 9 |
| A9 | Post | Time: Debrief (group) | 9 |
| A10 | Reporting | Time: write up time for report and/or studies | 9 |
| A11 | Data Transfer | Time: pull notes, data, visuals for EVA debriefing | 9 |
| A12 | Maintenance | Time: repairing, improving spacesuits and field equipment | 9 |
| A13 | Crew | List: The crew in the field (anonymous tagging of people?) | 9 |
| A14 | IV Crew | Crew in hab / hab-communication (anonymous tagging of people?) | 8, 9 |
| A15 | Distance | Total traversed distance (km) | 9 |
| A16 | Suit Type | Recording which suit is used each EVA (mass estimation / suit) | 7 |
| A17 | Communications | Time: losing and reestablishing communication issues | 9 |

### B. ERAU Aerospace Physiology: Biometrics

As MDRS Crew 188 plans were developing in the Fall semester of 2017 at ERAU, the S.U.I.T. Lab was conducting an ERAU Institutional Review Board (IRB) approved spacesuit study on campus. ERAU's undergraduate program in Aerospace Physiology allowed two students to join the team adding biometric data collection capabilities and analysis to the operations-focused lab. This opened the opportunity to collect pilot data at MDRS with several devices capable of recording biometric data during the scheduled EVAs and to determine which measurements were compatible with suit activity. While donned with a spacesuit, the subject also wore a Hexoskin © (**Figure 2**), a generic pulse oximeter (**Figure 3**), and a 2-inch Smarttemp Bluetooth wireless thermometer by Infanttech © (**Figure 4**). Before each EVA, the subject connected himself to all of the data collection devices, noting the time at which data collection began with the intentions of using the EVA Log (spreadsheet) to help reduce the data in later work.

The Hexoskin is a skin-tight shirt capable of measuring an array of biological data through the use of electrodes and various sensors including: heart rate and related metrics; breathing rate and related metrics; and acceleration rates used to calculate steps and cadence. The Hexoskin was worn underneath the spacesuit, against the subject's skin, to assess biometric data collection methods and sample data for post processing in this pilot study.

A pulse oximeter would be useful for real-time monitoring by a flight surgeon or crew trainer who is remotely watching the crew to make sure their heart rate and oxygen saturation are operating within a safe or ideal threshold. Oxygen saturation issues experienced at high altitudes may be similar to what an astronaut may experience working in a lower pressure environment in their spacesuit compared to their habitat pressure. Lower oxygen saturation leads to higher heart rates and increased energy expenditure. For reference, MDRS is at an altitude of 1,371 meters (4,498 feet), high enough that some days are needed for general adaptation, but much more for athletic levels. The pulse oximeter was worn on the earlobe in the first few EVAs, but as time progressed, that location became too uncomfortable for the user and several data loss periods occurred. The device was worn on the thumb for one EVA, the only location that would fit inside of the Final Frontier Design Thermal Micrometeoroid Garment (TMG) gloves, but that led to comfort complications as well.

The intent of the ERAU Aerospace Physiology students working with the PI was to create methods of measuring muscle metabolic activation through slight changes in muscle temperature. A preliminary investigation used a Bluetooth wireless thermometer for data recording during the MDRS EVAs. This small disk was worn by the subject under his armpit against the skin to monitor auxiliary body temperature. It was not clear if the axillary artery was covered by the sensor so at best, this was a measure of skin temperature.

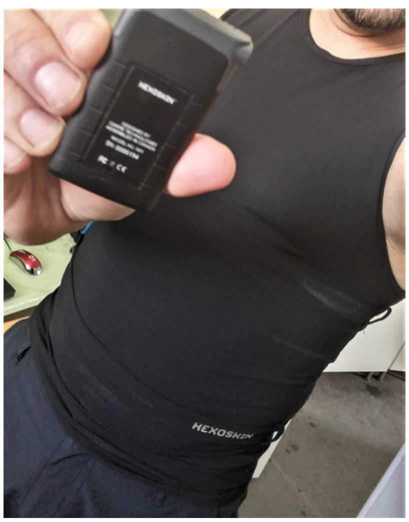


**Figure 2: Hexoskin worn during MDRS Crew 188 EVAs used to primarily collect heart rate data for calculating workload.**


