Sleep Quality Questionnaire
Short-Duration Flyers

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National Aeronautics and
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Johnson Space Center
Houston, TX 77058

July 2013
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## Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/G</td>
<td>Air/Ground</td>
</tr>
<tr>
<td>BHP</td>
<td>Behavioral Health and Performance Element</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>EVA</td>
<td>extravehicular activity</td>
</tr>
<tr>
<td>HRP</td>
<td>Human Research Program</td>
</tr>
<tr>
<td>ISS</td>
<td>International Space Station</td>
</tr>
<tr>
<td>LSAH</td>
<td>Longitudinal Study of Astronaut Health</td>
</tr>
<tr>
<td>STS</td>
<td>Space Transportation System</td>
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<tr>
<td>WCS</td>
<td>Waste Collection System</td>
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I. Overview of Study

In 2009, the NASA Human Research Program (HRP) Behavioral Health and Performance Element (BHP), in collaboration with the Space Medicine Division, implemented a study to characterize the subjective sleep experience of astronauts during Space Shuttle missions. The study participants were NASA astronauts who have flown Shuttle since the “Return to Flight” missions (Space Transportation System [STS]-114) in 2005, through those who flew on STS-130 in February 2010. A total of 64 astronauts completed both the survey and the interview, and an additional 10 astronauts completed just the interview, rendering this study the largest systematic assessment of the subjective sleep experience in space.

The content of the survey relates to sleep during Shuttle missions and sleep on Earth, including factors that may inhibit sleep (“stressors”) both in space and on Earth; and specific countermeasure strategies used and their subjective effectiveness. Follow-up interviews with each participant provided an opportunity to gather additional information on sleep stressors and countermeasures.

The survey results indicated individual variability exists with regard to sleep in flight. Some factors predictive of reported sleep quality were identified. Results from this investigation will be used to provide recommendations to astronauts preparing for spaceflight missions to the International Space Station (ISS), the Soyuz, and those training for future missions. The findings are particularly relevant to spacecraft design for exploration class missions since such vehicles will be of limited net habitable volume owing to launch and mass constraints. Additionally, this study will also shape the BHP research strategy by helping identify gaps related to needed countermeasure development and implementation, as well as providing insight into the use of sleep medications in space.

II. Background and Significance

In preparation for future long-duration missions beyond low Earth orbit, NASA BHP conducts and supports applied research to address three human health and performance risks: Risk of Behavioral and Psychiatric Conditions (“B-Med Risk”); Risk of Performance Decrement Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team (“Team Risk”); and Risk of Performance Errors due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness and Work Overload (“Sleep Risk”). BHP, in collaboration with internal and external research investigators, NASA flight surgeons, astronauts, and mission planners, identifies “gaps” in knowledge and technology within each risk, particularly when considering future exploration missions. Specific gaps related to quantifying the likelihood and consequences of behavioral health and performance risks, and gaps related to mitigating risks, are fully discussed in the NASA Human Research Program Integrated Research Plan (HRP-47065, National Aeronautics and Space Administration, 2010).
BHP subsequently manages and conducts research tasks to address and close these gaps through either risk assessment and quantification or development of countermeasures and monitoring technologies. The resulting deliverables, in some instances, support current medical operations and/or mission operations for the ISS, particularly for the Sleep risk. BHP utilizes a risk-to-mitigation framing strategy, promulgated by the HRP, that ensures research will yield deliverables and products that are operationally relevant and acceptable to the end user.

The current effort provides subjective information related to several knowledge and technology gaps: Sleep Gap 2 (How is performance in spaceflight affected by fatigue due to sleep loss, circadian desynchronization, extended wakefulness and work overload?, and Does sleep loss, circadian desynchronization, work overload and extended wakefulness as it is experienced in spaceflight affect well-being, crew interaction, and performance? If so, how?) Sleep Gap 6 (How can individual crewmembers optimally use sleep and alertness medications prior to and during spaceflight?), Sleep Gap 9 (What are the countermeasures needed to treat/recover from chronic partial sleep loss, work overload, and/or slam sleep shifting?), and Sleep Gap 10 (What flight rules and requirements improve sleep, circadian desynchronization, fatigue, and work overload?).

Sleep issues have been noted by astronauts during recent missions and since the days of Apollo (Flynn-Evans et al., 2012; Dijk et al., 2001; Frost et al., 1976; Monk et al., 1998; Santy et al., 1988; Scheuring et al., 2007). Objective evidence, from a preliminary data analysis on Shuttle missions (n=64), indicates that sleep is markedly reduced on orbit, to approximately 6 hours per night, and at times prior to critical operations (Flynn-Evans et al., 2012). In addition, given the large body of ground-based evidence demonstrating sleep loss negatively affects performance (Ayas et al., 2006; Barger et al., 2006; Dingess et al., 1997; Landrigan et al., 2004; Lockley et al., 2004; Mollicone et al., 2007; Van Dongen et al., 2003) and the association between chronic sleep decrements and health outcomes (Institute of Medicine, 2006), it is essential to characterize and mitigate this risk in spaceflight. Developing mitigation strategies, however, requires a better understanding of the factors that may affect sleep in flight (Korth, Leveton, and Dingess, 2006; Whitmire et al., 2008). Through interviews with astronauts regarding their sleep experience during Shuttle missions, this investigation provides subjective knowledge related to stressors and countermeasures in the spaceflight environment for short durations and limited volumes.

**Sleep Environment.** Within the Shuttle vehicle, most crewmembers slept in the middeck, but some have reported sleeping on the flight deck, which offered a level of privacy and allowed for less crowding in the middeck. In the flight deck however light poured in through the windows, minimizing the use of this area for sleep. Once in a designated area, crewmembers positioned themselves using sleeping bags, which they could tether to stable items such as a wall, ceiling or floor, keeping them from floating into objects or other crew and disrupting their sleep period. (Figure 1.)

Harnesses and tether points throughout the Shuttle allowed each crewmember to select their
own sleeping area and customize it to their liking. Astronauts could have a just few tether points on their sleeping bag tied down or multiple, depending on the preference they had for feeling more secure. Crewmembers could strap the harnesses as taut or as loose as they preferred. The more firm the harness, the more pressure the astronaut could feel, which simulated laying down on an actual bed or mattress on Earth. Other crewmembers have reported they preferred to ‘free float’ (Fuller, n.d.).

**Figure 1.** The STS-112 crewmembers sleep on the middeck of the Space Shuttle Atlantis. Pictured are mission specialists Sandra Magnus, David Wolf, Piers Sellers, and Commander Jeffrey Ashby.

**Mission Factors.** Sleeping on the Shuttle involved adjusting to not only the environmental aspects, but also mission-related factors such as the schedule and the workload. Shuttle missions were often regarded as high-tempo “sprints” as crewmembers worked diligently to complete tasks within their approximately 2-week visits into space. While flight rules generally protected 8 hours of sleep time, astronauts had to accommodate incidents of nighttime operations, slam shifting and “schedule creep” that would occur when workloads spilled into times that were ‘off the clock’.

**Individual Adaptation.** The sleep experience of each crewmember depended not only on the environmental and the mission-related factors, but also on the individual’s vulnerabilities, resiliencies, and their personal adaptation to spaceflight. As noted by Baker, Barratt and Wear (2008), crewmembers are largely functional upon arrival into microgravity, but several stages of adaptation occur over periods of days to weeks as their physiological systems adapt to weightlessness, individually and in combination with other systems. Notable responses include fluid shifts, of which symptoms have been reported lasting a few hours (e.g. nasal discomfort)
to potentially more longer term outcomes (e.g. slightly elevated intracranial pressure), as well as space motion sickness, which has affected crewmembers for a period of over several days into their missions. In addition, anecdotally, individual crewmembers have reported a feeling of “space fog,” where their thinking is fuzzy and not as clear headed as usual. Individual adaptation to the physiological demands of microgravity, therefore, served as a potential contributor to crewmembers’ ability or inability to sleep on orbit, but characterizing its influence is beyond the scope of this investigation.

III. Specific Goals and Aims

The goal of this study is to identify strategies that crewmembers use to improve their sleep during spaceflight missions. These are the specific aims of the study:

(1) Obtain and analyze subjective data from a representative sample of current astronauts who have flown short-duration STS missions, on their sleep behaviors and sleep quality on Earth, during training periods, and during Shuttle missions;

(2) Based on an analysis of these data, identify and recommend to current and future astronauts specific strategies for ensuring sleep quality and quantity during spaceflight missions;

(3) Provide recommendations for flight rules and requirements and for crew health and habitability standards, recommendations for managing sleep-loss-related fatigue problems in spaceflight related to fatigue caused by sleep loss; and

(4) Assess the feasibility of implementing the full survey instrument, or portions of it, as a standardized operational measure for all spaceflight missions to capture the information in the Longitudinal Study of Astronaut Health (LSAH).

A summary of how each of these aims was addressed in this investigation is presented in the Discussion section.

IV. Methods

Based on anecdotes of in-flight sleep difficulties—in addition to reports of optimal sleep in space—the Principal Investigator (PI), Dr. James Locke, a NASA flight surgeon, contacted NASA’s Human Research Program’s BHP Element in 2008 to discuss a collaborative effort between research and medical operations aimed at characterizing sleep in flight. BHP research staff and a BHP external investigator, a world-renowned subject matter expert in sleep and performance, met with the NASA Flight Surgeon to identify major issues related to sleep on orbit. The interview questions developed from this assessment were aimed at characterizing issues experienced by Shuttle astronauts during their missions. In the Fall of 2007, a proposal for a pilot study was
submitted to the NASA Institutional Review Board (IRB); approval was granted in October of 2007. In the Spring of 2008, interviews were implemented with 10 Shuttle astronauts returning from flight. Each of the 10 participants was interviewed by the study PI (NASA Flight Surgeon). Completed interviews were evaluated to determine how to best formulate questions for the rest of the astronaut corps. Questions amenable to statistical analyses were transformed into Likert-scale items, redundant questions were removed and/or refined, and previously unconsidered topics were considered. A revised set of interview questions were developed, as well as a separate online survey with primarily Likert-scale questions. The survey and interview sets were submitted to three astronauts to review face validity. Investigators addressed reviewer questions and modified the survey and interview items to ensure that the measures being used were acceptable and meaningful to crewmembers. Prior to implementing this second and larger iteration of the study, a revised proposal underwent an element-led review by the NASA Human Research Program Science Management Office. The protocol was then submitted to the NASA IRB and approval was granted by the IRB in December of 2008.

**Participants.** Active astronauts who have flown Shuttle missions since the 2003 Columbia tragedy were recruited for the study. These included Shuttle flyers from the single 2005 mission, STS-114, through astronauts returning from STS-130 in February 2010. The PI solicited a total of 72 potential participants for the study. Of the 72 solicited, 68 agreed to participate (94% participation rate).

