Rim-to-Rim Wearables at the Canyon for Health (R2R WATCH): Experimental Design and Methodology

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Abstract. The Rim-to-Rim Wearables At The Canyon for Health (R2R WATCH) study examines metrics recordable on commercial off the shelf (COTS) devices that are most relevant and reliable for the earliest possible indication of a health or performance decline. This is accomplished through collaboration between Sandia National Laboratories (SNL) and The University of New Mexico (UNM) where the two organizations team up to collect physiological, cognitive, and biological markers from volunteer hikers who attempt the Rim-to-Rim (R2R) hike at the Grand Canyon. Three forms of data are collected as hikers travel from rim to rim: physiological data through wearable devices, cognitive data through a cognitive task taken every 3 hours, and blood samples obtained before and after completing the hike. Data is collected from both civilian and warfighter hikers. Once the data is obtained, it is analyzed to understand the effectiveness of each COTS device and the validity of the data collected. We also aim to identify which physiological and cognitive phenomena collected by wearable devices are the most relatable to overall health and task performance in extreme environments, and of these ascertain which markers provide the earliest yet reliable indication of health decline. Finally, we analyze the data for significant differences between civilians' and warfighters' markers and the relationship to performance. This is a study funded by the Defense Threat Reduction Agency (DTRA, Project CB10359) and the University of New Mexico (The main portion of the R2R WATCH study is funded by DTRA. UNM is currently funding all activities related to bloodwork. DTRA, Project CB10359; SAND2017-1872 C). This paper describes the experimental design and methodology for the first year of the R2R WATCH project.

Keywords: Cognitive markers · Quantifying fatigue · Physiological markers · Bloodwork · Extreme environments · Early health indicators

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1 Introduction and Project Scope

When in extreme environments, such as the Grand Canyon, civilian hikers must remain healthy enough to complete the task. If their health deteriorates beyond recovery, they may require rescue out of the Grand Canyon or face extreme, even fatal, consequences. The situation is similar for warfighters, although in a different context. Warfighters must remain healthy to deliver peak performance and ensure mission success; if they do not, the consequences are also extreme and include mission incompletion, injuries of a fellow team member which slow down the unit, or death. The recent explosion in wearable and agile devices to collect data for various combinations of biomarkers and performance metrics presents the opportunity to use wearable devices to provide the earliest possible warning of deteriorating health. It is unclear currently which markers are most pertinent and reliable for early indication of emerging illness, determining likelihood of task success, or determining a cause for a detected health decline. Most research into biomarkers indicative of health deterioration use lab settings or mild tasks to gauge performance. Studying Rim-to-Rim (R2R) hikers provides an opportunity to quantify which health markers could provide the earliest indication of health and performance decrement.

In this study, we collect three different forms of health data: (1) physiological data through wearable devices, (2) cognitive data through a cognitive task taken every 3 hours, and (3) blood samples obtained before and after completing the hike. We collect this data to examine physiological measures such as heart rate and oxygenation, decision making abilities, and the deeper, changing composition of hikers' biological processes. Data is collected from two different populations, civilian and warfighter hikers, to apply findings to various activities performed in extreme environments. We will describe our approach for data analyses in this paper. Our goal is to:

- understand the effectiveness of each COTS device and the validity of the data
- identify which physiological and cognitive phenomena are the most associated with overall health and task performance in extreme environments
- ascertain which markers provide the earliest yet most reliable indication of health decline
- identify significant differences between civilians' and warfighters' markers and their relationship to performance.

2 Study Collaboration

Many of the same physiological and cognitive phenomena that serve as indicators of declining health due to infection or chemical exposure, such as changes in heart rate, respiration, body temperature, pupil dilation, alertness, response speeds, and fatigue (Harden et al. 2015), are also associated with the human body's response to extreme altitude and temperature changes during intense physical exertion (Chase et al. 2005; Wickens et al. 2015). Thus, determining measurable changes in physiology and cognitive aptitude over time for individuals subjected to extreme altitude and temperature changes during intense physical exertion will provide critical learnings for the further development of advanced wearables capable of relaying the earliest indications of warfighter infection or chemical exposure. Volunteers included in this study will be subjected to these conditions as they attempt to complete the Grand Canyon Rim-to-Rim (R2R) hike.