**Figure 3: blood oximeter worn under the TMG glove for EVA 4. The tethered recorder was in a pocket within the spacesuit.**

**Figure 4: Wearable skin temperature sensor used on all MDRS Crew 188 EVAs under the left armpit.**

## III. Results from MDRS Crew 188 Pilot Data

### A. Physical Metrics

An enormous amount of data can be mined from the GPS data collected along with the raw EVA handwritten notes used to fill out the EVA tracking log. Additionally, for several EVAs the PI took time-lapsed GoPro videos with images every 5 seconds that visually show the activities in detail for the majority of the EVAs. Several other cameras were used, for both videos and photos, which could be used to verify time stamps and key milestones. The GPS unit (GPSMAP® 64sc) has a built-in camera and key road intersections were photographed for future reference to guide follow-on EVAs in the same routes either in briefings or while out in the field. The following data in Table 2 highlights were either calculated using the EVA tracking log (Excel file) or GPS tracks. The intent is to showcase top level statistics and then how they measure up against historical data. Additional details are provided in the table footnotes and special attention is given to EVA 4 to Phobos Peak in this work.

**Table 2: EVA physical metrics highlights and MDRS Crew 188 stats**

| Description | Statistics |
|---|---|
| Crew size | 6 |
| Operational time | 12 days |
| EVAs | 15 |
| EVAs per day average | 1.25 |
| Estimated EVA prep time | 2 people, 1 to 2 hours each night |
| EVAs per crew | Range 6 to 9 |
| Crew per EVA | 3 or 4 |
| EVA total time | 33 hours, 46 minutes |
| EVA total person-hours | 105 hours, 54 minutes* |
| EVA total time per person | Range 12.2 to 20.9 hours |
| EVA average time per person | Range 2.0 to 3.5 hours |
| EVA total time including spacesuit don/doff | 48 hours, 26 minutes |
| EVA total person-hours including spacesuit don/doff | 152 hours, 54 minutes |
| Maximum EVA time (EVA 4 to Phobos Peak)** | 3 hours, 8 minutes |
| EVA total distance traversed | 86.9 mi (139.9 km) |
| EVA total distance per person | Range 38.7 to 62.7 mi |
| EVA maximum distance (as crow flies) | 3.7 mi (6 km)*** |
| EVA longest traversed distance (EVA 11) | 15.4 mi (24.8 km)**** |
| Operational Radius | < 4-mi (6.4 km) |

* Important because helps with estimated amount of consumables needed in a real mission.
** Total distance traversed was 2.8 mi (4.5 km) as shown in Figure 7 with GPS moving time of 1 hour, 35 minutes. Average moving speed was 1.78 mph. Ascent total on EVA was 377 feet as shown in Figure 6.
*** Location: Lith Canyon as shown in Figure 5.
**** Location: ATVs to Copernicus Highway.

Continuing on the previous work from Battler [2008], Table 3 is updated as a quick comparison of EVA mission data of MDRS 188 to F-XI LDM and the accumulated Apollo surface mission data.

**Table 3: EVA data comparison between Apollo surface missions, F-XI LDM, and MDRS 188.**

| | Apollo 11, 12, 14-17 | F-XI LDM | MDRS 188 |
|---|---|---|---|
| Total mission days (surface) | 12.48 | 100 | 12 |
| Total EVAs | 14 | 88 | 15 |
| Avg. total EVAs per person | 2.33 | 39.14 | 7.83 |
| Avg. EVAs per day | 1.12 | 0.88 | 1.25 |
| Total hours on EVA | 80.57 | 288.33 | 33.75 |
| % surface hours on EVA | 26.9 | 12.0 | 11.7 |
| Total distance traversed (km) | < 100 | 1074 | 139.9 |
| Avg. total distance per person (km) | --- | 518.39 | 73.01 |
| Avg. distance per day (km) | < 8 | 10.74 | 11.66 |