**Procedure.** Once an astronaut indicated to the PI that he or she was interested in participating, the PI contacted NASA’s BHP Element research staff to coordinate the interview. The coordinator then contacted an administrator at the Astronaut Office to schedule a 45-minute appointment to interview the astronaut one-on-one, in a conference room within the Astronaut Office at the NASA Johnson Space Center. The BHP coordinator then e-mailed a calendar invitation to the astronaut participant, including a link to the secure survey online. The participant was also provided with general information about the study, and asked to provide their unique individual identification (ID) number when coming to the interview so that responses to the interview questions and to the survey items could eventually be linked. The participants were asked to complete the survey at their leisure before the scheduled interview. The e-mail also included the BHP coordinator’s full contact information, as well as that of the study PI, in case the participant needed to contact them.

Once the participants accessed the link to the secure online survey, they were asked to key in their unique ID number, then read a “layman’s summary” of the aims of the study. Participants were then asked to read a consent form and provide their consent to participate before completing the survey. All but one of the astronauts who had previously agreed to participate consented. Those who consented to participate completed the survey online via Survey Monkey. Answers were stored on the secure Survey Monkey Web servers.

Before the interviews were scheduled, a seasoned NASA interviewer (an Industrial/organizational psychologist) trained BHP staff and the study PI on the interview
process. Training helped standardize practices among all interviewers. The BHP staff consisted of six potential interviewers: two trained interns with bachelor’s degrees, one scientist (a doctoral student) with a master’s degree, and three senior scientists with doctoral degrees. The other interviewer was the study PI, a NASA medical doctor (M.D.).

For the interview, the interviewer provided copies of the layman’s summary and consent form that the participant completed online before the survey, as well as a copy of the interview questions, and a digital tape recorder. The interviewer arrived several minutes before the scheduled interview time. Upon greeting the participant, the interviewer gave a brief overview of the study, provided the participant with the summary and consent form, and reminded the participant that they could, at any time, refuse to answer any of the questions or terminate the interview. The interviewer also provided the participant with the PI’s contact information and their own contact information in case the participant wanted to follow up with questions. The interviewer asked the participant for permission to record the interview session in order to transcribe participant responses in a non-attributable database. All participants agreed to the recording.

The interviewer then asked the interview questions and allowed the participant to answer. When the interview—typically lasting 45 minutes—was completed, the interviewer thanked the participant for their time.

**Managing and Coding Interview Data.** The data from the recordings were transcribed by trained BHP staff into a separate Excel database. Each participant’s responses were transcribed onto an individual row, with each question in its own column. A separate Excel spreadsheet was also maintained. The spreadsheet included each question in a column, with each participant’s responses in a separate row. Transcriptions were conducted in such a way that:

- Utterances (such as ‘uhm’ and ‘mmm’) and small talk were not captured
- Responses to the questions were transcribed, even when detailed
- Information provided more than one time that was relevant to more than one question was transcribed and ‘placed’ with each related question. Likewise, if a repeated statement was made but it only addressed one question, that response was only transcribed with that one question, and was not transcribed with an unrelated question.

For the level of analysis undertaken for this iteration, the purpose of transcribing the interview data was to conduct frequency counts and identify whether recurring ‘themes’ emerged in response to questions. Two BHP staff members, both trained on content analysis and frequency coding, individually reviewed the interview questions and the responses that were given to determine categories for coding the responses to each question. The staff members then met to discuss discrepancies and come to consensus on the appropriate way to categorize the responses to each question. This process for several questions was reviewed with a senior staff member.
The staff members then separately coded the responses to each of the questions by counting the number of times a response was given. Hence, if asked, “what kept you from falling asleep?” and a respondent indicated noise kept them from falling asleep, that response was coded with a specific number. Each time a participant indicated noise was a cause of hindered sleep onset, within the most appropriate categories, and cross-checked one another’s coded ratings for accuracy. This process yielded frequency counts on more than 4000 lines of data.

All recorded files were pulled from the recorders and placed on a password-protected computer maintained in a locked office by BHP.

Managing and Coding Survey Data. The data from the surveys were stored in an Excel database on the secure Survey Monkey Web site. The survey responses were coded on a Likert scale from 1 to 5. Depending on the items, 1 represented “strongly disagree” or “never” and 5 represented “strongly agree” or “always.” A copy of the survey instrument can be found in Appendix A. For analysis, the data were brought into the Statistical Package for Social Sciences software program. A description of the study analysis and results are found in section IV.

Once data collection was completed, post hoc factor analysis was conducted so that data could be evaluated using relevant constructs, or categories. Fifteen constructs based on the analyses were identified, with the first three representing outcomes: 1) falling asleep in space, 2) staying asleep in space, 3) sleep over the course of a space mission, 4) falling asleep on Earth, 5) staying asleep on Earth, 6) sleep medication use on Earth, 7) sleep medication use in space, 8) preflight preparation, 10) preparing with crewmates, 12) commander restrictions, 13) thinking as sleep hindrance in space, 14) fatigue effects, 15) physical comfort, 16) scheduled workload.

Only one survey item assessed “falling asleep in space,” and one item assessed “staying asleep in space.” For this reason, those constructs are represented by a single item, whereas the other constructs are represented by three or more items. Multiple items in the survey did not specify “in space” or “on Earth”; these were not used in the analysis. When only one item was available, analysis was conducted on that single item (such as backache) and its association with the outcome was analyzed.

Overview of Results. Factors that relate to three outcomes—“falling asleep in space,” “staying asleep in space,” and “sleep over the course of the space mission”—were evaluated using the survey data and the interview data. The report therefore divides the analysis into these three sections.

The first section of the report discusses factors on the survey as they relate to the outcome of “falling asleep in space.” A factor analysis had previously identified several items on the survey that ‘loaded’ onto single constructs. The team looked at the correlations between these constructs and the outcome of “falling asleep in space.” Correlations between constructs and the outcome were evaluated. Where significant correlations exist (i.e., sleep medication use was positively correlated with ability to fall asleep in space), additional analysis of related
survey items and/or frequency counts from related interview questions were provided. We also conducted a multiple regression analysis to determine how factors predicted the outcome when accounting for the variance shared between the factors.

After discussing the survey results for the outcome of “falling asleep in space,” we reviewed the responses to the interview question, “Talk about the things that kept you from falling asleep.” The frequency of responses had been previously coded as described above. Several categories of responses emerged. The categories of responses that emerged to this interview question were consistent with most of the statistically significant factors as seen in the survey. A few factors were brought up by several astronauts during the interviews; however, correlation analysis completed using the survey data did not find that these factors were significantly associated with the outcome. These factors were considered “emerging factors” and are further evaluated by conducting frequency counts on the responses given to related questions.

This process for the analysis was similarly conducted for the other two outcomes, “staying asleep in space” and “sleep over the course of the space mission.”

V. Results

Factors relating to three outcomes—“falling asleep in space,” “staying asleep in space,” and “sleep over the course of the space mission”—were evaluated. Bivariate correlations between potential predictors and the outcomes were assessed. Multiple regression analyses for “falling asleep in space” and “staying asleep in space” were also conducted. Factors that arose in the interviews but were not found to be statistically significant from the surveys are also discussed where applicable.

The results of the data analysis are reported below, in the following format:

Falling Asleep

1. An overview of “falling asleep in space,” and “falling asleep in space” versus “falling asleep on Earth.”

2. An overview of the survey results, including the factors that are significantly associated with ease of falling asleep in space (as reported by astronauts).

3. An overview of the interview results, including factors that astronauts discussed as hindrances to falling asleep in space.

4. A section for each significant factor, including additional results from related survey items and/or relevant reports from astronauts acquired during the interview.

5. Multiple regression analysis to test which of the significant factors, when taken together, predicted ease of falling asleep in space.
Staying Asleep

1. An overview of “staying asleep in space,” and “staying asleep in space” versus “staying asleep on Earth.”

2. An overview of the survey results, including the factors that are significantly associated with the ability to stay asleep in space (as reported by astronauts).

3. An overview of the interview results, including factors that astronauts discussed as creating awakenings during sleep in space.

4. A section for each significant factor, including additional results from related survey items and/or relevant reports from astronauts acquired during the interview.

5. Multiple regression analysis to test which of the significant factors, when taken together, predicted ability to stay asleep in space.

Sleep Over the Course of the Mission

1. An overview of sleep over the course of the mission.

2. An overview of the survey results, including the factors that are significantly associated with changes in sleep over the course of the mission (as reported by astronauts).

3. A section for each significant factor, including additional results from related survey items and/or relevant reports from astronauts acquired during the interview.

Outcome 1: Falling Asleep in Space

Participants were asked to indicate their level of agreement with the item “Other things being equal, it was easy for me to fall asleep in space” (i.e., during their Shuttle mission) on a five-point Likert scale. The rankings were “strongly disagree,” “disagree,” “neither agree nor disagree,” “agree,” and “strongly agree.” For the analysis below, responses indicating “strongly disagree” and “disagree” were combined into one “disagree” category, and responses indicating “strongly agree” and “agree” were combined into one “agree” category.
Many crewmembers reported it is not easy to fall asleep during Shuttle missions. Although just over half (54%) of the participants agreed that it is easy to fall asleep in space, 36% disagreed that it is easy to fall asleep in space (Figure 2). However, as will be shown later, some crewmembers used medications to help them fall asleep. The responses to this item therefore may reflect the perspectives of crewmembers that used medications to facilitate sleep onset.

Falling asleep in space and falling asleep on Earth. By comparison, 79% of participants agreed that it is easy to fall asleep on Earth, whereas 14% disagreed (Figure 2). Ease of falling asleep on Earth did not predict ease of falling asleep in space (r = .02, not significant). Therefore, the fact that astronauts fall asleep easily on Earth does not mean that they will do so in the spaceflight environment. However, astronauts who find it difficult to fall asleep on Earth are less likely to fall asleep easily in space (r = .27, p = .03). Most crewmembers reported experiencing more difficulty with falling asleep in space than with falling asleep on Earth. When it comes to how easily an astronaut falls asleep, a “good” sleeper on Earth is not necessarily a “good” sleeper in space. However, a “bad” sleeper on Earth is likely to be a “bad” sleeper in space.

<table>
<thead>
<tr>
<th>In Space</th>
<th>Agree</th>
<th>Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>54%</td>
<td>35%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>On Earth</th>
<th>Agree</th>
<th>Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>78%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Figure 2. Percentage of participants who agreed (strongly or not) or disagreed (strongly or not) that it was easy for them to fall asleep in space (blue) or on Earth (green).

Factors Related to Falling Asleep in Space: Overview of Survey Results

Different aspects of the spaceflight scenario may contribute to difficulty with sleep onset for different individuals. The survey and interview included items related to various potential stressors: mission characteristics, such as schedules and work-related concerns; environmental factors, such as noise and light; crew factors, such as commander policies; and individual factors, such as “seeing” light flashes and the use of stimulants. The items were categorized into four primary topics, each composed of several factors (Figure 3).
Factors that were significantly associated with the outcome “falling asleep in space.”

