Behavioral Health and Performance in Space

David F. Dinges, MS, MA, PhD
Professor and Chief, Division of Sleep & Chronobiology
Director, Unit for Experimental Psychiatry
Department of Psychiatry
Perelman School of Medicine
University of Pennsylvania
Philadelphia, PA

TRISH Red Risk School 2019
Translational Research Institute for Space Health (TRISH) webinar series
June 6, 2019
11:00 – 12:00 CT (12:00 – 1:00 ET)

Disclosure: The presenter has research funding from NASA and TRISH. The information and views expressed in this presentation are those of Dr. Dinges, and do not represent NASA, TRISH or other organizations.
BHP problems in space are a potential impediment to a successful exploration mission.

**Historical reasons for concern about BHP issues in space:**

- Some prior Russian space flight missions were terminated early due to “psychological decrement” (Sipes et al., 2017).

- In 1973-74 a Skylab mission had a 1-day “mutiny” by the 3-person crew, due to the high workload during the 84-day mission, which caused the crew to fall behind. After 6 weeks, the crew turned off all communication with ground control for a day.

- In 2007 an astronaut was arrested for attempted kidnapping of a 2nd astronaut. The NASA Administrator commissioned an independent NASA Astronaut Health Care System Review Committee to examine how well NASA attended to the mental health of its astronauts.
Potential factors that may interact to compromise astronaut behavioral health and performance

Adverse effects on health and behavior, if not mitigated

- Spacecraft Complexity & Habitat Limitations
- Mission Control & Other Astronauts
- Emergencies
- ICP / VIIP
- Cognitive Problems
- Hygiene Concerns
- CO₂ ↑ O₂ ↓
- Nutrition
- Slam-Shifts
- Monotony
- Inadequate Sleep Time/Quality
- Confinement & Isolation from Family
- Microgravity
- Radiation
- Medications
- High Workload
- Non-24h Light-Dark Cycles
- Noise
Examples of behavioral health issues during exploration missions & simulations

- Drug addiction in crewmember: Nansen North Pole expedition (1893)
- Psychotic state in crewmember: Shackleton South Pole expedition (1907)
- Bizarre/irrational behavior post-flight: ISS
- Anger at Mission Control (MC): Skylab, ISS, Mars 520-day mission
- Crew mutiny (turned off radio to MC): Skylab
- Stress from physiological effects of microgravity: Skylab, ISS
- Complaints about cognitive “space fog”: ISS
- Psychosomatic manifestations of conflict: Soyuz missions
- Stress/cognitive deficit from inadequate sleep: ISS, Mars 520-day mission
- Circadian disruption eroded crew coordination: ISS, Mars 520-day mission
- Inability to maintain daily exercise required: ISS, Mars 520-day mission
- Frustration at outside communication via MC: ISS, Mars 520-day mission
- Unhappiness about food quantity/quality: ISS, Mars 520-day mission
- Adverse reaction to psychoactive medication: ISS, Hypnotic Pharmacodynamics
- Disruptive behaviors; crew conflict; deception: Mir, Mars 520-day mission
- Alcohol-induced crew conflict aborted mission: Russian 110-day chamber study
- Deceptive behaviors by crewmembers: Russian 105-day chamber study
- Personality disorder: Mars 520-day mission
- Depression: Mars 520-day mission
- Impulsive actions/errors: Mars 520-day mission
- Concern about loved ones on Earth: All missions
Humans to Mars (and back):
Can BEHAVIORAL HEALTH adapt to being in microgravity or partial gravity and away from Earth for 1.5 years?

The shortest trip to Mars will require 8 months in flight, using an elliptical orbit and currently planned rocket technologies.

In order to have sufficient fuel to get back to Earth, it may be necessary to spend 3 months on Mars. The return trip may require another 8 months in flight.

A round-trip Mars mission using currently planned technologies may require a minimum of 1.5 years. Most of that time the astronauts will be in an isolated, confined, extreme (ICE) environment.

Mars is slightly more than 10% of Earth’s mass, with a third of Earth’s gravity.
Human health and effective functioning require circadian (~24h) rhythms and daily sleep. Their origin dates to Earth’s beginning.

Giant impact hypothesis: Mars-size planet impacted Earth approximately 4.1 billion years ago, tilting Earth on its axis 23.5°, slowing Earth’s rotation on its axis, and producing the Moon.

Early Earth

Theia (planet)

Earth’s Moon

Moon rocks show oxygen isotope and aluminum compositions similar to Earth rocks

Earth rotates every 24h through a light-dark cycle and annually around the Sun

24h cycle

2017 Nobel Prize in Physiology or Medicine
Jeffrey Hall, Michael Rosbash, Michael Young

Human brain has a ~24h (circadian) biological clock sensitive to light

Factors stimulate transcription of genes encoding proteins. As the proteins accumulate they act as transcriptional repressors of their own genes.

Melatonin receptor binding on the human suprachiasmatic nuclei (SCNs) in the hypothalamus

Circadian rhythms in physiology occur throughout our bodies
Examples of space analog environments used to study the effects of isolation, confinement, and extreme (ICE) conditions on crew behavioral health, performance and crew coordination.