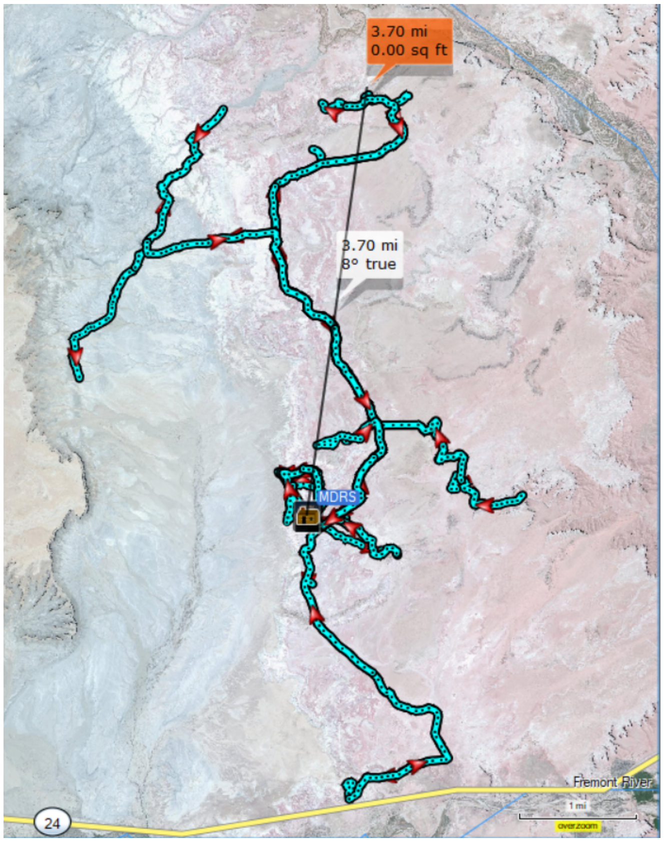

**Figure 5: MDRS Crew 188 GPS ground tracks during 15 EVAs. The crew operating radius zone of exploration [screenshot: Garmin BaseCamp software].**

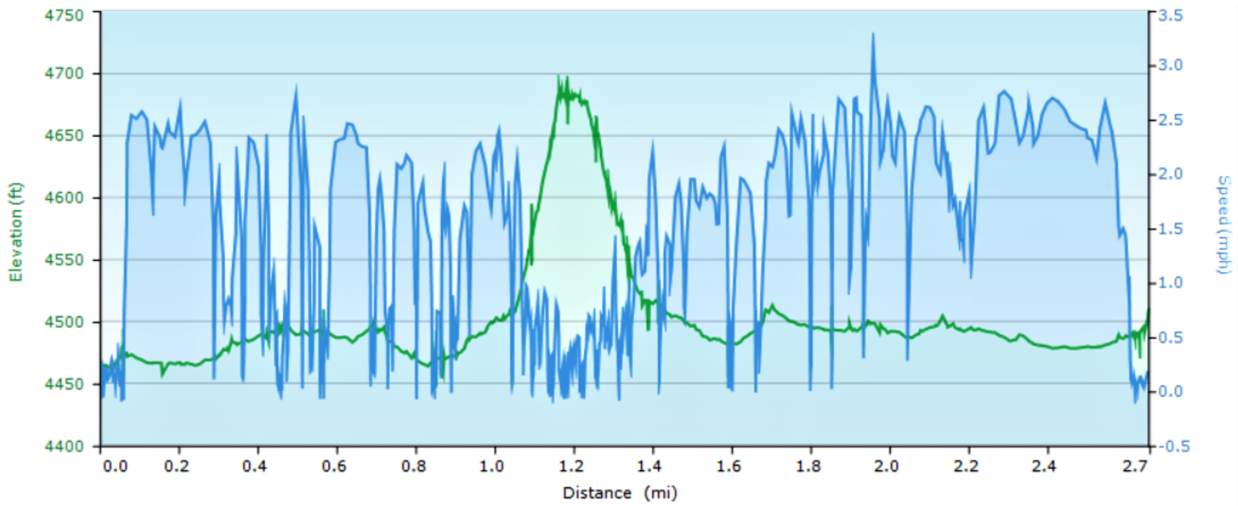

**Figure 6: MDRS Crew 188 EVA 4 to Phobos Peak showing elevation gain and speed [screenshot: Garmin BaseCamp software].**


**Figure 7: EVA 4 ground track to Phobos Peak with waypoints [screenshot: Garmin BaseCamp software].**

## B. Biometrics

The MDRS Crew 188 data collected by researchers at ERAU was the first step in standardizing biomedical measurements to integrate with physical data and provide feedback on their relevance. The data that was recorded can paint a strong picture of what the workload is like during simulated Martian EVAs and help determine what data is critical.

