Sleep Patterns of Crewmembers in Mission IV of the Hawaii Space Exploration Analog and Simulation (HI-SEAS): A Pilot Study

Panagiotis Matsangas[1], Nita Lewis Shattuck[1], Christiane Heinicke[2], and Jocelyn Dunn[3]
[1] *Operations Research Department, Naval Postgraduate School, Monterey, CA*
[2] *Department of Earth and Life Sciences, Vrije Universiteit, Amsterdam, NL and International Lunar Exploration Working Group (ILEWG), NL*
[3] *School of Industrial Engineering, Purdue University, West Lafayette, IN*

The Hawaii Space Exploration Analog and Simulation (HI-SEAS) conducts simulated Mars missions to study the biopsychosocial impacts of isolated and confined living conditions and to assess space-flight crew dynamics, behaviors, roles and performance. This pilot study assessed the sleep-related behaviors of crewmembers during one month of Mission IV. Participants (N=4) wore actigraphs and completed activity logs. We identified substantive individual differences in sleep-related behaviors, physical activity and exposure to light between the crewmembers. These factors are important determinants of human alertness, stress, and mood. Due to the small crew of astronauts on a Mars mission and the conditions in which they will have to live for extended periods of time, the effect of these stressors on team performance, cohesion, and resilience may be exacerbated. Recommendations are provided for the holistic sleep-related assessment of the crewmembers participating in the 8-month Mission V.

INTRODUCTION

Background

Put forth in 2004, one of the goals of the "Vision for Space Exploration" is to "extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations" (NASA, 2004). In many ways, however, long-duration space exploration missions like the one to Mars remain a *terra incognita* with important questions yet to be answered. The mission of human exploration of Mars faces unprecedented technological and human challenges (Ad Hoc Committee of Members of the Space Medicine Association and the Society of NASA Flight Surgeons, 2008). The humans, both the crewmembers and ground control, will operate in physiologically and psychologically challenging conditions (Salas et al., 2015).

In particular, the team of astronauts on such a mission will be required to endure and sustain team performance never seen before (Salas et al., 2015). The environment in which the astronauts will live and work during the 6-month transit will be characterized by limited space and extreme isolation. During the approximately 3-year mission, astronauts will be required to operate as efficiently as possible and to function more autonomously than ever before due to a 3- to 22-minute one-way delay in communications.

As part of the overall effort of the journey to Mars, the National Aeronautics and Space Administration (NASA), as well as international agencies, has funded a number of simulations to assess team adaptation and resilience, and to explore the requirements to survive on Mars (Anglin & Kring, 2016; Basner et al., 2014). In general, these simulations are conducted in isolated environments with terrain characteristics similar to those of Mars. Such analogs include the Desert Research and Technology Study (D-RATS), the NASA Extreme Environment Mission Operations (NEEMO) (Anglin & Kring, 2016), and the Hawaii Space Exploration Analog and Simulation – HI-SEAS (www.nasa.gov/analogs).

HI-SEAS has previously completed four missions, two 4-months long, one 8-months long, and Mission IV which was 12 months long. The focus of the HI-SEAS project is to assess space-flight crew dynamics, behaviors, roles and performance, especially for long-duration missions (Binsted et al., 2016; Caldwell, Roma, & Binsted, 2016). The research goals of Missions I to IV were to study crew cohesion and crew performance. Beginning with Mission V, the focus shifted from crew cohesion and performance to crew selection and composition.

The HI-SEAS habitat

The HI-SEAS crews live and work in a solar-powered geodesic dome (i.e., the habitat) on the slopes the Mauna Loa volcano in Hawaii. The crews are isolated during their missions with only e-mail communication with a Mars-like 20-minute delay with the outside world. Communication with mission support also has this deliberate delay of 20 minutes. Without capability for real-time guidance from Earth, this Mars-like delay in communication simulates the requirement of crew autonomy and self-sufficiency.

Located at 8,200 feet above sea level, the dome is compised of an aluminum frame with a white vinyl covering. During most of the mission's duration, the dome is covered with a reddish camouflage. With 1200 fsquare feet of floor space and 13000 cubic feet of habitable volume, the habitat is divided into two levels. The common areas (kitchen, lab, work area, and bathroom) are located on the first level of approximately 900 square feet. The staterooms, one for each participant, and a half-bath are located on the 424 square foot upper level. The habitat also includes an attached workshop made from a converted shipping container. The space and amenities provided to the crewmembers of the habitat are an approximation of what a crew on Mars is likely to have. Crewmembers have a limited water supply and can shower only for a total of 6-8 minutes per week. When outside the habitat for extravehicular activities (EVAs), the crewmembers wear mock space suits. These EVAs are for exploring the geology of the surrounding volcanic terrain, collecting resources, adjusting the communication antenna, or for performing other habitat maintenance tasks.