**Falling Asleep in Space**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinking about the mission</td>
<td>$r = -0.54, p = 0.001$</td>
</tr>
<tr>
<td>Mission schedule</td>
<td>$r = 0.38, p = 0.002$</td>
</tr>
<tr>
<td>Lights – inadequate window shades</td>
<td>$r = -0.39, p = 0.002$</td>
</tr>
<tr>
<td>Use of sleep medications</td>
<td>$r = -0.51, p &lt; 0.001$</td>
</tr>
<tr>
<td>Use of stimulants</td>
<td>$r = -0.28, p = 0.03$</td>
</tr>
<tr>
<td>Light flashes</td>
<td>$r = -0.30, p = 0.02$</td>
</tr>
<tr>
<td>Fatigue</td>
<td>$r = -0.30, p = 0.02$</td>
</tr>
</tbody>
</table>

*Factors that were significantly associated with the outcome “falling asleep in space.”

**Figure 3.** (Upper) Four primary topics. (Lower) Correlation coefficients of the factors and their significance.
Factors Related to Falling Asleep in Space: Overview of Interview Results

During the interviews, participants were asked to discuss what kept them from falling asleep. Their responses were later coded and categorized. The primary responses that emerged from the interviews (Figure 4) were consistent with most of the responses from the survey. Other potential contributors to sleep difficulties, such as the unfamiliarity of the environment and physical discomfort, were also brought up by astronauts during the interviews.

As a result, the relationship between the factors and the outcome “falling asleep in space” was evaluated; results are reported in Figure 5. Where significant correlations existed, additional analysis of related survey items and/or qualitative analysis of related interview data were conducted. Interview discussions related to “unfamiliarity with environment” and “physical discomfort” were prevalent despite the lack of significant relationship found in the survey data. Therefore, additional information generated from the interviews is also provided for these topics.

![Figure 4](image4.png)

**Figure 4.** Factors, within three primary topics, that were revealed by interviews to be potential contributors to sleep difficulties.

As a result, the relationship between the factors and the outcome “falling asleep in space” was evaluated; results are reported in Figure 5. Where significant correlations existed, additional analysis of related survey items and/or qualitative analysis of related interview data were conducted. Interview discussions related to “unfamiliarity with environment” and “physical discomfort” were prevalent despite the lack of significant relationship found in the survey data. Therefore, additional information generated from the interviews is also provided for these topics.

![Figure 5](image5.png)

**Figure 5.** Percentage of participants who discussed the indicated factors when asked what kept them from falling asleep in space. Based on a total of 107 responses \(n = 70\). Participants could provide more than one response.
When crewmembers were asked to discuss factors that may have kept them from falling asleep during the mission, 21% of their responses indicated that difficulty falling asleep was a non-issue, whereas 79% of their responses were about hindrances to sleep onset.

“Thinking /active mind” was reported as a primary hindrance to sleep onset; 21% of the responses revealed that “thinking” about upcoming tasks, concerns or anxiousness about the mission, or other concerns, hindered sleep; a few responses (4 out of 26) related to “excitement.”

Workload, timeline, and schedule issues were identified as hindrances to sleep in 11% of the responses. For some individuals, the scheduled workload infringed on “pre-sleep” time and did not allow for “wind-down.” One participant stated, “On Earth, I get physically tired and that helps me sleep; I don’t get that in orbit. There, you have to get your mind ready to sleep, and I didn’t feel I was able to unwind, and I wasn’t physically tired. I had to take Ambien.”

Other hindrances to sleep that were identified included physical discomfort, lighting, and unfamiliarity with the environment and microgravity. In addition to discussing hindrances, 18% of the responses mentioned that sleep medication aided with sleep onset. In 20% of the responses, participants stated that difficulty falling asleep was not an issue.

Survey Results: “Thinking” and Falling Asleep

Five items assessed whether certain concerns kept participants from being able to sleep during their mission. Post hoc factor analysis defined the construct of “thinking” by these items, which included anxiety about the mission, upcoming tasks, safety, and individual and crew performance. The frequency analysis in Figure 6 demonstrates, however, that when crewmembers reported thinking as a hindrance to falling asleep, these concerns were typically mission- and task-related concerns. Thinking related to safety or crewmates’ performance was minimally identified as an issue. A significant negative correlation was found between thinking/anxiousness and falling asleep; the more astronauts thought about the mission, the less easily they fell asleep (r = –.54, p = .001).
Interview Results: “Thinking” and Falling Asleep

The interview questions did not include items specific to thinking or ruminations. Interview questions about workload, schedules, and hindrances to falling asleep, however, yielded statements related to thinking, anxiousness, and concerns:

“[Unknowns did affect sleep]. It’s not something that really kept me awake at night, but I think it was just something, just another thing that was on my mind. It was the first couple of days and I think it was just sort of the anxiety of, ‘I’m in space and I don’t want to screw up,’ and, ‘what am I going to do tomorrow?’ Just sort of the general, ‘I’m really here. It’s really the mission and my actions really matter now, and I don’t want to screw up.’ It was that sort of just brain wander kind of thought that kept me from sleeping those first couple of nights, I think.”

“My brain wandering [inhibited sleep]. Once you’re there for a couple of days, and you do your normal routine, and you realize, ‘I’m trained for all this stuff and none of it is really stuff I’ve never seen before,’ other than habitability kind of things. That’s the stuff you haven’t seen before, but once you do a day or two of pre- and post-sleeps, and you figure out your routine, it’s then that it’s okay.”
“The night before the event and that’s why I’m up late, studying. I’m kind of running through that in my mind, and so if I’m going to have trouble getting to sleep it’ll be on those kinds of nights. Similarly on orbit, particularly on orbit before ... EVA days and the rendezvous and handoff, they were real big-hitter days for me, and those were also on the early part of the mission.”

“I’m sure my stress level increased as the mission went along just because you’re getting more and more fatigued, so I think I’m more easily stressed. That may have contributed to a greater difficulty sleeping more hours during the night later in the mission.”

“I think for the folks who didn’t get a lot of sleep, it was probably the anxiety over the workload more than the complexity of the task that was driving it. All the sleep loss on ours was stress related. “

“It’s more my thoughts or my level of alertness or excitement which got me awake.”

“The timeline keeps you from falling asleep because you’ve got too much to do, and you’re worried about the next morning and what you have to do and there was a couple of days where we had time off where they schedule in for a half day and you can relax a little bit, but I don’t remember relaxing a whole lot at any time in the, on any of my missions. You can’t relax and you’re rushing to go to bed and you know that you’re an hour into your pre-sleep and you’ve got to get up in like 6 hours and you’re going to get 4, 4-and-a-half hours of sleep..”

Conclusion: Thinking and Falling Asleep

Astronauts who report thinking about the mission and upcoming tasks generally report more difficulty falling asleep in space. Thus, future flyers should, before spaceflight, consider methods that could help manage their thoughts and concerns. Strategies from cognitive behavioral therapy, such as taking a few moments to jot down thoughts and concerns before attempting to go to sleep, may be useful to flyers. Preflight training should be provided that incorporates such strategies, which are implementable in the spaceflight environment.

Survey Results: “Scheduled Workload” and Falling Asleep.

Post hoc factor analysis defined “scheduled workload” as mission workload, time for winding down, time for setting up for sleep, and unexpected problems. A significant correlation was found between scheduled workload and difficulty falling asleep; the more demanding astronauts perceived the schedule, the less likely they were to fall asleep easily \( r = .38, p = .002, \) Figure 3).

Additional items on the survey assessed workload issues, timelines, and wind-down.

Schedule-related issues led to not being ready for sleep at lights-out “frequently” or “always” for some crewmembers. Whereas 59% of respondents indicated that lack of time to wind down
“rarely” or “never” made them “not ready for sleep,” 20% indicated that lack of time to wind down “frequently” or “always” made them “not ready for sleep” (Figure 7). Lack of time to set up for sleep was identified as a sleep hindrance “frequently/always” by 13% of the respondents, while 12% of respondents indicated that working late resulted in a sleep hindrance “frequently/always.”

**Schedule Issues**
There were times I was not ready for sleep at lights out because: (n=65)

<table>
<thead>
<tr>
<th>Reason</th>
<th>Rarely/Never</th>
<th>Frequently/Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>I did not have enough time to...</td>
<td>59%</td>
<td>20%</td>
</tr>
<tr>
<td>I did not have enough time to...</td>
<td>72%</td>
<td>13%</td>
</tr>
<tr>
<td>I had to work late due to an...</td>
<td>71%</td>
<td>9%</td>
</tr>
<tr>
<td>I had to work late due to being...</td>
<td>65%</td>
<td>12%</td>
</tr>
</tbody>
</table>

**Figure 7.** Schedule-related reasons given by survey respondents (n = 65) for not being “ready for sleep,” rarely or never vs. occasionally or frequently.
Wind-down time is an important factor for many crewmembers. Close to half of the crewmembers disagreed that “it was not important to wind down in order to go to sleep in space”; that “the mission schedule did not affect my ability to wind down for sleep”; and that “the mission schedule provided adequate time for me to wind down for sleep” (Figure 8).

**Figure 8.** Percentage of survey respondents (n = 64) who agreed or disagreed with the indicated survey items about the importance of wind-down time and accommodation of the mission schedule for it. Responses indicating “Strongly Agree” and “Agree” were combined into one “Agree” category, and responses indicating “Strongly Disagree” and “Disagree” were combined into one “Disagree” category.
**A variety of options can facilitate wind-down.** Participants were asked to indicate on the survey what they did for wind-down time in space, and what they do for wind-down time on Earth (Figure 9). In space, “nothing” was identified as the most common way they spend wind-down time (50%), followed by spending time with crewmates (41%), listening to music (31%), other (17%), reading (9%), internet and email (8%), looking out the window (7%) and watching movies (3%). Most respondents who indicated “nothing” in space related the inactivity to the fact that there simply was not enough time for wind down, rather than their choosing to do “nothing” for wind-down time.

Crewmembers indicated that on Earth, watching television (59%) serves as their primary way to wind down, followed by reading (53%), spending time with spouse/family (48%), nothing (17%), listening to music (16%), and other (11%). Notably, spending time with other crewmembers represented a sizeable percentage of wind-down time in both scenarios.

**What did you do to wind down for sleep in space/on Earth?**

![Figure 9.](image) Percentage of participants (n = 64) who engaged in the indicated activities to wind down for sleep in space (blue) or on Earth (green). Based on a total of 97 responses for space, 135 responses for Earth. Participants could provide more than one response.

**Interview Results: Scheduled Workload**

Consistent with the survey results, when asked during the interview to discuss how the scheduled workload affected sleep, 35% of the crewmember responses indicated that the workload did not affect their sleep; however, 32% stated that the workload affected their sleep by either reducing sleep time or hindering their ability to fall asleep or stay asleep (Figure 10). A fifth of the responses described workload effects on pre-sleep. As described by one
crewmember, “Pre-Sleep wasn't really for winding down—was more for doing things you had to do before sleep.” For others, however, the pre-sleep period included an opportunity to wind down. As seen in the survey analysis, wind-down time was considered an important precursor to falling asleep. Interestingly, 13% of the responses indicated that the scheduled workload facilitated sleep. One astronaut stated that the workload “helped me sleep better because I was so tired.”