The Grand Canyon 24.2 mile R2R hike represents a rigorous performance task including extreme changes in altitude and external temperature; this 24.2-mile hike involves an elevation change of nearly 7000 feet from rim to canyon floor, with temperature differentials up to 50 °F. Completing the R2R hike in one day is discouraged by the park service, but nevertheless has become a goal for many thousands of hikers each season. Each year, over 300 hikers require rescue from the canyon, with 175 people being airlifted from the canyon by helicopter. Many hikers develop symptoms of heat illness and dehydration, while a handful also present with symptoms of exercise-associated hyponatremia, a dangerous condition of low blood sodium levels. These illnesses are a testament to the rigor of this hike, requiring the body to endure fatigue and stress, and to adapt to rapidly changing environmental conditions (Garigan and Ristedt 1999; Ghiglieri and Myers 2001).

The University of New Mexico (UNM) Emergency Medical Service Consortium, providing emergency medical services (EMS) medical direction to Grand Canyon National Park rangers, recognized the heightened expense and safety risks associated with these rescues, and became interested in identifying nutritional and biological characteristics of hikers that were most likely to develop these (hyponatremia, dehydration, heat illness) and other critical health conditions while hiking the Grand Canyon. For the last two years, UNM Emergency Response physician and professor, Dr. Jon Femling, and former NPS Preventive Search and Rescue Ranger, Emily Pearce, have collaborated to study the food and water intake of Grand Canyon visitors hiking from the North Rim to the South Rim, or vice-versa. UNM hopes to better prepare hikers for their physical endeavor by correlating food and water intake to successful hiking outcomes. This grew into a funded project through DTRA and a partnership with Sandia National Laboratories, specifically cognitive psychologist Dr. Glory Aviña and geneticist Dr. Catherine Branda. The study was expanded to collect and analyze cognitive and physiological data collected through wearable devices. The interdisciplinary team of physicians, psychologists, computer scientists, statisticians, and biologists, as represented by this paper's authorship, set this study up to collect and holistically analyze data across various fields.

3 Empirical Background and Literature Review

3.1 Physiological Markers

One study, in the *Journal of Human Performance in Extreme Environments*, collected physiological (blood pressure, pulse, skin resistance) and psychological (anxiety) data from eight mountaineers who climbed Mount Everest. The researchers concluded that the data was connected to inhibition of overload, hypersensibility, and exhaustion. This study encountered both opportunities and difficulties with wearable devices in extreme environments: telemedical assessment is possible and necessary in order to determine and predict deficits in behavior and health risks for individuals at high altitudes, but requires devices tailored to such conditions (Stück et al. 2005).

Sleep deprivation, which can be related to extreme fatigue, has also been studied in the context of extreme physical demands. In a sample of ultra-marathon runners, there was a positive correlation between sleep-time before the race and race completion time (Poussel et al. 2015). One can conclude that signs of fatigue are early indicators of performance decrement. Therefore, it is necessary to investigate the physiological and cognitive indicators of fatigue.

Sensitivity of physiological measures to evaluate workload has also been investigated. Heart rate, blood pressure (from beat to beat), respiration and eye blinks were recorded in 14 subjects while they performed a complex task in a flight simulator (Veltman and Gaillard 1998). It was found that heart rate and blood pressure were both affected by task difficulty.

Physiological relationships, such as the impact of nutrition on performance, have been recognized by military contexts. The Uniformed Services University hosted a conference in July 2008, entitled "Warfighter Nutrition: Advanced Technologies and Opportunities" with Health Affairs and the Defense Advanced Research Projects Agency to develop strategic and tactical plans that could enhance Force Health Protection (FHP) by optimizing warfighter nutrition within the Department of Defense (DoD). The conference concluded that nutritional optimization represents an integral and proactive approach to prevent illness, injury, and performance degradation throughout all phases of military service. The overarching consensus achieved was that warfighter nutrition, as a cornerstone of FHP, warrants the critical attention of both medical and line leadership to move quickly to support current initiatives and future advanced technologies (Deuster et al. 2009).

3.2 Cognitive Markers

Extreme fatigue and stress on the body, caused by the demands of the physical environment, has negative effects on cognitive functioning. Temperature and altitude are both characteristics of the physical environment that impact cognitive ability. Enander (1989) and Hancock and Vasmatzidis (1998) found that even mild levels of thermal stress can have a negative impact on human performance. In a study conducted by Hocking et al. (2001), the Digit Span task and the AX-continuous performance task were used to measure attention, memory, verbal learning, information processing, and concentration. These cognitive abilities were negatively impacted when participants were exposed to extreme temperatures. Time and vigilance have also been found to share a curvilinear relationship with temperature: performance increases up to 85 °F, at which point it reliably decreases (Grether 1973). Cold temperatures also have an impact. A series of studies have examined the effects of cold temperatures on physical and cognitive performance. Exposure to cold air resulted in decreased performance on serial choice-reaction time tasks (Ellis 1982; Ellis et al. 1985) and working memory deficits have been reported after core body temperatures dip beneath 36.7 °C. In a study of naval special operations forces during actual winter warfare training, Hyde et al. (1997) found that cold temperatures were associated with decrements in hand strength and fine motor skills. Additionally, performance was especially affected when temperature varied over time and had extremely high temperatures (Enander 1989).