The photographs in Figure 1 and 2 show an outside view of the habitat, and an inside view of the second level, respectively.

Figure 1. The HI-SEAS habitat (http://hi-seas.org/)

Figure 2. The inside of the berthing compartments (http://hi-seas.org/)

Study goals

The Mission IV pilot study had two objectives. First, we sought to assess the quantity, quality, and sleep-related behaviors of the crew of the HI-SEAS mission IV. Second, we wanted provide recommendations for how best to conduct a holistic assessment of crewmember sleep during Mission V.

METHOD

Participants

A team of six scientists and engineers participated in the 12-month mission IV of the HI-SEAS project. Four of the crewmembers volunteered to participate in the pilot sleep study (24 to 33 years of age, two males).

Equipment and Instruments

At the beginning of the sleep study, participants had been living and working for six months in the HI-SEAS habitat. Hence, there were restrictions for introducing extra workload in the crewmembers daily schedule. For this reason, our research approach in this pilot study was limited to using wrist-worn actigraphy as a non-invasive method to assess sleep patterns. The Philips Respironics Spectrum actiwatch was used to assess sleep. Data were collected in 1-minute epochs, and were scored using Actiware software version 6.0.0 (Phillips Respironics, Bend, Oregon). The medium sensitivity threshold (40 counts per epoch) was used, with 10 immobile minutes as the criterion for sleep onset and sleep end (all values are default for this software). The light detector was set to collect white, red, green, and blue light data.

We also used activity information from a log that the crew had been completing each day of the mission. Age, gender, typical bed time/wake up times, and typical daily sleep duration were used in our pilot study. The activity log also included questions about sleep/wake times, napping, the adequacy of sleep quantity (sufficient, insufficient), sleep quality (satisfactory, unsatisfactory), whether the participants felt sleepy during the day (yes, no), sleep habits, and the activities the participants were involved in prior to their sleep.

Procedures

This study was longitudinal and quasi-experimental in nature. During the 365-day HI-SEAS mission IV, participants resided in the habitat from August 28, 2015 to August 28, 2016. This study is based on data collected between 25 May and 30 June 2016. The Naval Postgraduate School (NPS) Institutional Review Board (IRB) determined that the analysis of the de-identified data provided to the NPS team did not constitute human subject research (IRB determination 2016.0017). In order to collect reliable light data from the actiwatches, participants were asked to roll their sleeves up to expose the light sensor to any light sources as much as possible. During their stay in the HI-SEAS habitat, participants did not have a set schedule to sleep or wake up.

Analysis

Statistical analysis was conducted with a statistical software package (JMP Pro 12; SAS Institute; Cary, NC). Data are presented as mean (M) ± standard deviation (SD). Sleep analysis was based on the actigraphy data, assisted by the activity logs to determine the start and end times of sleep intervals.

RESULTS

Behavioral Patterns

With the exception of Participant 4446, all participants showed good compliance in completing their activity logs. Participants reported that they did not use sleep promoting medications or eye masks. Participant 4583 reported using ear plugs in approximately 80% of his/her sleep episodes. None of the participants reported drinking coffee before bedtime. Participants reported having dinner between 1830 and 2000.

In terms of physical activities, Participant 4583 and Participant 5007 were physically active in 88% and 97% of days, respectively. Both crewmembers worked out frequently (using the treadmill, biking, etc.) and participated in EVAs. Participant 4583 engaged in 11 EVAs with an average duration of 172 minutes ranging from 39 to 351 minutes. Participant 5007 engaged in 8 EVAs with an average duration of 103 minutes ranging from 39 to 339 minutes. In contrast, Participant 7339 was physically active for 35% of the study days, participating in 13 EVAs (n=13, with an average duration of 44 minutes ranging from 15 to 79 minutes). Participant 4446 participated in 11 EVAs with an average duration of 107 minutes (41 - 341 minutes). Even though Participant 4446 did not complete any physical activity information in the activity log, data collected in another part of the study suggested that Participant 4446 worked out on average 2.5 hours per day and was the most physically active crewmember.