During MDRS, a total of fifteen EVAs were completed by Crew 188. Two of these EVAs were of particular interest to the researchers: EVA 4 and EVA 11. The purpose of EVA 4 was to test the limits of the crew members by having them walk-to and climb Phobos Peak (see Figure 8). During this EVA, both heart rate and temperature were recorded for one of the members of the crew. The average heart rate observed during this EVA was 116 beats per minute (bpm), while the maximum observed heart rate was 177 bpm (Figure 9). It is obvious that this EVA was extremely intense and required high levels of effort from the entire crew. EVA 11, on the other hand, was the least strenuous of all the activities. During this EVA, crew members went on a reconnaissance mission to the Copernicus Highway riding ATVs with minimal on-foot exploration. The average heart rate was 88 bpm while the maximum heart rate was observed over 130 bpm briefly during the EVA as seen in Figure 10. The averages still show that EVA 4, climbing a mountain, was significantly more effortful than the basic, everyday activities associated with EVA 11. In Figure 9 and Figure 10 the thin blue vertical lines mark exiting the airlock and re-entering after EVA, timestamps that were recorded in the EVA log.

**Figure 8: Crew 188 on top of Phobos Peak near MDRS, Utah, USA [photo courtesy of Julia DeMarines].**

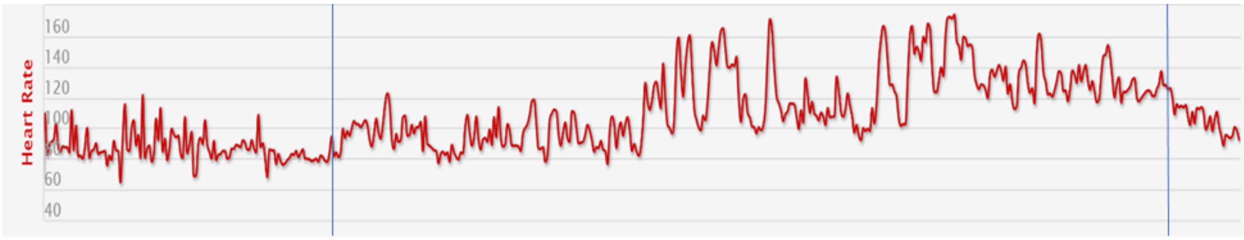


**Figure 9: EVA 4 heart rate sample data on strenuous EVA to Phobos Peak summit and back to the Habitat [screenshot: Hexoskin web interface]. Total recording time 4:29 with EVA duration indicated by blue lines.**

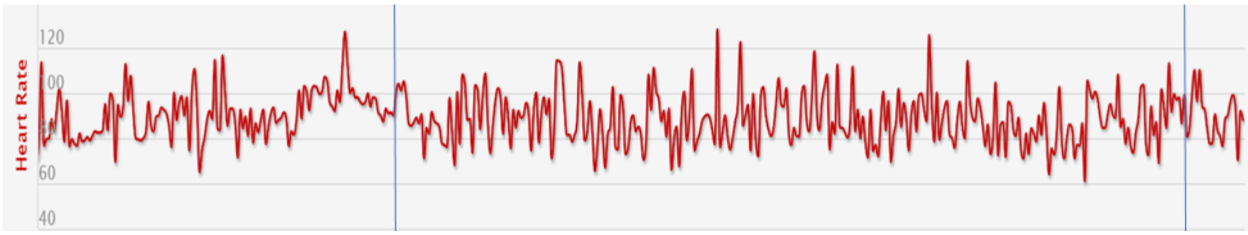


**Figure 10: EVA 11 heart rate sample data for ATV dominated EVA [screenshot: Hexoskin web interface]. Total recording time 3:56 with EVA duration indicated by blue lines.**

Temperature data was also collected during the MDRS mission. Data recorded during EVA 4, the Phobos Peak hike, showed a steady increase in temperature as the crew members scaled the mountain. Once the subjects reached the summit, the data showed a decrease in body temperature, possibly due to the high levels of wind found atop the mountain after being shielded on the sunlit face with no wind. Unfortunately, researchers experienced a loss of signal on several occasions while using the Bluetooth thermometer device. This loss of signal can be observed in the somewhat patchy results collected from this device as seen in Figure 11.