HAUGHTON MARS (Devon Island)

Harsh polar desert in Canadian High Arctic

NEUMEYER STATION (Germany)

Antarctica

ISS

Low Earth Orbit

HI-SEAS (isolated habitat 8,200 ft above sea level on Mauna Loa)

Mars-like environment for high-fidelity field work by humans and robots.

NEEMO Aquarius

Research lab on Atlantic ocean floor 3.5 miles off Key Largo, FL.

NEK facility

NASA JSC

HERA

Moscow
Reaction Self Test (RST) on ISS

• Reaction Self Test (5 min.) is a computerized PVT-B (3-min) and subjective responses (2 min).

• The PVT-B measures performance parameters:
  o Psychomotor slowing (response speed)
  o Lapses of attention (errors of omission)
  o Impulsive responses (errors of commission)
  o Stability of alertness

• Subjective measures (VAS) include:
  o Workload
  o Stress
  o Fatigue
  o Tiredness
  o Sleep-wake times
  o Sleep quality
  o Sleepiness
Reaction Self Test (RST) visual analog scales (VAS)

Astronaut could move the pointer in either direction in response to the question: How are you feeling right now?

Astronauts performing RST on ISS

- **Workload?**
  - Very high
  - Very low

- **Sleep quality?**
  - Good
  - Poor

- **Tiredness?**
  - Tired
  - Fresh, ready to go

- **Mental fatigue?**
  - Mentally sharp
  - Mentally fatigued

- **Physical energy?**
  - Energetic
  - Physically exhausted

- **Stress?**
  - Not stressed
  - Very stressed

- **Sleepy?**
  - Very sleepy
  - Not sleepy

Pre-set pointer

How difficult was it to perform the PVT-B test?

- O Not difficult
- O Somewhat difficult
- O Very difficult
N = 24* astronauts on N = 19 ISS increments (2009-2013) Crewmembers from: USA, Canada, Europe, Japan (5 females)

<table>
<thead>
<tr>
<th>Time of RST:</th>
<th>Morning</th>
<th>Evening</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-flight RSTs:</td>
<td>213 (68%)</td>
<td>181 (57%)</td>
<td>394 (63%)</td>
</tr>
<tr>
<td>In-flight RSTs:</td>
<td>1,105 (88%)</td>
<td>1,004 (80%)</td>
<td>2,109 (84%)</td>
</tr>
<tr>
<td>Post-flight RSTs:</td>
<td>191 (80%)</td>
<td>162 (67%)</td>
<td>353 (74%)</td>
</tr>
<tr>
<td>Total RSTs:</td>
<td>1,509 (83%)</td>
<td>1,347 (74%)</td>
<td>2,856 (79%)</td>
</tr>
</tbody>
</table>

*N = 21 of 24 astronauts provided the bulk of the data.
Comparison of mean total sleep time (SEM) within n=21 astronauts (letters) across 3 mission phases

A subset of astronauts (6/21 = 28%) had at least 2 mission phases in which sleep averaged >7h/day (and none <6h/day).

A subset of astronauts (7/21 = 33%) had at least 2 mission phases in which sleep averaged <6.4h/day (and 7 who had at least 1 phase <6h/day).

Pre-Flight = blue   In-Flight = red   Post-Flight = green
Total sleep time ≤6h on ISS involved slower PVT-B response speeds relative to longer sleep times.

Covariate analyses indicated that astronauts were slower on the evening test bout (p = 0.0206) and if they reported being distracted (p = 0.0052), while age, gender, and the use sleep and pain medications were not associated with PVT response speed.

Based on review of 5,314 scientific articles, the American Academy of Sleep Medicine and Sleep Research Society used a modified RAND Appropriateness Method to conclude that “Adults should sleep 7 or more hours per night on a regular basis to promote optimal health.”

The report also found that sleeping less than 7 hours per night on a regular basis was associated with adverse health outcomes, including weight gain and obesity, diabetes, hypertension, heart disease and stroke, depression, and increased risk of death. Sleeping less than 7 hours per night was also associated with impaired immune function, increased pain, impaired performance, increased errors, and greater risk of accidents.

In-flight some astronauts sustained a high level of alertness and psychomotor speed (left graphs), while others appeared to be less able to do so (right graphs).
Astronauts rated their stress levels higher 1-week Pre-Flight; in the 4th mission quarter In-Flight; and on Weekdays relative to Weekends

**Graph A:** Stress ratings 1-Week Pre-Flight were higher than ratings In-Flight ($p = 0.0004$) and Post-Flight ($p = 0.0001$, $p = 0.0005$).

**Graph B:** Stress ratings in the 4th mission quarter (Q4) were significantly higher than in Q1 ($p = 0.0037$) and in Q2 ($p = 0.0038$).

**Graph C:** Stress ratings were higher on weekdays than on weekends ($p = 0.0004$).

Daily moving average VAS stress ratings during 6-month ISS missions (N=21 astronauts). Linear trend line projects the ratings to 360 days.