Altitude is another environmental characteristic that affects cognition. Cognitive deficits, particularly in memory, have been associated with altitude change (Muza et al. 2004). A cognitive test battery known as WinsCAT, which stands for the Spaceflight Cognitive Assessment Tool for Windows, was designed to assess neurocognitive status of astronauts on missions of long duration at various altitudes (Lowe et al. 2007). Habituation to altitude change seems to occur: decreased performance in the running memory task of the WinsCAT was reported between 0.5 and 4 hours after ascent, however these were not present at the tests given at 12 and 24 hours. It could also be that cognitive performance is affected by variability in altitude over short periods of time. The cognitive deficits reported also largely occurred before physiologic symptoms of mountain sickness were reported, indicating the need for further research on the relationships between possible markers.

Fatigue and stress also negatively influence cognitive abilities such as attention, executive function, memory, and reaction time (Karatsoreos and McEwen 2010; Bourne and Yaroush 2003). Highly trained astronauts given a cognitive battery of tests after acute sleep deprivation showed reduced affect vigilant attention, cognitive throughput, and abstract reasoning (Basner et al. 2015). In studies of fatigue and performance, fatigue is consistently shown to negatively impact visual attention, vigilance, decision-making, and other complex cognitive functions (Bourne and Yaroush 2003). This reduction in cognitive ability could be particularly problematic in extreme environments such as the Grand Canyon R2R—even simple tasks such as drinking water can have extreme consequences if not executed properly (Wickens et al. 2015).

3.3 Biological Markers

Part of the endeavor to understand the relationships between psychophysiology and performance is to know how to mitigate and address health risks when they arise. For example, altitude illness refers to a group of environmentally mediated pathophysiologies. Many people will suffer acute mountain sickness shortly after rapidly ascending to a moderately hypoxic environment, and an unfortunate few will develop potentially fatal conditions such as high altitude pulmonary edema or high altitude cerebral edema. Some individuals seem to be predisposed to developing altitude illness, suggesting an innate contribution to susceptibility. The implication of altitude-sensitive and altitude-tolerant individuals has stimulated much research into the contribution of a genetic background to the efficacy of altitude acclimatization. To date, 58 genes have been investigated for a role in altitude illness and, of these, 17 have shown some association with the susceptibility to, or the severity of, these conditions. Additional research is needed to examine the genome and hypoxic environments that contribute to an individual's capacity to acclimatize rapidly and effectively to altitude (MacInnis et al. 2010).

Although we know that these three markers collectively are indicators of performance, little research has been to done to understand the relationships between them. There is also limited research on their collective relationship to performance.

4 Experimental Design

Data collection will occur twice a year over two weekends, once in May and then again in October. This project is anticipated to take place over three years from October 2016 to May 2019 and has already completed its first weekend of data collection. Note that UNM has already completed two years of nutritional and survey data prior to the R2R WATCH study, which had its first round of data collection in October 2016.

The R2R WATCH team sets up check-in stations at the three major trailheads at the Grand Canyon: South Kaibab (SK), North Kaibab (NK), and Bright Angel (BA). The check-in stations are equipped with the data collection materials and researchers to interact with study participants. Since the R2R hikers can complete the hike in multiple directions (SK to NK, BA to NK, NK to SK, NK to BA), the three trailheads are prepared to collect both start and finish survey data, to accommodate hikers starting or finishing the R2R. There is also a team of researchers at the bottom of the canyon at Phantom Ranch to collect mid-hike survey data.

When hikers first approach one of the trailheads to start their hike, they are asked if they will be attempting the Rim-to-Rim hike in a single day. If they respond yes, they are asked if they are 18 years or older and would like to participate in a voluntary research study. If they again respond positively, they are taken to the check-in station and a researcher walks them through a consent process, as approved by the human subjects boards of the researchers' institutions. Each hiker is told that their data will be anonymized and that personally identifiable information will not be collected at any point of the study. Each hiker is given a wrist band with a unique identification number and then completes the start-hike survey. Once they complete the survey, they are asked if they would be willing to participate in the wearable device and/or blood work parts of the study. If they respond yes to either or both, they are led to a team of researchers, who provide a package of wearable devices for the hiker to wear (more details below), and/or to an RV where medical professionals collect blood samples. The hiker may ask as many questions as needed and is informed that they may withdraw from the study at any time. The hiker then proceeds to start the R2R.