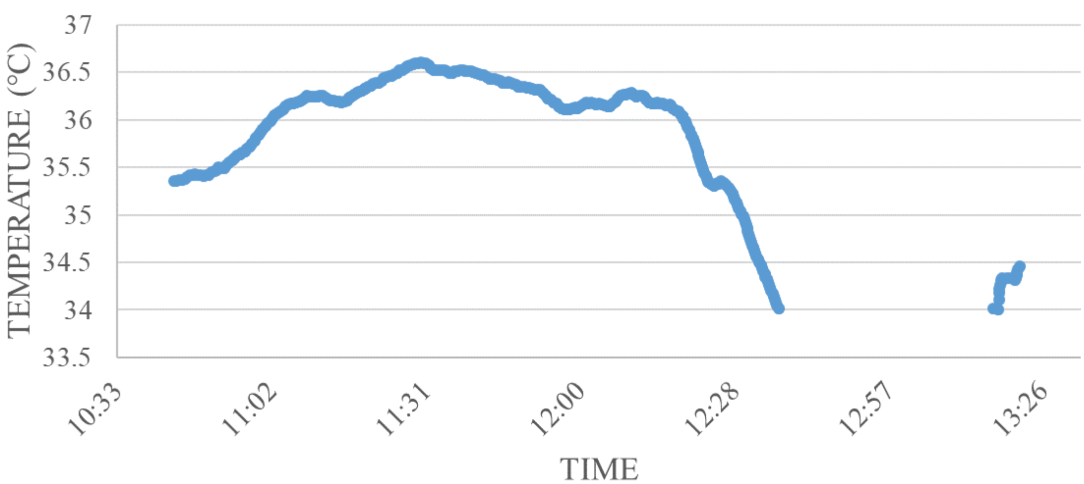


**Figure 11: EVA 4 skin temperature sample data on strenuous EVA to Phobos Peak summit.**

### C. Workload Energy Expenditure Estimations

There are several results that can formulated from the collection of physical and biological EVA metrics. The focus remains on making human exploration more efficient, whether it be by EVA mission planning or by throttling our effort based on accumulated biometric data (for example excessive Calories expended over multiple days) or real time displays (for example an elevated heart rate). Of particular interest to the spaceflight community is the total workload energy expenditure by an explorer on EVA for a variety of design factors including but not limited to: consumable estimation (such as oxygen, water, power, food supplements, and carbon dioxide and trace contaminant removal); dietary needs; field equipment (spacesuits) expected number of uses; airlock number of cycles; and upper limits of exertion and lower limits that may act as a prescribed minimum amount of physical activity to prevent deconditioning. From the author's experience "an EVA a day will keep the doctor away" may be optimistic for a short duration mission, but it is sustainable to obtain the critical field samples and data on EVAs. For a long duration mission, that value would be a strain on the systems and the crew. During the F-XI LDM mission, the crew conducted 88 EVAs during 100 operational days. This was actually a fairly high load as two EVAs per day were required mid-mission (approximately near the end of June) to take samples of the permafrost layer shifting for a variety of investigations. The physical and mental impact was apparent with increased stress [Bishop, 2010]. The workload for missions will continued to be investigated, but a multi-variable approach will be needed to factor in many mission architecture elements as well as human workload, and EVA metric collection will help create estimations in advance of planetary exploration. To estimate the Energy Expenditure (EE) in kJ/minute for EVA 4 (for the pilot data user weighing 72.6 kg and age 38) to Phobos Peak compared to standard exercise activities [Blair, 2001] (summarized in Table 4), calculations were based on Equation (1) below by Keytel et al. [2005]. Although this is crude estimate of energy consumption, simple devices and wearables have aided society to become more health aware while advance instruments aid in optimizing athletic performance. For comparison, the Hexoskin data from EVA 4 estimated 1810 kilocalories (or Calories, or Cal) burned (and 5986 steps), which would equate to approximately 10 kilocalories/minute for 3 hours. Even though the shirt was worn longer (4.5 hours) minimal energy was being used to prep for EVA and don/doff the spacesuit. However, this full value is important because some suit prep can be strenuous and is summarized for the pilot data user in Table 5. Future work could validate the step counter estimates with GPS data and investigate elevation gain. Selecting EE calculation methods are dependent on the accuracy of the raw data collected by a device.

$$EE = \mathbf{gender}[(-55.0969 + 0.6309(\text{heart rate}) + 0.1988(\text{weight}) + 0.2017(\text{age})] \\ + (1 - \mathbf{gender})[-20.4022 + 0.4472(\text{heart rate}) - 0.1263(\text{weight}) + 0.074(\text{age})] \quad (1)$$

Where, **gender** = 1 for males and 0 for females,
weight is in kg, and
age is in years.

