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Using consumer-grade wearables and novel measures of sleep and activity to analyze changes in behavioral health during an 8-month simulated Mars mission

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ABSTRACT

For analyzing changes in an individual's health over time, this research has developed objective measures for comparing behavioral patterns, including sleep quality and activity scores. These novel measures of behavioral health have provided insight about how sleep debt accumulates after long, extended days, how sleep disruption and recovery from wakefulness occur during the night, and when cross-correlations exist between measures. This data-driven approach to quantifying behavioral patterns is informed by minute-by-minute data from consumer-grade, wrist-worn wearables. In this 8-month longitudinal study, Jawbone UP wristbands and the Jawbone UP API were utilized to collect minute-by-minute data about the behavior of crewmembers participating in a simulated Mars mission. To study the challenges of living and working on the planet Mars, for eight months, these crewmembers were confined to a Mars-like habitat, living in close quarters, isolated from the rest of humanity at a high elevation on Mauna Loa volcano in Hawaii, wearing mock spacesuits while exploring the volcanic terrain, consuming shelf-stable foods, restricted in water usage, relying on solar energy, and delayed in communications with 20-min lag-times for delivering messages to and from the crew. Analyzing the behavior of these astronaut-like individuals has led to the development of objective measures for quantifying sleep patterns, that have potential for contributing to the development of next-generation, smart wearables.

1. Introduction

Toward the goal of understanding behavioral health and performance challenges that astronauts will face on the first human mission to Mars, researchers have designed Mars analog environments for immersing crews in Mars-like conditions to measure biological, psychological, and social changes over time. During an 8-month simulated Mars mission conducted by Hawaii Space Exploration Analog and Simulation (HI-SEAS), six crewmembers were isolated from the rest of humanity, at an elevation of 8200-feet on the red, rocky slopes of Mauna Loa volcano in Hawaii (Appendix A). Crewmembers were confined to a living space of 1000 square-feet in a geodesic dome habitat, except when going outside the habitat to explore the volcanic terrain while wearing mock spacesuits. HI-SEAS crewmembers had to cope with group-living in close quarters, only consumed shelf-stable foods, were restricted in water usage, relied on solar energy, and had 20-min lag-times on e-mail systems to simulate Earth to Mars communication.

Conducting wearables research in a Mars analog research environment is an intermediate step between laboratory work and real-world data collection. In contrast to monitoring directed behaviors for short periods of time in a controlled laboratory setting, crewmembers are behaving autonomously without any direction from researchers on how to schedule their sleep and activity periods, which results in complex data that is similar to real world behavior. This research environment has limited modes of entertainment, nutrition, social interaction, and work projects for the crew, as compared to the innumerable factors on health and behavior in the real world. During the 8-month mission, wrist-worn wearables were implemented for recording sleep, activity, and heart rate data on a minute-by-minute basis., These data have

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potential for improving self-awareness and crew performance by promoting behavioral health changes, such as increased activity and more consistent sleep schedules.

Minute-by-minute wearable device data collection about the behavior of these "astronaut-like" crewmembers is a first step in the development of unobtrusive behavioral health and performance monitoring systems for future astronauts. As currently planned, a mission to Mars will be a 3-year journey for a small crew of 4-6 astronauts who will need to be resilient to the stressors of isolated and confined living conditions in a highly complex work environment [1]. Remote health monitoring has useful applications for astronauts on a mission to Mars, but also for many other health and performance applications, including at-home patient care, athletic training, and military deployments. Wearables, mobile applications, and telehealth systems enable examinations of health to extend beyond intermittent visits with coaches and medical professionals. Wearables data can be transferred to healthcare providers or other leaders and coaches as an automated, reliable method for gaining information about behavioral patterns that reflect lifestyle choices and health status, and wearable users can receive interpretations of these data as well as reminders and incentives for continuing treatment plans or practice regimens to promote behavioral health changes and improved performance. Other uses of behavioral monitoring with wearables may include health education, parenting and care-taking in families, as well as personal challenges to incentivize sleep hygiene and consistent exercise, including competitions among coworkers, friends, and family.