**How did the scheduled workload impact sleep?**

<table>
<thead>
<tr>
<th>Response</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not impact sleep</td>
<td>35%</td>
</tr>
<tr>
<td>Reduced sleep time / sleep quality</td>
<td>32%</td>
</tr>
<tr>
<td>Affected scheduled pre-sleep</td>
<td>20%</td>
</tr>
<tr>
<td>Slept better</td>
<td>13%</td>
</tr>
</tbody>
</table>

*Figure 10.* Percentage of interview participants (n = 60) who gave the indicated responses when asked how the scheduled workload affected sleep in space. Based on a total of 71 responses. Participants could provide more than one response.

**Interview Comments by the Participants: Scheduled Workload**

“It really didn’t [affect sleep]. We all got to bed on time, and if somebody was running behind, somebody else helped them; but I think for the most part we pretty much stayed on time with stuff.”

“As far as that goes, the schedule was the schedule. We had plenty of time in the morning to do our breakfast and hygiene. We had plenty of time at night to write an e-mail or look out the window, so I think there was a very good balance between work and sleep and some personal admin time.”

“We ended up with some days that were really short on sleep, 6 hours maybe at most is what we had scheduled, and even then, maybe a couple of us woke up just a couple of us woke up early or something like that. I think we had a lot of work, the inspection stuff
that we did both flight day two and then the two days of final inspection before we came home were really long days. EVA days were really long days.”

“A couple of times we had to get up early we did some sleep shifting, too, to get things latched up for undock or something, I think. So for the most part it actually officially ate into our sleep on probably three or four of the 11 days or the 11 nights, and then we, with our own discretion, went ahead and shaved off another hour of pre-sleep and maybe a half an hour of real sleep on a couple of extra days beyond that, too.”

“We’re busy when we’re up there, but I felt that there was enough time scheduled for pre- and post-sleep to kind of take care of business and ‘wind down.’ The other thing was that our crew was also – everybody kind of pitched in if we had to [work] pre-sleep time, you have four people there doing it instead of the people who are just timelined to kind of get things done so people could start unwinding. So getting … we kind of put a team effort to get in all the little stuff you got to do, so that you can focus on getting your bed set up and those kinds of things, so I think that was helpful.”

“It is very fast paced. The biggest thing about being up there is you don’t get a sense for where you are in the day. You really just can’t sit there and say whether it’s morning, afternoon, or evening. I just have to keep on looking at the schedule on my watch and see where the heck I am. Still I can’t tell you it’s evening, I could tell you it’s 3 hours before I’m going to bed, but it doesn’t register to me like that’s nighttime or that it would be 7:00 at night versus 9:00 at night. It’s just to me, like, time to do something. Everything that works for me is how long before I have an event coming up. So that makes it kind of weird and it probably plays into your over all psyche and then the big thing is since the chronic fatigue, since it’s cumulative, you don’t know where you are in that if you had like a scale of how fatigued am I, you don’t really know.”

“I would be busy from the time I got up in the morning to the time I went to sleep that I had no problems falling asleep and I’d pretty much sleep through unless somebody got up and kicked you or started the WHC, which wasn’t very often.”

**Conclusion: Scheduled Workload and Falling Asleep**

Since schedule-related issues led to not being ready for sleep at lights out “frequently” or “always” for some crewmembers, and wind-down time is an important factor for many crewmembers to facilitate sleep onset, flight planners should consider scheduling a specific allotment of time for wind-down. Time allotted for winding-down would help manage thoughts and concerns before spaceflight. Commanders should make every effort to understand crewmembers who require time to unwind before sleep and should encourage those crewmembers to take time to unwind.
Survey and Interview Results: Noise and Light, and Falling Asleep Noise.

The survey analysis indicated that noises such as the galley water pump ($r = .02$, ns), alarms ($r = -.09$, ns), and Air/Ground (A/G) communication bleed ($r = -.18$, ns) did not keep astronauts from falling asleep easily. This finding might be attributable to earplug use on orbit.

The survey did not include an item to determine who wore earplugs during their space mission, or which types of earplugs they may have worn. The interview questions did include the item, “How much did noise exposure affect your sleep in space and how did you manage it?” Thirty-four of the responses mentioned wearing earplugs in flight, but this does not necessarily indicate that the other respondents did not wear earplugs in flight. Unfortunately, there is no way to quantify who did and who did not wear earplugs during their mission.

Noise was not discussed as a hindrance to falling asleep when participants were asked, “What kept you from falling asleep in space?” Lights, however, were brought up as a hindrance to sleep in 4% of the responses.

**Lights.** During the interviews, crewmembers were asked, “How much did light exposure affect your sleeping in space, and how did you manage it?” While 27% responded that light was not an issue in flight, 38% discussed wearing eye masks and 6% mentioned that light intrusion was sometimes an issue in space. Those who indicated that light was not an issue in flight may have also indicated that they used countermeasures such eye masks and window blinds. Respondents who specifically discussed light as an issue on orbit also mentioned that they did not like wearing the eye masks.

Consistent with this finding, survey analysis found that lights, in the form of inadequate window shades ($r = -.39$, $p = .002$) did keep astronauts from falling asleep easily.

Light was an issue for some individuals. The flight deck was recognized as having “light leakage” through the blinds. A variety of eyeshades should be provided so that crewmembers who find the current ones uncomfortable can have a means through which to minimize light exposure during sleep episodes.

**Interview Comments by the Participants: Lights**

“I have the blackout blinds and curtains, so it’s pretty dark in my room. So I don’t like any extra light....[Light] comes in through little cracks, but also [with the] ...recent soft shades to cover the flight deck windows, the each one of those stitches [across the middle] is a little hole for light leakage. So on the day side of a pass, no matter how well you try to block the light, it’s still pretty damn bright......I don’t like the eye thing, bugs me in space.”

“I think we were very meticulous about [covering the window in the Middeck] and then we had the inner deck access covered. The Middeck is pretty dark and then a lot of
times you can sleep with those little masks blindfold things.”

“Eyeshades are really good; I never wear those on Earth. They were a huge advantage. In the flight deck, with the window shades carefully placed up... there's still light in there; the sun is just so bright, those window shades don’t make it dark. On orbit, we kept middeck dark by closing the shutter between the middeck and the flight deck. We also wore eyeshades, and kept the lighting low. People who used the WCS didn’t turn the lights on. Lighting can be a problem but we managed it on the Shuttle flight.”

**Conclusion: Noise, Light, and Falling Asleep**

Since light hinders sleep onset for some individuals, and noise was not reported as a hindrance to sleep onset (however, this may be because of earplug use), a variety of earplugs and eyeshades should be made available to crewmembers so that they can select the ones that are most comfortable for their mission.

**Survey Results: Crew-Related Factors and Falling Asleep**

The survey included items to assess the perceived effect of commander’s sleep policy. Post hoc factor analysis defined “commander policies” by items related to whether the commander had assigned sleep locations and set restrictions regarding lights out, after-hours activities, and noise. Analysis showed that whether the commander established a sleep policy did not affect how easily astronauts fell asleep \( r = .10, \text{ns} \). Looking at just the lights-out aspect of the commander’s sleep policy, a strict lights-out policy did not make it easier for astronauts to fall asleep \( r = .004, \text{ns} \).

The survey included items to assess the degree of pre-mission sleep preparation undertaken by the crew. Post hoc factor analysis defined “sleep preparation” by items related to whether the crew had discussed factors related to sleep such as lights out, Waste Collection System (WCS) usage, early awakenings, and use of sleep medicines. Correlation analysis showed that discussing sleep issues before the mission did not affect how easily astronauts fell asleep \( r = .14, \text{ns} \).

The survey included items to assess the degree of crewmember noise and activity experienced during sleep episodes. Post hoc factor analysis defined “crewmember noise and activity” by items related to the assessment of crewmembers engaging in noisy activities or otherwise disruptive activities such as use of WCS and snoring. Correlation analysis showed that crewmembers who snored \( r = .03, \text{ns} \), turned on the lights \( r = -.12, \text{ns} \), were noisy \( r = -.04, \text{ns} \), jostled others \( r = -.03, \text{ns} \), or used the WCS \( r = -.17, \text{ns} \) did not keep their fellow crewmembers from falling asleep.
Conclusion: Crew-Related Factors and Falling Asleep

These results and the lack of discussion of these issues during the interview suggest commander policy and discussing sleep before launch did not help or hinder sleep onset. Fellow crewmembers also did not hinder sleep onset.

Survey Results: Sleep Medication and Falling Asleep in Space

Sleep medication use was a primary topic in the survey. Participants were asked to report why they used sleep medication during spaceflight missions; each respondent could indicate more than one reason. Whereas 22% of responses indicated that participants did not take medications during their mission, 71% of the responses indicated that participants used sleep medications to fall asleep during their spaceflight mission. It is important to note that some participants were first time flyers, while others were veteran flyers; the data presented below do not differentiate between these two categories.

Interestingly, ease of falling asleep in space was negatively associated with taking sleep medications ($r = -.51, p < .001$). These results may be due to our measurement of perceived ease of falling asleep rather than actual time it took to fall asleep. Additionally, sleep medication use may have been reported by those who do not fall asleep easily in space: those who struggled with falling asleep therefore tended to use sleep medications, while, on the other hand, astronauts who did not report difficulty falling asleep, typically did not take sleep medications.

Figure 11 visually depicts the relationship between ease of falling asleep and sleep medicine use.

Figure 11. Ease of falling asleep in space and use of sleep medicine. Ball indicates the number of astronauts endorsing the option. The cluster of dark blue balls illustrates that those who fall asleep easily in space did not use sleep medicines whereas those who had difficulty falling asleep in space did use medicine as a sleep aid.
Ease of Falling Asleep in Space and Use of Sleep Medicine on Earth

Use of sleep medicine on Earth ($r = .51$, $p < .001$) and to a greater extent use of sleep medicine on Earth when traveling or schedule-shifting ($r = .69$, $p < .001$) predicted use of sleep medicine in space. Astronauts who are willing to use sleep medicine on Earth are more likely to use sleep medicine in space.

Figure 12 graphically illustrates that use of sleep medicine is much less common on Earth than it is in space (Figure 11) and that astronauts also find it much easier to fall asleep on Earth than in space. However, comparing Figure 12 to Figure 11 shows that when astronauts experience difficulty falling asleep in space, they are more likely to use sleep medicine.

![Graph illustration of ease of falling asleep on Earth and use of sleep medicine.](image)

**Figure 12.** Ease of falling asleep on Earth and use of sleep medicine. Ball indicates the number of astronauts endorsing the option. The cluster of darker green balls illustrates that most astronauts sleep well on Earth and do so without sleep medication. The lack of balls on the right half of the chart indicates that astronauts do not habitually use sleep medicine on Earth.
Ease of Falling Asleep in Space and Type of Sleep Medication

Participants were asked to indicate which type of medications they took during their missions. Of the 64 participants, a total of 102 responses were given (Figure 13). The most commonly used medication was Ambien (65%), followed by Sonata (28%) and then Ambien CR.

**Which medicines did you use during your spaceflight(s)?**

![Bar chart showing medication usage percentages](image1)

**Figure 13.** Percentage of participants who mentioned the indicated medicines when asked about their medication use during spaceflight. Based on a total of 102 responses (*n* = 64). Participants could provide more than one response.