Participant 4583 and Participant 5007 reported 8.7 hours of screen time per day, ranging from 2 to 14 hours (no data for Participant 4446 and Participant 7339).

Sleep

During the entire period of the study, participants spent on average 8.6 ± 1.5 hours time in bed (TIB) and slept for 7.8 ± 1.4 hours. Daily sleep was distributed in 1.2 ± 0.4 sleep episodes per day; some naps were evident. In terms of daily sleep duration, Participant 7339 slept substantively less than the rest of the participants. These results are shown in Table 1. Participant 4446 and Participant 7339 have the largest difference between their rest and sleep duration, approximately one hour. No statistically significant time trends were identified.

Table 1. Sleep metrics, M±SD

Daily sleep metrics	Part4446 28 yrs	Part4583 30 yrs	Part5007 24 yrs	Part7339 33 yrs
TIB, hrs	8.4±0.9	9.5±1.4	8.7±0.9	7.7±1.9
Sleep, hrs	7.4±0.7	8.8±1.3	8.2±0.8	6.7±1.6
Sleep episodes, #	1.1±0.2	1.2±0.5	1.2±0.4	1.1±0.3

The daily sleep duration by participant is shown in Figure 3. The horizontal dotted line represents the average daily sleep duration for all participants. From lower to upper, the horizontal lines in each box represent the 25th, the 50th, and the 75th percentiles respectively. Participants with the highest and lowest daily sleep amount had the largest variability in their daily sleep. Specifically, Participant 4583 had a range of 5.3 hours, from 6.68 to 12 hours of sleep per day. Participant 7339 had a range of 6.52 hours, from 2.88 to 9.4 hours of sleep per day.

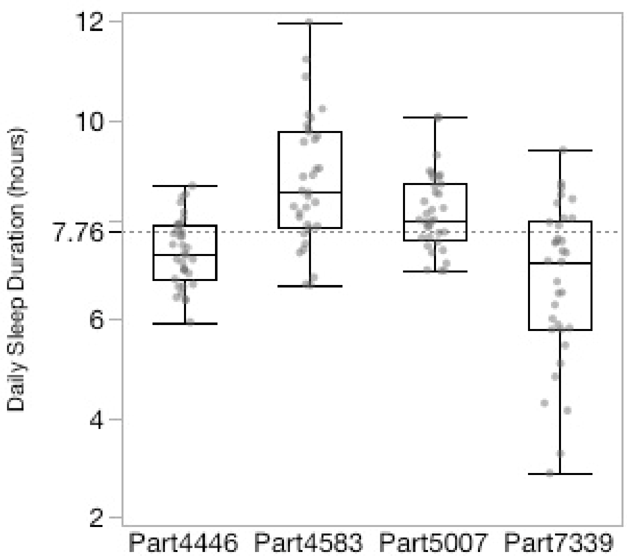

Figure 3. Daily sleep duration by participant. Each dot represents one day.

Notably, our data suggest that crewmembers did not change their general pattern of pre-mission bed times during the data collection period. Participant 4446 continued to go to bed at approximately 11 pm, whereas Participant 4583 and Participant 7339 were awake until after midnight. Their wake up times, however, shifted to the right; that is, those crewmembers woke up later. Consequently, sleep duration increased on average by approximately one hour compared to the sleep duration crewmembers reported they received before the mission.

Next, we assessed crewmembers' opinion about sleep quantity, sleep quality, and whether they felt sleepy. Our results showed an interesting pattern. Even though having slept less than the other crewmembers (~6.7 hours per day), Participant 7339 felt satisfied with sleep in terms of quantity (91% "sufficient" responses) and quality (97% "satisfactory" responses). Participant 7339 also reported feeling sleepy on only 9% of the days. In contrast, Participant 4583 and Participant 5007 were less content with their sleep. Even though both crewmembers slept on average more than eight hours per day, they felt their sleep amount was insufficient, their sleep quality was unsatisfactory, and reported feeling sleepy for two-thirds of the study days.

In terms of exposure to light, our analysis showed the differences in behavioral patterns between participants, with Participant 4446 resting and waking up earlier than the other participants. Participant 4446 was also exposed to more white light between 1100 and 1700 hours compared to the other crewmembers. In contrast, Participant 7339 was exposed to less daylight. Interestingly, Participant 7339 had a source of blue light in the room while sleeping. These results are shown in Figure 4.