Data for the wearable devices and blood parts of the study are only collected going from South Kaibab (start) to North Kaibab (finish) to streamline data collection. The R2R WATCH team works in shifts and mans the check-in stations for about 48 hours, starting at 2:00 am one morning and completing at 11:55 pm the next day.

Once hikers complete the R2R at their own pace, there is a check-in station to collect post-hike data. As previously stated, the survey post-hike data can be completed at any of the three trailheads. For the bloodwork and device data, post-hike data is collected at the NK trailhead. After they are offered congratulations and a chair, hikers' wearable devices are turned off, the data is saved, and the devices are collected. Hikers who originally consented to be in the blood portion of the study are also led to a tent where a post-hike blood sample is collected by a team of trained phlebotomists. Hikers are reminded that their data is anonymous and thanked for their participation in the study.

4.1 Participants

Data is collected from two populations: day-of volunteer civilian hikers and warfighter hikers. Volunteer hikers show up to the Grand Canyon to hike the Rim-to-Rim hike and agree to participate in the study as they approach the trailheads and study check-in stations. Participants are not recruited to hike the Rim-to-Rim; only hikers who are already planning to hike the Rim-to-Rim are enrolled in this study. This is to avoid encouraging an unfit participant who may become ill or injured due to lack of preparedness. Warfighter hikers are from a specific group in the military and are asked prior to the study weekend if they will be interested in completing a hike at the Grand Canyon as a personal training exercise. They are provided with the details of the R2R WATCH study. Their time is on a volunteer basis and hikers are told that they are under no pressure to hike the Rim-to-Rim at the Grand Canyon. This method is taken to draw a warfighter population to the Grand Canyon but still prevent recruitment so as not to increase risk of unprepared hikers hiking the R2R. Warfighters show up to the check-in station the same as civilian hikers and blend in with the normal population for security and protection purposes. Their data is given a different form of identification number but is also anonymized.

In October 2016, 288 pre and post surveys were collected and 50 participants provided wearable device data. In combination between a very small pilot study in May 2016 and October 2016, 51 participants provided pre- and post-bloodwork samples. Surprisingly, hikers' willingness to participate in a research study such as the R2R WATCH, even moments before they are about to start their hike, is fairly high. Most people who decline to participate do so because there is already a crowd of participants at the check-in station and the hikers do not want to wait, especially when the weather is cold.

4.2 Survey

Potential participants are invited to participate in a simple, short survey which is administered at the start, middle, and finish of their R2R. The survey contains questions regarding nutritional intake, basic biometric data, previous experience, activity times, and self-reports of fatigue and preparedness.

4.3 Wearable Devices

Civilian hikers are given one of two wearable device packages. "Basic package 1" includes a fitness wristwatch device, an environment temperature recording device that hangs on their pack, and an iPod Touch which contains a cognitive battery. "Basic package 2" includes a different fitness wristwatch device, the same temperature recording device, an enhanced GPS recording device, and the iPod Touch with the same cognitive battery. For warfighter hikers, the "Advanced package 1" contains multiple types of wearable devices: a different fitness wristwatch device, two environment temperature recording devices, a chest strap, a smart hat, a core temperature device, and an option to wear sensor shorts. The "Advanced package 2" also contains the same two temperature devices, a different fitness wrist watch, a chest strap, and smart hat. Although the packages are slightly altered after each round of data collection, the goal is to have a low-maintenance package for hikers who do not have much time to spend checking in to the study and more in-depth packages for hikers who are willing to put more time and effort into the study. All wearable devices are non-invasive and commercial off-the-shelf products. The wearable devices are changed out each year of the study so as to validate data collected through two weekends of data collection with the same set of devices but also diversify data collected through various wearable devices.

Each hiker, whether they have a basic or advanced package, is given an iPod Touch that they can wear in an armband while hiking or put in their pack. Each iPod Touch has a cognitive battery, which is a 5–10 minutes task with three different cognitive "games." The cognitive battery is developed by Digital Artefacts, a company that has created an application entitled BrainBaseline (https://www.brainbaseline.com/). BrainBaseline is a series of validated cognitive tests that can be put into a customizable application. Our customized app, installed on each iPod, includes two to three cognitive tests plus a fatigue survey to ensure the tasks can be completed quickly. Every three hours, an alarm goes off to remind the hiker to take the cognitive battery. Each participant also completes the cognitive battery at the start and end of the hike.