Please note participants were asked to consider their medication use on all of their missions. Interview data reveal that some participants may have not taken any medications (hence, “none”) on one mission, but taken medications during a later mission. Repeat flyers’ experience with sleep and medications on orbit may differ from those with a single flight experience. Additionally, participants were asked to indicate all that apply; thus, a medication that may have been tried once received a “check,” just as did a medication that was taken multiple times throughout a mission.
Interview Results: Sleep Medications

During the interviews, participants were asked to discuss reasons why they chose a particular medicine, advantages and disadvantages of that medication compared to other medications, and recommendations to others for using medication during spaceflight. The types of responses given to these questions varied. Comments about side effects or strengths of a medication, for instance, were often mentioned in answering the first question about why particular medications were taken; as a result, the subsequent question about advantages and disadvantages may not have been posed again. Responses to these four items, therefore, were coded and categorized as a whole.

Table 1 presents a summary of the number of participants who indicated that they have used at least one of the listed medications in space. Within the number of participants who used each medication, a subset of them brought up disadvantages of those medications. Questions about specific side effects of the medications were not asked; rather, the questions were open-ended. The responses generated, therefore, may present the most salient aspects of that medication for those individuals.

**Table 1.** Number of participants who said they used the indicated sleep medications during spaceflight and number and percentage who brought up the indicated disadvantages to using them.

<table>
<thead>
<tr>
<th></th>
<th>Ambien</th>
<th>Sonata</th>
<th>Ambien CR</th>
<th>Phenergan</th>
<th>Restoril</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of participants who used</td>
<td>40</td>
<td>21</td>
<td>16</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Participants citing negative attributes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General side effects</td>
<td>4 (10%)</td>
<td>2 (10%)</td>
<td>2 (22%)</td>
<td>1 (25%)</td>
<td></td>
</tr>
<tr>
<td>Specific side effects</td>
<td>6 (15%)</td>
<td></td>
<td></td>
<td>1 (25%)</td>
<td></td>
</tr>
<tr>
<td>Ineffective</td>
<td>2 (5%)</td>
<td>3 (14%)</td>
<td>1 (6%)</td>
<td>1 (25%)</td>
<td></td>
</tr>
<tr>
<td>Negative effects after prolonged use</td>
<td>3 (8%)</td>
<td>3 (19%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groggy in the A.M.</td>
<td>5 (13%)</td>
<td>1 (5%)</td>
<td>3 (19%)</td>
<td>2 (22%)</td>
<td>1 (25%)</td>
</tr>
<tr>
<td>Too short acting</td>
<td>7 (18%)</td>
<td>2 (10%)</td>
<td>1 (6%)</td>
<td>1 (25%)</td>
<td></td>
</tr>
<tr>
<td>Delayed onset</td>
<td>2 (5%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Too strong/heavy</td>
<td></td>
<td>2 (5%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference between Earth and space</td>
<td>2 (5%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Used, but prefer to avoid</td>
<td>8 (20%)</td>
<td>2 (10%)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Likewise, advantages of the medications were mentioned during the interview (Table 2). Specific questions about advantages of the medications were not asked; rather, the questions were open-ended. The responses generated, therefore, may present the most salient aspects of each medication for the individuals who used it.

### Table 2. Number of participants who said they used each of the indicated sleep medications during spaceflight, and the number and percentage of that subset who brought up the indicated advantages of the medication.

<table>
<thead>
<tr>
<th></th>
<th>Ambien</th>
<th>Sonata</th>
<th>Ambien CR</th>
<th>Phenergan</th>
<th>Restoril</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of participants</td>
<td>40</td>
<td>21</td>
<td>16</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>who used</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participants citing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>positive attributes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No side effects</td>
<td>8 (20%)</td>
<td>3 (14%)</td>
<td>3 (19%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effective</td>
<td>13 (33%)</td>
<td>4 (19%)</td>
<td></td>
<td>2 (22%)</td>
<td></td>
</tr>
<tr>
<td>Not groggy in the A.M.</td>
<td>6 (15%)</td>
<td>5 (24%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short acting (positive)</td>
<td>1 (3%)</td>
<td>6 (29%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not addicting</td>
<td>1 (3%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lasted through the</td>
<td>4 (10%)</td>
<td></td>
<td>2 (13%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>night</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Of all medications,</td>
<td>2 (5%)</td>
<td></td>
<td>1 (6%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>works the best</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A summary of advantages and disadvantages of the five sleep medications in bar graph form (Figure 14) indicates that 19% to 33% of crewmembers who took Phenergan, Sonata, or Ambien found it effective. In the aggregate, disadvantages “outweighed” advantages for Phenergan and Ambien but not Sonata. Difference between Earth and Space was considered a negative effect for a handful of users who had reported taken Ambien.

**Figure 14.** Sleep medications in order of the number of astronauts using them, with frequency and type of positive and negative attributes shown.
Conclusion: Sleep Medication Use
Astronauts, even those who tend to fall asleep easily on Earth, in general report more difficulty falling asleep in space. Use of sleep medications was much less common on Earth than in space, and astronauts report using sleep medications when they have difficulties falling asleep in space. Future flyers should be willing to try sleep medications in space, even if they have never tried them on Earth or rarely take them on Earth.

Interview data suggests, however, that participants should ground-test medications before flight if possible. Individuals reported different experiences with sleep medications. Ground testing should be implemented in a manner analogous to a spaceflight scenario. One crewmember reported ground-testing medication to evaluate its effectiveness for a daytime nap rather than overnight sleep, but the crewmember found that this ground testing prior to a nap inadequately represented how he used sleep medication later on orbit (before retiring for the night).

Survey Results: Use of Stimulants and Falling Asleep
Survey analysis showed that astronauts who reported having used stimulants (caffeine pills and Provigil) in space did not find it as easy to fall asleep as those who were stimulant-free ($r = -0.28$, $p = .03$).

The survey did not include a question specifically regarding the amount of caffeine that crewmembers drank on orbit. However, keeping caffeine use in space equivalent to usage on Earth did not affect whether it was easy to fall asleep in space ($r = -.07$, ns), and a possibility of withdrawal effects due to heavy consumption of caffeine on the ground (more than 2 cups of coffee or 5 sodas a day) also did not predict ease of falling asleep in space ($r = -.06$, ns).

Interview Results: Stimulants and Falling Asleep
On the survey ($n = 65$), 10 participants indicated that they had taken Provigil during their mission; two participants in the pilot study interviews ($n = 10$) also indicated that they had taken Provigil, for a total of 12 participants out of 75 (16%). Eleven participants specified that they brought Provigil on their mission but did not use it.

During the interviews, participants were asked to discuss the use of Provigil during their mission. Twenty participants provided feedback related to Provigil, about their ground experience or flight experience, or simply general comments about its effects. Feedback was generally mixed, with 50% of comments favorable toward the use of Provigil, 25% not favorable, 15% neutral, and 10% reflecting concerns about other crewmembers using Provigil (Figure 15).
Interview Comments by the Participants: Alertness Medications

"I had [Provigil] with me, I didn't use it. I have used it since on particular, a couple of critical days where I've been up all night, and still have more to do the next day and I wanted to make sure I'm still alert. And it actually works really well. If somebody really needed it, you know, I might recommend Provigil, but I don't know. Do we know that much about it? Do we know if there are any effects?"

"At least here on Earth, it's very effective. And it's not like doing a No-Doze, it's very effective without ... it's like the lights go on and you're, 'Oh I'm awake now.' Then you can go to sleep. It's very nice."

"My main problem on my first flight was that the more I worried about getting enough sleep, the less I slept... [During this recent flight] I took an alertness medication before EVA. I didn’t see any adverse effects at all from it [and knowing it was available] probably gave me the ability to get an extra hour of sleep each night because I wasn’t worried about stuff anymore."

"When I drug tested Provigil the first time, I actually went to sleep with the stuff. I thought it might be a sleep med. I didn’t really know what it was.... I just didn’t use it [during the mission]."
"I think it’s fair when I say I observe that [people use the stimulants] and I was a little bit worried about it. The use of stimulants is done quite a bit. I do not understand why though."

"I used it before my second and third EVA. The reason why I did that was because on my first EVA, I was incredibly fatigued, so much so that I wasn’t even sure I could do it. And I said I didn’t want to go through that again, so I took half of one before my second and third EVA and that was with good results. I don’t really like to use more than what is absolutely necessary. So it was a necessary trade off. I don’t like using it, but I thought it was more dangerous not to use it. So that was my threshold when it became more dangerous not to use it, I would use it. Not that I think it’s that dangerous, it’s just ... I would rather not if I have to."

"Yeah, I would recommend it, especially if you’re not getting a lot of sleep and you know you’re sleep shifted and you are coming out of another sleep shift and you know, you got to perform and you got to be able to focus in and you’re a little bit groggy. It helped me focus in."

"I think it’s different for everybody. Everybody’s body reacts differently. I just wanted to have it available if I thought I might need an alertness medication and that’s the way I would do it. Just be prepared but don’t count on it."

Conclusion: Stimulant Use and Falling Asleep

On the basis of the varying reports on Provigil and its effectiveness, ground testing of Provigil is recommended. Additionally, further information and protocols for evaluating alertness medications are recommended.

Survey Results: Fatigue and Falling Asleep

Survey analysis revealed that astronauts who said that when they were fatigued, it was harder for them to fall asleep, also reported that they did not fall asleep easily during their mission ($r = -.30, p = .02$). Astronauts who stated that they do fall asleep more easily when fatigued did not report falling asleep more easily during their mission ($r = .12$, ns).

Interview Results: Fatigue and Falling Asleep

When asked during the interview to discuss the effects of fatigue during their mission, 38 (57%) of the crewmember responses indicated that they did not perceive any impact from fatigue, whereas 29 (43%) indicated that they were cognizant of fatigue during their mission. Of those 29, seven (21%) stated they it was effortful to work through the fatigue and felt slowed down, six (21%) stated they felt cumulative effects of fatigue toward the end of their mission, five (17%) attributed mistakes or lapses in attention and short-term memory to fatigue, and two individuals (7%) stated that their crew and ground interactions were noticeably different when they felt fatigued.
Interview Comments by the Participants: Fatigue and Falling Asleep

“Fatigue had the effect that I’d ask somebody to watch me, especially towards the end of mission you get pretty tired. And it’s just “Hey, let’s just watch things today. Everybody is getting a little bit tired. It’s been a long mission.” It affected me in that you had to pull the team in more. To my knowledge at least, I didn’t make any mistakes based on being tired. That just may be a factor that I had made sure people were watching me.”

“I never really felt super tired. I just kind of felt pretty good the whole time.”

“[Fatigue] was accumulating through the whole mission so it was harder and harder to keep pushing on. I wanted to pull back and do less. No motivation.”

“It was just that one day that it was getting close to bedtime and I actually started finding myself, while standing around the table talking to crewmembers, just caught myself dosing off, standing up. It was kind of cool. I don’t know if I really felt “fatigued-fatigued,” it was just the good kind of fatigue where you put in a hard day’s work.”