By recording sleep and activity data, wearables are collecting volumes of information about users. However, in the research community, there is uncertainty about the accuracy of consumer-grade, wrist-worn wearables for activity, sleep, and heart rate measurement. Consumer-grade devices have not reached a level of acceptability to replace gold-standard research methods, such as polysomnography; however, collecting data about a large population offers "big data" value, as it is estimated that over 60 million people in the United States are using consumer-grade wearables, such as Jawbone and Fitbit wristbands [2]. Although consumer-grade, wrist-worn wearables data are less accurate than clinical research tools for sleep analysis, this research is leveraging the high volume of data collected from these devices to analyze changes over time [3].

Here, concepts of sleep debt, sleep quality, activity patterns, and relationships between these measures are defined and quantified. These measures have shown promising potential for answering both practical questions of wearable device users, such as how much sleep is needed for a given individual, when is sleep debt accumulating over time, how do activity levels impact sleep quality, and open research questions about how to define what behavioral guidelines are most applicable for a given individual, how to measure when lifestyle choices are impacting biological health, and how does allostatic load accumulate over time [4,5].

2. Background

For comparing sleep performance, both the quantity and quality of sleep should be objectively measured. Astronauts on the ISS sleep on average about 6 hours per night which is less than is typical on Earth, and astronauts have been shown to have circadian misalignment while in space that is correlated to lower perceived sleep quality [6,7]. Sleep quality reporting has been shown to be more related to sleepiness than sleep duration [8]. Rather than relying on subjective assessments of perceived sleep quality, this research aims to develop objective sleep quality measures from wearables data for analyzing patterns of sleep and wakefulness during the night.

With Jawbone devices, sleep phases are defined as: deep sleep (D), light sleep (L), and awakening (A). In addition, Jawbone has a proprietary algorithm for computing a quality score for each sleep event. With the proprietary Jawbone quality score, longer duration sleeps tend to receive high quality scores, and short duration sleeps, even if they are entirely deep sleep, still receive low quality scores. Intuitively, it seems that a sleep session that has primarily deep sleep and is without awakenings should be scored as high quality; furthermore, research has shown that perceived sleep quality is not correlated with sleep duration [8]. However, as shown in Fig. 1, the Jawbone "quality" score is 93% correlated with sleep "quantity," or sleep duration. There is a need for sleep quality measures that differentiate various patterns of sleep and are not based solely on quantity.

The sleep quality score presented here is a weighted sum of sleep phase durations with a novel method of assigning penalties for awakenings during the night (Table 1 and Fig. 2). Sleep measures in the literature include sleep onset, wake after sleep

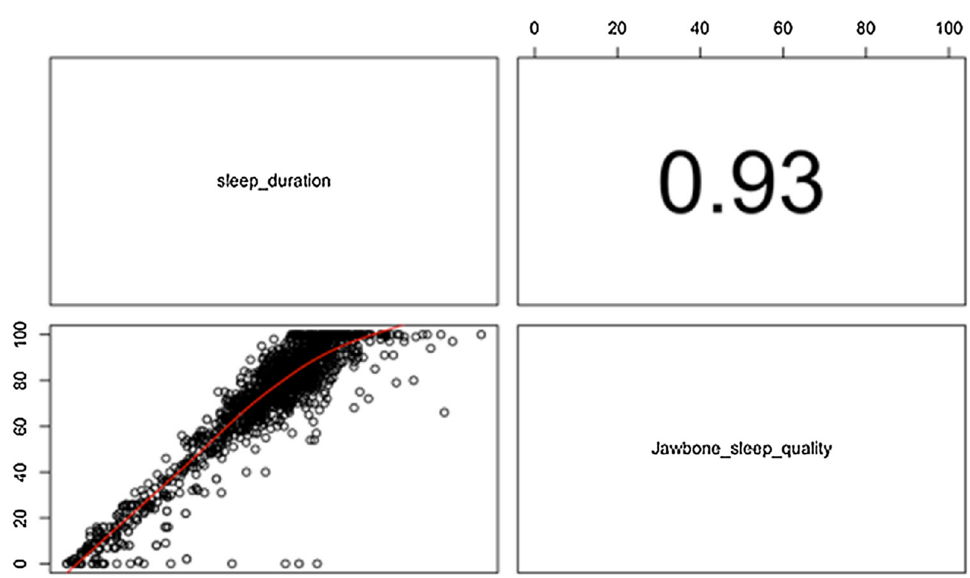

Fig. 1. Jawbone sleep quality score is highly correlated with sleep duration.