Increasing to “100 = very stressed”

Decreasing to “0 = not stressed”
Russia’s facility and crew for the simulated 520-day mission to Mars

Multinational Mars 520 Crew

Pressurized Facility
Volume & configuration comparable to a spacecraft. Artificial atmospheric environment. Isolation from Earth’s daily changing environment.

- 550 cubic meters (1804 cubic feet)

Sleeping Quarters

Actigraph was worn continuously throughout the mission
- Sleep timing and duration
- Activity levels
- Light intensity levels
Data 98% valid & complete (4,396,333 min = 73,272 h)

10-min assessments (AM & PM) once a week during mission
- PVT-B performance
- VAS (fatigue, etc.)
- Moods & depression
- Conflicts
- Sleep quality
Data 100% complete & valid (N=888 tests)
Data 100% complete & valid (N=444 tests)

Mars Landing
In the 17 months of confinement (to/from Mars) only 2 (green areas) of the 6 crewmembers coped well and maintained good behavioral health.

A. Sleep displaced into diurnal phase; and severe social isolation
B. Disrupted sleep-wake periodicity; out of phase with crew 16% of mission

C. Adequate sleep quantity & quality; good performance & mood
D. Adequate sleep quantity & quality; frequent exercise; optimal performance & mood

E. Chronic poor sleep quality; depressed mood; conflicts
F. Chronic sleep loss; impulsivity; poor sleep quality; conflicts
Conflicts decreased in frequency with communication delays. Crewmembers with more behavioral health problems also reported greater conflicts.

Crewmember e was depressed throughout the mission.

Crewmember a was socially isolated throughout the mission.

Crew members c & d had good behavioral health by maintaining stable circadian sleep-wake and exercise cycles and frequent contact with other crewmembers.

Crewmembers e and f remained socially isolated throughout the mission.
The use of sleep medications In-Flight was associated with reduced TST per day \((p < 0.0354)\), which may reflect the use of sleep medications to increase TST In-Flight. The use of pain medications In-Flight was not associated with TST per day.

*Mean ± SEM*
NASA JSC operational ground testing randomized control trial protocol to optimize astronaut sleep medication efficacy and individual effects on abrupt (emergent) awakening from sleep.*

Attention deficit after abrupt awakening on 10mg zolpidem, and 30 minutes later

Working memory deficit after abrupt awakening on 10mg zolpidem and 30 minutes later

Current preventative measures taken by NASA to promote behavioral health and performance in space

- Astronaut Selection
- Astronaut Candidate Training
- Stress Resiliency
- Cross-Cultural Training
- Conflict Management
- Expeditionary Skills
- Unassigned Crew Training
- Annual Behavioral Medicine Examinations
- Clinical Services
- Family Support Office
- Assigned-Crew Training
- Crew Medical Officer Training

- Psychological Factors of Extended Space Flight (Crew and Family)
- Psychological Support Familiarization
- Psychological Support Planning
- Practical Planning for Long Duration Missions
- Pre-flight Assessments
- In-flight Tracking and Discussions
- Private Psychological Conferences via videoconferencing per 2 weeks
- In-flight Psychological Support Services
- Private Family Conferences
- Crew Discretionary Events
- Post Flight Assessments & Debriefings
Measures for determining Behavioral Health status have been undergoing feasibility validation in space analogs and on ISS.

<table>
<thead>
<tr>
<th>Measures Completed</th>
<th>Complete Data Acquisition from HERA (N=16)</th>
<th>Complete Data Acquisition from Neumayer (N=7)</th>
<th>Data being Collected on ISS (N=2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROBoT-r Tests</td>
<td>N = 238 Tests</td>
<td>N = 73</td>
<td>In progress</td>
</tr>
<tr>
<td>Cognition Tests</td>
<td>N = 288</td>
<td>N = 82</td>
<td>In progress</td>
</tr>
<tr>
<td>Journals</td>
<td>N = 156</td>
<td>N = 37</td>
<td>In progress</td>
</tr>
<tr>
<td>Visual Analog Scales (12 VAS items)</td>
<td>N = 960</td>
<td>N = 82</td>
<td>In progress</td>
</tr>
<tr>
<td>Sleep Diary Days</td>
<td>N = 480</td>
<td>N = 165</td>
<td>In progress</td>
</tr>
<tr>
<td>Conflict Scales</td>
<td>N = 480</td>
<td>N = 82</td>
<td>In progress</td>
</tr>
<tr>
<td>Social Desirability Scales (SDS-17)</td>
<td>N = 16</td>
<td>N = 7</td>
<td>In progress</td>
</tr>
<tr>
<td>Beck Depression Inventories (BDI-II)</td>
<td>N = 80</td>
<td>N = 81</td>
<td>In progress</td>
</tr>
<tr>
<td>Profile of Mood States (POMS-SF)</td>
<td>N = 572</td>
<td>N = 84</td>
<td>In progress</td>
</tr>
<tr>
<td>Team Measures</td>
<td>N = 1,405</td>
<td>N = 444</td>
<td>In progress</td>
</tr>
<tr>
<td>Wrist Actigraphy Days</td>
<td>N = 204 days</td>
<td>N = 1,764 days</td>
<td>In progress</td>
</tr>
</tbody>
</table>