“I mean, you’re tired; you’re maybe a little bit of a headache because of the CO₂. You know the gears and wheels aren’t moving up there as well. You’re slower and you have to think more, and you just feel a little bit listless, and you know, like you need some sleep. But you can’t sleep because you don’t – it’s not sleep time, you don’t have the time. The CO₂ issues are a huge deal for some people and I’m one of them, and they make it worse because you’re continually there. You’re going on with a bad-splitting headache the whole time, too. So it’s tough to feel that you can’t tell if you’re just fatigued, if it’s CO₂ or if it’s both. But you know, after a while, the lack of … 4-and-a-half, 4 hours of sleep a night in a high-CO₂ and things like that, it starts getting to people. You can tell with some people when they’re really tired or fatigued because they get irritable. You can tell behavioral changes in them…”

“I think the crew really performed well until the end of the mission. I don’t think it affected anybody else’s ability to do anything. We managed to get everything done. We work together, we work as a team. We work – never go solo on critical activities. We watch out for each other. We built that into the whole plan.”

“I didn’t see any degradation in performance from people due to fatigue. I know we had long days, but everybody seemed to be fine. I didn’t see anybody have to say, “Oh man, I’m really getting tired and I need a break.” I didn’t notice that.”

“I have to be frank: We were tired, all of us were tired, and I was worried about us on our first mission. I never made a mistake that had an impact, which I felt pretty lucky about. I did notice between us that we were making mistakes, perhaps never hit the switch, but we were making mistakes between us before we hit the switch. And as you
got fatigued that happened more. But because of the way we do it, we never made a mistake that impacted anything. Most of the mistakes were prior to “hitting a switch”.

“When you’re fatigued, you double that up. Kind of slow down because it’s more important not to make a mistake then how fast it took you to set things up. So you kind of slow down and do it very consciously... On my first mission, I did notice, and again, I think because I am aware of fatigue because of all that previous experience and how you have to manage it, I did notice that between us we were making mistakes, perhaps never hit the switch, but we were making mistakes between us before we hit the switch. And as you got fatigued, that happened more. But because of the way we do it, we never made a mistake that had an impact on anything. Most of the mistakes were prior to hitting a switch. So I was pleased with that, but frustrated with how stupid we were going out to the pad tired. In such a wonderful experience and you’re fatigued from ignition time at lift off. I realized next time we’re going to do this better.”

Conclusion: Fatigue and Falling Asleep

The interview responses highlighted certain aspects of fatigue that are important to consider. Some crewmember responses suggest that some respondents sought evidence of fatigue based on their general level of “tiredness” throughout the mission. Hence, if they did not feel “tired,” these crewmembers may have dismissed fatigue-related performance effects as possible outcomes. Ground research has shown that although some individuals under conditions of chronic partial sleep deprivation indicate low levels of subjective sleepiness, their performance continues to degrade, as measured by cognitive tools such as the Psychomotor Vigilance Task (Van Dongen et al., 2003).

Other crewmembers, however, present a considerable awareness of potential fatigue effects. As noted by several crewmembers, tasks had to be performed more carefully because of fatigue. One respondent noted, “I was able to maintain the same level of performance, but that came at a much higher concentration level.”

Crewmembers discussed countermeasure strategies for mitigating the effects of fatigue. Training and education of crewmembers could assist with systematic implementation of (or, in some instances, enhancement or continuation of) such strategies, which include

- awareness of the potential deleterious effects of fatigue on performance, well-being, and crew interaction;
- awareness of potential effects in others (such as irritability) to help offset crew conflict;
- closely working with other crewmembers to “back up” one another on tasks;
- processes (that is, checklists) to prevent fatigue-related errors; and
- protecting scheduled sleep times. Feelings of fatigue could be related to not only sleep loss, but also workload and adjustment to the environment.
Survey and Interview Results: Physical Discomfort and Falling Asleep

Survey analysis revealed that physical factors such as use of restraints ($r = -0.18, \text{ns}$), headache ($r = -0.10, \text{ns}$), back pain ($r = -0.02, \text{ns}$), needing to use the WCS ($r = -0.08, \text{ns}$), or being too hot ($r = -0.04, \text{ns}$) or too cold ($r = -0.12, \text{ns}$) did not affect how easy it was to fall asleep.

During the interviews, however, when participants were asked to discuss what kept them from falling asleep during their mission, 9% of the responses given related to physical comfort. For this reason, some of the interview items related to physical comfort are evaluated below.

**Head Restraint.** Sixty-eight percent of participants indicated they used a head restraint, whereas 32% did not. Of the participants who indicated they used a head restraint, about 31% stated that restraining their head was an important aspect of ensuring optimal sleep. Various methods were discussed for restraining the head, including the Velcro strap, the sleeping bag, and articles of clothing, such as a pair of pants. Some crewmembers indicated various reasons for their use of a restraint, such as to alleviate “a bloated head” and ambient light exposure, as well as to create a sense of pressure against a pillow. Some participants started their missions using the restraints, citing the initial importance of the restraints, but then adapted to the feel of their head “floating” in microgravity and ceased using the restraint. The head was the most frequently cited part of the body mentioned as needing to be restrained to aid sleep onset.

**Arm Restraint.** In discussing arm restraints, participants responded by indicating whether their arms were usually kept inside their sleeping bag (43, or 57%), usually kept outside of their sleeping (11, or 14%), or varied (22, or 29%). Of the respondents, 23 (30%) revealed that their preference was based on temperature.

**Leg Restraint.** In discussing leg restraints, participants provided varying responses that included restraining legs during earlier missions or at the beginning of each mission, as well as indicating they did use a restraint—the sleeping bag—or that they let their legs float freely in the sleeping bag. Thus, responses were not amenable to frequency counts. Of the 74 respondents, however, 33 (45%) discussed restraining knees into the fetal position, and half of the respondents who indicated they pulled their knees into the fetal position, mentioned that this was done to alleviate back pain.

**Torso Restraint.** Most participants did not seem to use torso restraints: 23% indicated they used torso restraints, and 77% did not.

**Headache.** No interview questions were specific to headaches; however, during the discussions related to caffeine and airflow, headaches were mentioned by crewmembers. Participants indicated that they continued to drink caffeine on orbit so as to not incur a caffeine headache. With respect to airflow, 60 (85%) of the crewmembers indicated that airflow did not prevent them from getting a good night’s sleep while 11 (15%) stated that they, at times, did not get enough air. Carbon dioxide
(CO$_2$) “pockets” were discussed as a potential hindrance to sleep. CO$_2$ seems to be a concern for crewmembers and, in some instances, crewmembers pointed out that they were unsure whether adverse effects (such as headaches) were related to fatigue or high CO$_2$ levels.

**Cold.** Sleeping near a vent (such as in the air lock) reportedly aided potential issues with CO$_2$ pockets; however, these locations are often cold, and thus present another aspect of discomfort for crewmembers to consider. Several crewmembers mentioned “being cold” as a hindrance to falling asleep in space.

**Back pain.** No interview questions were specific to back pain, but during discussion of some of the questions, back pain was mentioned by participants. In response to the item regarding “leg restraints,” a number of individuals (17 respondents) reported restraining the knees for the purpose of alleviating back pain.

**Conclusion: Physical Discomfort and Falling Asleep**

Interview responses revealed that back pain and headaches (often attributed to CO$_2$), as well as being cold and head “sensations” (attributed to microgravity) caused some discomfort for some individuals. Further investigations into alleviating back pain in the microgravity environment and characterizing CO$_2$ levels in flight are recommended.

**Multiple Regression Analysis and Falling Asleep in Space.** Only those predictors with a significant relationship to “Falling Asleep in Space” were entered in the regression equation. Multiple regression analysis was used to test which significant factors predicted participants’ experience of falling asleep in space. The results of the regression indicated that three predictors explained 54% of the variance ($R^2 = .54, p < .01$). It was found that that thinking about the mission significantly predicted difficulty falling asleep ($\beta = -.91, p < .001$), as well as sleep medication use ($\beta = -.43, p < .001$), and inadequate window shades ($\beta = -1.87, p < .003$). Scheduled workload, use of stimulants, and fatigue did not predict difficulty falling asleep.

**Conclusion: Falling Asleep in Space**

The findings and recommendations detailed below are based on the accumulated evidence shared by Shuttle flyers. We have summarized what these astronauts said about falling asleep in space:

- Being able to fall asleep easily on Earth does not ensure that you will find it just as easy to fall asleep in space. However, if you have difficulty falling asleep on Earth, you are likely to have difficulty falling asleep in space.
- Thinking about the mission and upcoming tasks makes it harder to fall asleep.
- A heavy mission schedule makes it harder to fall asleep.
- Light makes falling asleep more difficult.
• Sleep medicines make it easier to fall asleep in space. Many astronauts who do not use sleep medicines on Earth use them in space.
• Fatigue may make it harder to fall asleep.

A crewmember who cannot fall asleep may wish to follow these recommendations based on the results of the study:

• Use a sleeping mask.
• Write out thoughts, concerns, and plans for the next day’s activities before going to sleep.
• Allow a few minutes (at least) for a brief wind-down time.
• Minimize the use of stimulants. Astronauts who used stimulants in space found it harder to fall asleep.
• Take a sleeping pill.

The interview data further indicated that physical discomfort (temperature, headache, backache, etc.) and adjusting to the new environment may pose difficulty in falling asleep for some individuals. The survey results did not yield significant findings, however, when the relationship of these factors to falling asleep was evaluated.

Outcome 2: Staying Asleep in Space
Participants were asked to indicate their level of agreement with the item “In space, I am rarely disturbed during my sleep and can sleep through anything” on a five-point Likert scale. The rankings were “Strongly Disagree,” “Disagree,” neither “Neither Agree nor Disagree,” “Agree,” and “Strongly Agree.” For the analysis below, the responses “Strongly Disagree” and “Disagree” were combined into one “Disagree” category, and the responses “Strongly Agree” and “Agree” were combined into one “Agree” category.

Many crewmembers report it is not easy to stay asleep during Shuttle missions. Forty-seven percent of the participants agreed that their sleep was rarely disturbed in space, and 42% disagreed (Figure 16).

Staying Asleep in Space and Staying Asleep on Earth. By comparison, 42% of participants reported that their sleep is rarely disturbed on Earth, whereas 36% disagreed that their sleep is rarely disturbed on Earth. Whether sleep was disturbed on Earth did not predict whether sleep was disturbed in space (r = .06, ns). Thus, participants who report that they sleep without being disturbed on Earth should not assume that they will sleep as soundly in space, and those who report sleep disturbances on Earth should anticipate awakenings from sleep in space.
Factors Related to Staying Asleep in Space

Different aspects of the spaceflight scenario may contribute to difficulty with staying asleep for some individuals. The survey and interview included items related to various potential stressors: mission characteristics, such as schedules and work-related concerns; environmental factors, such as noise and light; crew factors, such as commander policies; and individual factors, such as use of stimulants. The items were categorized into these four primary topics, each composed of two or three factors (Figure 17).

Figure 16. Percentage of survey respondents who agreed or disagreed with the survey item “In space [On Earth], I am rarely disturbed during my sleep and can sleep through anything.” Responses indicating “Strongly Agree” and “Agree” were combined into one “Agree” category, and responses indicating “Strongly Disagree” and “Disagree” were combined into one “Disagree” category.