**Table 4: Energy Expenditure comparing EVA 4 to standard data for same age/weight crewmember**

| Activity | EE (Calories/minute) |
|---|---|
| MDRS Crew 188 EVA 4 (airlock exit to airlock enter) | 9.58 |
| Light (ex: cleaning, walking) | 2.9 to 3.2 |
| Moderate (ex: cycling, low impact aerobics) | 4.2 to 6.4 |
| Hard (ex: swimming laps, skiing, high impact aerobics) | 7.7 to 10.2 |
| Very Hard (ex: mountain biking, basketball) | 10.2 to 15.3 |

**Table 5: Hexoskin pilot data for crewmember on EVA**

| EVA | EVA Type* | EVA Duration | Hexoskin Recording | Max. HR | Energy (Cal) | Steps | Hexoskin EE** (Cal/min) |
|---|---|---|---|---|---|---|---|
| 1 | Rover***, light Pedestrian | 0:57 | 3:07 | 131 | 635 | 1127 | 3.40 |
| 3 | Rover, light Pedestrian | 2:40 | 3:42 | 150 | 688 | 2508 | 3.10 |
| 4 | Hard Pedestrian (Phobos Peak) | 3:08 | 4:29 | 177 | 1810 | 5986 | 6.73 |
| 6 | Rover, hard Pedestrian (Lith Canyon) | 2:52 | 4:07 | 155 | 1028 | 4960 | 4.16 |
| 9 | ATV, moderate Pedestrian | 2:38 | 4:17 | 161 | 1107 | 3984 | 4.31 |
| 11 | ATV, light Pedestrian | 2:23 | 3:56 | 172 | 917 | 4475 | 3.89 |
| 13 | Rover, hard Pedestrian (Candor Chasma) | 2:32 | 3:43 | 171 | 1493 | 6862 | 6.70 |
| 14 | Hard Pedestrian (Hab Ridge) | 2:33 | 4:04 | 151 | 1051 | 6746 | 4.31 |

* Perceived difficultly using Blair et al. [2001]
** Note EE includes Hexoskin don, pre-EVA spacesuit don, spacesuit don, EVA, spacesuit doff, and recording stop.
*** The rover vehicles are two person ATVs.

## IV. Recommendations & Future Work

### A. Physical Metrics

The fundamental question remains the same as the F-XI LDM mission on what data is critical to record, or what EVA statistics are needed to properly estimate crew workload. There was redundancy in the MDRS Crew 188 process creating reports for The Mars Society and filling out an Excel sheet, while these could have been combined into a hybrid database entry with pre-determined columns and sections for a narrative. The higher accurate GPS data that was acquired will be highly valuable in the ongoing post-mission analysis. It would be ideal for the S.U.I.T. Lab to circulate pilot data to see what metrics other analogue research investigators think are most critical to record. Overall the GPS data is the most critical recording device for EVAs as it captures a detailed activity log of the entire operation that can be linked to photos, radio calls, and subjective feedback. Since GPS is not available (yet) on the surface of the Moon or Mars, it is recommended that a coordinate system is established early in the mission architecture. This would allow the data collection of distances traversed, altitude gain, distance/speed acquisition, and the ease of post-processing on mapping software. The mapping software was also used to help plan EVA routes and estimate approximate EVA cut-off distances and times. The cut-offs were based on MDRS safety protocols, but could be more accurately modeled with consumable estimations, i.e. based on the energy expenditure and time elapsed the crew would know their remainder of allowable time on EVA because of an assumed oxygen supply (or other input or output variable). These could establish operational rules and constraints to increase simulation fidelity.