4.4 Bloodwork

Participants are asked to participate in two blood draws (start and finish). Peripheral blood is acquired through venipuncture by individuals trained in phlebotomy. Approximately one 6 mL tube of blood for serum and an additional 6 mL tube of blood for plasma is drawn from each hiker both at the start and finish of the participants R2R.

4.5 Starting and Finishing the Rim-to-Rim Hike

Each trailhead (South Kaibab, North Kaibab, and Bright Angel) is equipped with check-in stations for the pre- and post-hike surveys. The Rim-to-Rim hikers who participate in the wearable devices and bloodwork parts of the study are checked in at the South Kaibab trailhead and travel to the North Kaibab trailhead where they are checked out of the study once they finish the Rim-to-Rim.

4.6 Data Extraction

Blood obtained from patients before and after crossing the Grand Canyon is processed on site to obtain plasma and serum. These samples are labelled with the subject's study ID only and frozen, stored and archived for future use in the PIs −80 °F freezer in his UNM HSC based laboratory (MRF 108). These stored samples will be used for measurement of blood chemistries, inflammatory markers, heat-shock protein analysis, and other analysis of immune function and human performance.

5 Data Analysis

Data collected will serve two purposes. First, to establish a correlation between cognitive performance and health indicators, we will use confirmatory analyses based on data collected from wearable devices for relationships between health indicators and performance. Second, once we have established the connection between health measurements and cognitive ability, we would like to build a model for accurately predicting change in cognitive abilities based on health measurements.

5.1 Confirmatory Analysis

The objective of the confirmatory analyses is to validate the connection between health measures and cognitive abilities. As such, the statistical methodology will emphasize robustness and interpretability. We propose using a derived variable analysis (Hedeker and Gibbons 2006) to build summary measures from the longitudinal data collected by the devices. These measures will be correlated with cognitive performance at each of the trial times. A mixed-effects model should be used to account for subject variability because repeated measures are taken from each subject.

5.2 Predictive Models

Ultimately, we would like to build models to predict decline in cognitive abilities from data collected by the wearable devices. While the models used for the confirmatory analysis will inherently have some predictive power, there will be some important distinctions between the predictive and confirmatory analysis. First, the predictive model's focus is on prediction rather than interpretability of effects and validity of hypothesis tests. This frees us to use standard machine learning strategies to build models with complex interactions between variables. Second, in the confirmatory analysis, we can use the controlled structure of the study to find reliable indicators of fatigue. In our predictive model, we intend to use features that can be reliably constructed outside the environment of the original study. We propose using a derived variable analysis to generate features from the device data, but will begin with traditional machine learning methods, such as support vector machine (SVM) or neural nets, to build the predictive model and validate the model using cross-validation.

6 Conclusion

The R2R WATCH study focuses on measuring physiological, cognitive, and biological data as participants hike the Rim-to-Rim to understand which markers are most related to human performance and fatigue in extreme, physically challenging environments. Data collection so far has occurred over one weekend in 2016 and is anticipated to continue for five more weekends over the next three years. Our goal is to contribute to gaps in the empirical research by:

- collecting larger sample sizes than traditionally reported in extreme environment settings;
- looking at differences between civilian and special military groups;
- analyzing individual and combined effects across physiological, cognitive, and biological markers;
- refining our experimental design to target validity and reliability across all data sources (e.g., optical heart rate, cadence)

Overall, we aim to further understand how to identify the earliest indicators of performance decrement and fuse cognitive process with physiological and biological processes.

7 Graphics

Pictures were taken during October 2016 Data Collection (Figs. 1, 2, 3, 4 and 5).

Fig. 1. Check in station at the trailhead. The tent in the back is specially used for bloodwork.

Fig. 2. Hikers are asked to complete the post-hike survey as well as take the cognitive battery one last time to get a post-hike score.

Fig. 3. The Grand Canyon Rim-to-Rim hike has an altitude change of 3000–5000 feet and a 30–50 degrees Fahrenheit temperature change.

Fig. 4. Hyponatremia is a water-salt imbalance that affects many hikers that cross the R2R.

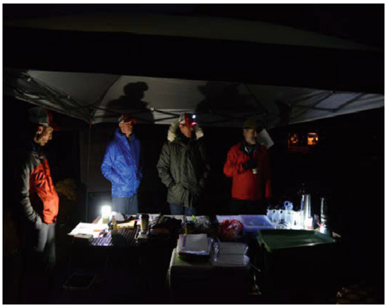

Fig. 5. The research team collects data for 48 hours straight, starting at 2 am one morning and finishing at 11:55 pm the following day.

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