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### Staying Asleep in Space

<table>
<thead>
<tr>
<th>Factor</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinking about the mission</td>
<td>$r = -0.37, p = 0.01$</td>
</tr>
<tr>
<td>Mission schedule</td>
<td>$r = 0.32, p = 0.01$</td>
</tr>
<tr>
<td>Noise</td>
<td>$r = -0.36, p = 0.003$</td>
</tr>
<tr>
<td>Crewmember noise and activity</td>
<td>$r = 0.26, p = 0.004$</td>
</tr>
<tr>
<td>Physical discomfort (back pain, WCS)</td>
<td>$r = -0.33, p = 0.001; r = 0.25, p = 0.005$</td>
</tr>
</tbody>
</table>

**Figure 17.** (Upper) The four primary topics, with factors marked (bold, *) that were significantly associated with the outcome “staying asleep in space.” (Lower) Correlation coefficients of the factors and their significance.
Factors Related to Staying Asleep in Space: Overview of Interview Results

During the interviews, participants were asked to discuss what kept them from staying asleep. Responses were later coded and categorized by the team. The primary categories to emerge from the interview responses were consistent with the categories and constructs included in the survey that showed a significant correlation with staying asleep (Figure 18).

As a result, the relationship between each of the survey constructs and the outcome of “staying asleep in space” was evaluated; results are reported in Figure 19. Where significant correlations exist, additional analysis of related survey items and/or qualitative analysis of related interview data were conducted.

Several participants further discussed “unexplained wake-ups” and “medication wearing off” during the interviews. Therefore, additional information generated from the interviews is also provided for these two topics.
When asked to discuss factors that may have awakened them from sleep during the mission, 20% of crewmember responses indicated that difficulty falling asleep was a non-issue, whereas 80% of crewmember responses discussed hindrances to sleep onset. Issues related to “physical discomfort” were reported as a primary hindrance to sleep onset; 19% of the responses discussed issues related to back pain, waking up to use the WCS, headaches, and temperature issues.

Noises related to the Shuttle (such as alarms) were identified as causing awakenings in 16% of the responses. Fourteen percent of responses indicated uncertainty about what factors were causing awakenings. Crewmember disturbances, such as noise or jostling, were identified in 13% of the responses. Thinking was identified in 8% of the responses, sleep medications wearing off in 5% of the responses, and other issues in 5% of responses. Comments from interviews:

“I can’t put my finger on anything that would have woken me up, but I tended to wake up after 3 or 4 hours of sleep, regardless of how I got to sleep or how long it took me to get to sleep. I would wake up and – without a noticeable stimulus to wake up, just woke up.

I’ve always thought it was just sort of a normal part of my sleep pattern. I get in one of those phases that you’re close to being awake and I wake up…or coming out of that four hour Ambien cycle where it was wearing off.”
“Big noises, jets firing, unplanned stuff when they don't tell you it's coming when you're in your sleep. Lights, and a couple of times people got up and running into stuff.”

“Nothing I could put my finger on. Occasionally a master alarm or something but that's pretty rare.”

“The only things that woke me up, I think, were just this crackling of the speaker, that even with earplugs in, it would just wake me up. Other than that, it was just things that delayed me getting to sleep but then once I got to sleep the only things that I remember waking up were noises, like this crackling or somebody going to the bathroom, which I really don't remember happening even the first night. So I think our crew was pretty good about that.”

“Nothing that I remember.”

“I would wake up but I couldn’t think of anything in particular. I think once I woke up and ... thinking about the mission. I’m sure part of that was thinking about what I’m going to do the next day, but I can’t think of anything in particular that woke me up.”

**Survey Results: “Thinking” and Staying Asleep**

Five items assessed whether thinking kept participants from being able to sleep during their mission. Post hoc factor analysis defined the construct of “thinking” by items asking participants to rate their level of anxiety about the mission, upcoming tasks, safety, and individual and crew performance. The frequency analysis on page 12, as well as Figure 6, demonstrates that when crewmembers reported thinking as a hindrance to falling asleep, these concerns were typically related to the mission and upcoming tasks. A significant negative correlation was found between “thinking” and staying asleep; the more astronauts reported thinking about the mission, the less they stayed asleep ($r = -.37$, $p = .003$).

**Interview Results: “Thinking” and Staying Asleep**

The interview questions did not include items specific to thinking or ruminations. Interview questions about factors that created awakenings, however, yielded statements from participants about thinking, anxiousness, and concerns. Participant responses included these:

“Sometimes if I have a lot on my mind. Like if I’m not able to do everything that I was supposed to do that day, not so much that I’m worried about it, but I’m trying to figure out how I can fit it in for the next day, or if there was some problem unresolved or some issue that we are working that is not well resolved or well understood, I’ll probably be thinking about that as I sleep. It may result in unrestful sleep.”
“You could be having a big day the next day, but if there’s some concern that it’s not going to work out well, it’s not going to have a good outcome, that’s when you’re going to lay awake tossing and turning.”

“Part of it too is I think there’s a fear on Shuttle missions. I want to make sure I get back to sleep because I need it. You’re like, “Hey, I want to try and stay rested.” It’s a long mission. It’s almost like, well, I can take this thing or I can chance it that I won’t fall asleep. If you are having trouble getting to sleep, you start thinking about it. Oh shoot, now you’re toast. It’s like when you have some big event and you’re worried about it which is keeping you from sleeping. Then you go, “Oh my god, I’ve been laying here 30 minutes and I’m still awake.” It just snowballs at that point because the mind just starts racing.”

“I could never get comfortable enough to sleep well, and it was mostly worry. And this happens sometimes [on Earth], if I need to get up early for something and am worried about being awake and ready the next day.”

Survey Results: “Scheduled Workload” and Staying Asleep

Post hoc factor analysis defined “scheduled workload” as mission workload, time for winding down, time for setting up for sleep, and unexpected problems. A significant correlation was found between scheduled workload and difficulty staying asleep; the more demanding astronauts perceived the schedule to be, the less likely they were to stay asleep ($r = .32, p = .01$).

Although this correlation was significant, the interview question “Please discuss the things that woke you up in space” did not yield responses related to schedules or timelines. Participants did bring up “thinking,” which was often associated with workload issues. As previously mentioned, “thinking” and “scheduled workload” are two interrelated constructs with shared variance. Partial correlation analysis controlling for “thinking” found a non-significant relationship between “scheduled workload” and “staying asleep in space” ($r = .19, \text{ns}$). A significant relationship was found, however, between “thinking” and “staying asleep in space” when controlling for “scheduled workload” ($r = -.28, p = .000$). Therefore, the correlation seen between “scheduled workload” and “staying asleep in space” is likely a result of thinking about upcoming tasks and the mission.
Survey and Interview Results: Shuttle Noise and Staying Asleep

Of the noises that arose from the Shuttle, only alarms woke astronauts from their sleep \( r = -0.36, p = 0.003 \). Noises such as the galley water pump \( r = -0.17, \text{ns} \) and A/G communication bleed \( r = -0.15, \text{ns} \) did not wake astronauts once they were asleep. Understandably, alarms are cause for awakening, but according to the results of crewmember interviews in this investigation, earplugs and other mitigation strategies kept noises such as the galley water pump and A/G communication bleed from disturbing their sleep.

Sixteen percent of responses provided during the interview indicated that some participants attributed sleep disturbances to noises from the Shuttle. Sources of the reported noises included

- alarm
- fan noise
- Shuttle printer turning on for uplinks
- the crackling of the speaker

Participants also said that unanticipated noises were the ones that awakened them:

“I think the key is whether or not the noises are expected, and expected noises don’t generally bother me. Unexpected noises are more interesting, so they tend to wake you up. On Earth, we manage that by trying to keep a quiet house, and on orbit we manage it by all getting to sleep at the same time so there really was no noise to worry about other than fans. That’s just a constant noise and it doesn’t worry anybody.”

“I generally kind of sleep pretty solid. I’m not saying it doesn’t bug me at all, but generally it’s got to be a loud noise or a very sudden noise to get me up. I think the nice thing about that airflow through that air duct, and then there’s the general airflow, is it did have sort of a low hum background noise because of the airflow going through this duct that was right by my head. I think that was enough of a little white noise level that any clunking that was happening in other nearby areas was masked.”

“Something unexpected or pretty loud, like somebody making noises while sleeping, that will wake me up, too, just because of the loudness and proximity.”

When asked to discuss “How much did noise exposure affect your sleep in space and how did you manage it?” 34 of the participants mentioned wearing earplugs whereas 14 specified that they did not. Several participants mentioned the earplugs were uncomfortable, while others emphasized how well they worked. Earplugs referred to as “Foamies” seemed to be a favorite of crewmembers. Participants stating earplugs were “uncomfortable” did not clarify whether these earplugs were Foamies as well.
Lights in the form of inadequate window shades ($r = -0.16$, ns) and light flashes ($r = -0.24$, ns) did not typically disturb astronauts once they were asleep. Two participants who slept on the flight deck (where external light is prevalent) mentioned that light occasionally woke them up.

**Survey Results: Crew-Related Factors and Staying Asleep**

The survey included items to assess the effect of the commander’s sleep policy. Post hoc factor analysis defined “commander policies” by items related to whether the commander had assigned sleep locations and set restrictions regarding lights out, after-hours activities, and noise. Analysis showed that the commander’s establishment of a sleep policy did not affect whether participants stayed asleep ($r = -0.04$, ns).

The survey included items to assess the degree of pre-mission sleep preparation undertaken by the crew. Post hoc factor analysis defined “sleep preparation” by items related to whether the crew had discussed factors related to sleep such as lights out, WCS usage, early awakenings, and use of sleep medicines. Correlation analysis showed that discussing sleep issues before the mission did not affect whether participants reported staying asleep ($r = -0.13$, ns).

The survey included items to assess the degree of crewmember noise and activity experienced during sleep episodes. Post hoc factor analysis defined “crewmember noise and activity” by items related to the assessment of crewmembers engaging in noisy activities or otherwise disruptive activities such as use of WCS and snoring. Correlation analysis showed that when crewmembers were noisy ($r = -0.26$, $p = 0.04$) they woke their fellow crewmembers. However, specific crewmember noise and activity such as crewmembers who snored ($r = -0.11$, ns), turned on the lights ($r = -0.24$, ns), jostled others ($r = -0.18$, ns), or used the WCS ($r = -0.19$, ns) did not disturb the sleep of their fellow crewmembers.

Based on the survey results, commander policy and discussing sleep before launch did not help or hinder sleep. General noise generated by fellow crewmembers was identified as a cause of awakenings, although specific crewmember noises and activities were not identified as causes.

The interview data yielded additional information related to crewmember disturbances. When asked to identify “what woke you up in space,” nine participants identified noise from the WCS, and four indicated jostling.