### B. Biometrics

During this pilot test of equipment at MDRS, researchers were able to discover and solve some key issues concerning data collection. Throughout the MDRS EVAs a pulse oximeter was used to monitor the subject's heart rate and oxygen saturation levels. As the EVA progressed, the subject complained of discomfort at the ear clip attachment site. Researchers suggested a change in the recording location from the earlobe to the finger. Although this was a more comfortable solution to the ear clip, it became problematic once the spacesuit gloves had to be donned and limited use of that hand during EVA. Due to the redundant heart rate measures recorded by the Hexoskin, researchers were able to make the decision to forego the use of the oximeter to allow for maximum comfort. For future studies, a more comfortable pulse oximeter recording attachment will have to be used.

Another equipment concern from this study was the limited shelf life of the Hexoskin. As time progressed, the skin-tight shirt became prone to stretching and was looser at the end of the analogue. This led to concerns about the accuracy and completeness of the data that was logged. A complete swap of systems may be necessary to eliminate this inevitable stretching. The Zephyr Bioharness, a device used in previous research at the ERAU S.U.I.T. Lab, is capable of measuring the same data as the Hexoskin. Instead of being a shirt, however, this device is a strap capable of wrapping around the user's chest. This system may be more secure and reliable than the Hexoskin but it is placed directly under the spacesuit backpack shoulder straps, which may also lead to data loss, uncomfortable spots, or worse, injuries.

The Bluetooth temperature patch also proved to be problematic for researchers during MDRS. For future studies, a form of data collection other than Bluetooth will have to be implemented. A device capable of logging temperature data without Bluetooth would have been ideal, rather than transmitting to a phone, which needed to be within proximity (pants pocket) for the connection to stay established for data recording.

In addition to these medical device concerns, the weak air flow rates (from malfunctioning fans in the air supply) within the simulated spacesuits led to carbon dioxide building up in the helmets. One crewmember reported that they felt dizzy and faint and needed to rest multiple times on the EVA. This factor most likely caused an increase in heart rate. This particular hardware issue is not something the researchers at ERAU can fix, however, these changes in carbon dioxide concentration can be monitored through the use of a capnograph. This device will help researchers know when these events are occurring, producing a possible explanation for the heart rate spikes, and prevent possible crew fatigue. Future studies may include saliva samples to measure cortisol, an adrenal cortical glucocorticoid that is an indicator of sympathetic arousal. By improving on these issues, researchers will be able to collect more precise data during Mars analogue missions.

### C. Workload Energy Expenditure

There are several next steps to take in estimating energy expenditure or workload from this pilot data in order to prepare for future analogue (and real) missions. Integrated heart rate data over time for specific EVA timestamps is desired to look at the physical activity split between spacesuit donning, airlock exit, EVA work, airlock return, and finally spacesuit doffing. The concept would be to take these commercial off the shelf biometric monitoring devices like the Hexoskin and be able to compare simulations while cross-referencing with the physical GPS data. Heart rates are elevated during spacesuit donning from the physical labor of putting on heavy equipment and mental stimulation, so it would be important to track energy expenditure during those activities as well. This could be further explored with the MDRS Crew 188 data in future studies because the operational timestamps collected could be mapped to the data. Overall, understanding and estimating a crew's expected workload on a spaceflight mission will help us plan and execute more efficient exploration.

### D. Analogue Research Workshop

It is recommended that an analogue research workshop be established to bring operational researchers together with space agencies to help address EVA Gaps. The first attempt to synergize work was at AIAA SPACE and Astronautics Forum and Exposition (AIAA SPACE) in 2017, but the event was cancelled due to Hurricane Irma. AIAA SPACE was supposed to feature a Forum 360 panel on Analogue Research and a by-invite only meeting to discuss collaboration. This could possibly be established as a special breakout session of the NASA Johnson Space Center EVA Workshop or at the International Conference on Environmental Systems.

## V. Conclusion

This pilot study was aimed at testing physical and biomedical tracking devices in a Mars simulation to analyze energy expenditure for EVAs. The goal is to increase analogue exploration efficiency and fidelity. The investigation of human performance data with respect to energy expenditure will help identify physical limitations, thus providing explorers with a schedule that maximizes their potential on EVA. This process could create prescribed systematic field operations and data collection standards that will prepare humankind for surface planetary expeditions. It is the intent of the ERAU S.U.I.T. Lab to act as a bridge between international efforts and as a repository of simulated mission EVA data for analysis and enhancement of human spaceflight exploration.

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