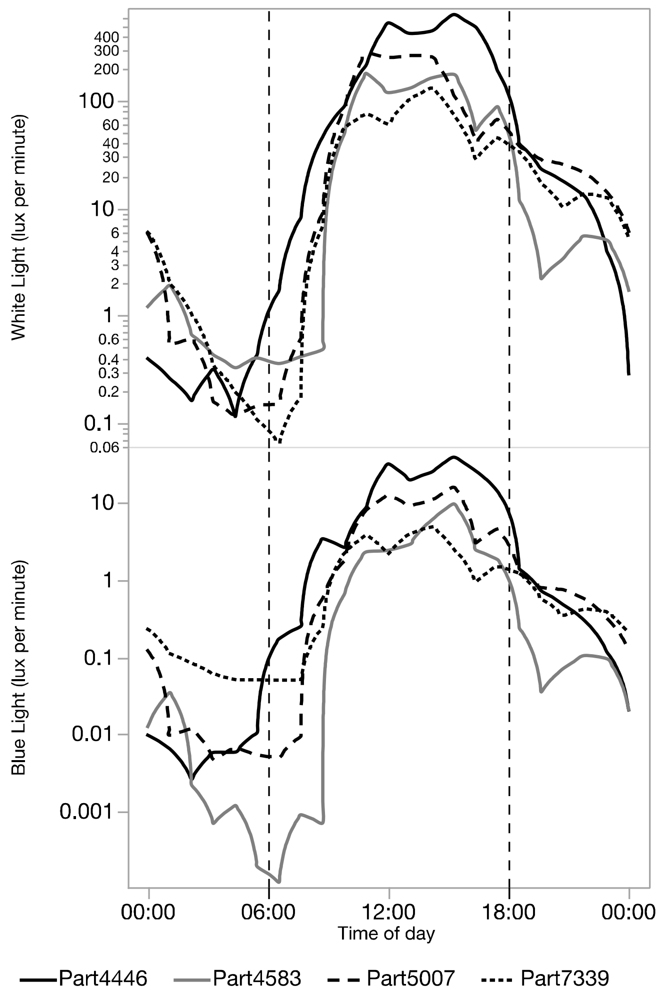

Figure 4. White and blue light exposure by time of day (in lux per minutes).

DISCUSSION

Overall, our results showed important behavioral differences between the four crewmembers who participated in this pilot study. These differences were obvious in daily sleep duration, in the variability of daily sleep between days, and in the timing of sleep. In general, three of the four crewmembers slept on average close to eight hours per day or more, which is the physiological recommended sleep amount for their age group. Two findings were interesting. First, the two participants sleeping on average 8.2 and 8.8 hours per day were less satisfied with their sleep both in terms of quantity and quality. Second, the participant with the least, and most variable, daily sleep duration was also less physically active compared to the other crewmembers in the study.

Even though definitive answers cannot be provided from the data from this pilot study, we postulate that light exposure may have contributed to the mixed results of sleep duration, timing, and satisfaction, as well as in the physical activity. The participants were exposed to sunlight during their EVAs, and were also using light emitting devices for many hours every day.

In conclusion, findings from this pilot study identified substantive individual differences in sleep-related behaviors, physical activity and exposure to light between the crewmembers. These factors have been shown to be important determinants of human alertness, stress, mood, and other aspects of behavioral health (Buckley, 2006; Salas, Cooke, & Rosen, 2008). Due to the small crew of astronauts on a Mars mission and the conditions in which they will have to live for extended periods of time, the effect of these stressors on team performance, cohesion, and resilience may be exacerbated (Maynard & Kennedy, 2016).

Based on our findings in this pilot study, our assessment during the ongoing 8-month Mission V of the HI-SEAS project will focus on the following topics of interest:

- To assess mood and sleep quality attributes using standardized questionnaires (Bastien, Vallieres, & Morin, 2001; Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989; Johns, 1991; McNair, Lorr, & Droppelman, 1971).
- To explore the association between morningness-eveningness tendency (Terman, Rifkin, Jacobs, & White, 2001) and sleep patterns, sleep-related behaviors, and mood.
- To assess changes in behavioral patterns, mood, sleep attributes, and physical activity during the course of the 8-month mission.
- To explore further the effect of ambient light and light emitted from hand-held devices on the behavioral patterns of the crewmembers.

Study limitations

This pilot study had a number of limitations. We did not have information about participant behavioral patterns before the study. Standardized mood and sleep quality questionnaires were not incorporated. The period during which sleep data were collected, approximately one month, was not enough to assess longitudinal changes in sleep patterns.

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