When asked to discuss how crowdedness affected their mission, many participants responded that crowdedness wasn’t an issue. “Spreading out” to other locations (on the flight deck and on the ISS) helped minimize the number of crewmembers in the middeck. These are some of the participant comments about crowding:

> "I think the first couple of days in space when you’re in this ‘honeymoon’, crowding doesn’t affect you at all because you’re just adapting to a new environment. Then we go
to the station. Then guys spread out all over the station, and so on the flight deck, we only had two people. So it never really changed. On the middeck when all the other five guys were on the middeck the first couple of nights, it didn’t seem too crowded. The perception was there was plenty of room. Then when we lived on the station for 12 days and then we came back in the Shuttle, I think that there was a huge perception that it was crowded and constrained. And everybody just wanted to get away from each other kind of thing."

"So my perception was [crowding] would have been troubling. It would have been troubling if I would have been on the middeck."

"Once you’re asleep, you don’t know you’re crowded. It is crowded, that’s why I slept on station. But you just deal with it."

"Well once you’re asleep, you don’t know your crowded, so you just go to sleep, ...but when you get up in the morning and you try to go to bed, you’re rushing around and you’re moving around in the Shuttle, that’s one of the reasons I went to sleep in station, because there’s in more space in station and it’s wider. I mean, you just deal with it and you go to sleep and you get up."

"Crowdedness was not an issue because we made sure we were restrained, everybody did a good job restraining themselves and nobody moved around once it was bedtime. It was the rule. You stay in bed."

"Bumped into a crewmember one night and that woke me up. I moved my bag a little bit the next night to eliminate that possibility."

Several discussion points were related to the degree of planning and communication involved with determining sleep locations to minimize awakenings. The salience of sleep locations can be seen in the crewmembers’ responses to the two questions about the positive and negative issues of their flight:

"The other part is to keep your own stuff out of the way, and as it gets toward bedtime, get all your stuff put away and all your areas and stuff cleaned up so that everyone can put their sleeping bag out. We call it self- Keep your stuff put away. All of it, especially at the end of the day."

"If they are people who maybe don’t need as much sleep or wake up early, they might like to go to the flight deck, but it does kind of constrain the middeck area to have a lot of people there which could be a CO2 issue or just maybe trying to find a comfortable space for everybody to sleep. If every crewmember likes to be on the floor sort in that
bed like orientation, it might be hard to find seven locations like that on the middeck. Make sure that the plan accommodates the orientation that people would like to sleep and/or if they want to be up to look out the window."

"One of the things is if crewmembers like me who do get up in the middle of the night or don’t need that much sleep, if they wanted to call home. You know because different times, it might be an ideal time to have satellite hookup so you could talk to your family. If you could provide a place that’s quiet enough for people to do that and not wake up the rest of the crew. That’s a benefit. The people that can’t sleep, it gives them something to do to connect with their family. If they’re tense, they can get over it."

"There were a couple of times where some people got up and you know, they’re new or they’re first time fliers and they’re banging around and all that flying by."

"Nobody slept on the flight deck for us and that was sort of the designated place. ‘Hey, if you can’t sleep, go up there. Don’t sit in your sleeping bag and be miserable. Just go up there and look at the Earth and enjoy the time while you’re in space and maybe you’ll get tired while you’re there and go back to bed.’ I liked that a lot. I never did that, but I thought it was a great idea, and it was a peace of mind kind of thing to know that there is a place where you can go and just kind of ‘chill out’ and not affect, nobody can hear you and you’re not going to wake others up if you go. You can flip on the lights up there and just exist and look at the Earth. When we were docked, I liked how we were all given the freedom to go sleep in other modules."

"Well, after docking to the space station and spreading out a lot more, that keeping the PP O2, well it keeps the PP CO2 carbon dioxide a little bit lower, which I think helps people sleep, too."

"Picking a sleep location and being conscious of WCS use and trying to minimize use."

**Conclusion: Crew-Related Factors and Staying Asleep**

Sleep location was related to sleep disturbances. Private sleeping quarters could have minimized the issues with crowdedness; crewmembers, however, managed for the duration of their mission to make the best of their situation. Recommendations from crewmembers indicate that there were advantages to spreading out for sleep between the middeck and flight deck (less CO2 buildup, roomier) and advantages to all sleeping on the middeck (allowing those who were awake to visit the flight deck). Planning ahead and communication were discussed as key aspects of ensuring optimal sleep location under the circumstances.

**Survey Results: Sleep Medication and Staying Asleep in Space**

Sleep medication use was a primary topic in the survey. Participants were asked to report why they used sleep medication during missions; each respondent could indicate more than one
reason. Whereas 22% of the responses indicated that participants did not take medications during their mission, 23% of the responses indicated that other participants did use sleep medications in flight to stay asleep, and 23% of the responses indicated that participants used sleep medications in flight to go back to sleep (71% of responses were for falling asleep; participants could mark more than one answer).

Sleep medication use was negatively associated with the item “My sleep was rarely disturbed in space” ($r = -.44, p < .001$). Participants who reported that they slept undisturbed in space did not typically use sleep medicine. Astronauts whose sleep was easily disturbed in space, however, did tend to use sleep medicine.

Figure 20 depicts the relationship between staying asleep and sleep medicine use.

![Figure 20](image-url)

**Figure 20.** Staying asleep in space and use of sleep medicine. Ball indicates the number of astronauts endorsing the option. The cluster of dark blue balls illustrates that those who report staying asleep in space did not use sleep medicines while those who had difficulty staying asleep in space did use medicine as a sleep aid.
Staying Asleep

Staying asleep during the night on Earth and use of sleep medicine on Earth are not related \( r = .04, \text{ns} \). Many astronauts sleep without waking during the night on Earth whereas many others frequently wake during the night (Figure 21). Regardless of how well they sleep, astronauts do not habitually use sleep medicine on Earth. However, comparing Figure 21 with Figure 20 (use of sleep medicine in space) shows that when astronauts have difficulty staying asleep in space, they are more likely to use sleep medicine.

Additional information related to sleep medications is discussed in Section 1, Falling Asleep in Space.
Survey and Interview Results: Stimulants and Staying Asleep

Astronauts who used stimulants in space were not more likely to report increased awakenings during the night than were their stimulant-free crewmembers ($r = -0.08$, ns). Interview data did not indicate that crewmembers attributed awakenings to their use of stimulants.

Survey Results: Physical Discomfort and Staying Asleep

The survey included items regarding backaches, headaches, needing to use the WCS, and temperature. Survey analysis revealed that astronauts identified back pain ($r = -0.33$, $p = .01$) and needing to use the WCS ($r = -0.25$, $p = .05$) as sleep disturbances. Other physical factors such as headache ($r = -0.23$, ns), being too hot ($r = -0.03$, ns), or being too cold ($r = -0.10$, ns) did not lead to awakenings.

Interview Results: Physical Discomfort

No interview questions were focused on specific comfort issues such as headaches or back pain; most questions related to physical comfort involved the use of harnesses and restraints. When participants were asked to discuss factors that may have awakened them from sleep during the mission, 19% of responses indicated that physical discomfort was a source of awakenings for crewmembers. Some specific statements provided by participants:

"Usually, it was some form of temperature discomfort I think. You know, when it was time to stick my arms out the holes or it was time to bring my arms back in the holes. Maybe it’s some lower back pain, or maybe a dry mouth, or a temperature discomfort would wake me up...I never remember having a problem falling back asleep."

"Peeing. I’d say over the 13-day mission it probably happened five times, five or six times."

"Early on, it was a little back pain, so I’d tend to reposition. After that I didn’t have that. After the first couple of nights, I didn’t have any. Like I mentioned before, somebody going to the restroom, or I think we had an alarm or two go off throughout mission, so that would wake us up briefly. I mean that’s probably normal, pretty standard, you’re going to get an alarm here and there. That’s about it. So nothing, just a couple of things here and there."

"I think I was uncomfortable. I guess I could never get comfortable enough to sleep well."

"The first night, I woke up because I kind of felt like I was falling and I think that was a function of me not having the sleeping bag pretty taut. One night, I can’t remember if it was the night before we came home or whatever, and I actually ran out of Ambien, I just didn’t sleep that night at all. I was pretty much conscious the entire night. I’m sure I
probably got a little bit of sleep here and there, but for the most part I really did not have a restful night of sleep."

"I can remember waking me up were being cold on several occasions, and then on the night I slept in the Middeck, it was being bumped by a crewmember who was getting up to go to the bathroom."

**Conclusion: Physical Discomfort and Staying Asleep**

Survey and interview responses indicated that physical discomfort was significantly associated with increased awakenings. Judging by the experiences of these crewmembers, future flyers should consider limiting liquids before bedtime and ensuring they have enough clothing to cover up if they feel cold. Several crewmembers mentioned that they restrained their legs into the fetal position as a means to alleviate backaches and pain. When asked about their use of leg restraints, 45% of participants discussed restraining their knees into the fetal position, and for over 50% of these responses, lifting the knees was discussed specifically as a way to alleviate back pain. The torso harness could be used to facilitate this sleeping position.

**Multiple Regression Analysis and Staying Asleep in Space.** Only those predictors with a significant relationship to Staying Asleep in Space were entered in the regression equation. Multiple regression analysis was used to test which significant factors predicted participants’ experience of staying asleep in space. The results of the regression indicated that one predictor explained 57% of the variance ($R^2 = .57, p < .01$). It was found that that thinking about the mission significantly predicted difficulty staying asleep in space ($\beta = -.64, p < .05$). Scheduled workload, Shuttle noise, crewmember noise and activity, sleep medication use, and physical discomfort did not predict difficulty falling asleep – although back pain approached significance ($\beta=.89, p < .059$).

**Interview Results: Unexplained Wake-Up**

When participants were asked to discuss factors that may have awakened them from sleep during the mission, 14% of responses indicated that they were not sure what led to the awakenings. These are some of the specific statements provided by participants:

"There were 2 nights up there that I just woke up early about an hour-and-a-half one night and maybe an hour or 45 minutes the other and couldn’t go back to sleep. I just got up early. Everybody has that-- I don’t want to make it sound like it’s every single night that I just go to bed for 8 hours and never, ever wake up. I’m just giving you the normal routine, but even on the Earth there’ll be the occasional you wake up and it’s 3:30 or 4:00 in the morning and you can’t go back to sleep. It’s very, very rare that I have that."

"Occasionally I’d wake up in the middle of the night for unknown reasons and then just move around a little bit. Stretch around a little bit and go back to sleep."
"Nothing specific, other than waking up early—not sure why, because I was still tired."

"I can’t put my finger on anything that would have woken me up, but I tended to wake up after 3 or 4 hours of sleep, regardless of how I got to sleep or how long it took me to get to sleep. I would wake up and – without a noticeable stimulus to wake up, just woke up."

"I think I’d just wake up, and that’s interesting because it wouldn’t be needing to go pee, so I don’t know what woke me up. I just woke up."

**Interview Results: Medication Wearing Off**

When participants were asked to discuss factors that may have awakened them from sleep during the mission, 5% of responses attributed awakenings to medication wearing off. These are some of the specific statements provided by participants:

"Nothing [woke me up]. Except Ambien wearing off after 4 hours. It’s to the minute. It’s like an alarm. It’s a sleep machine and an alarm clock all in one. So an alarm clock in 4 hours for me. Rarely did I get more than 4 hours of sleep, though, so it really was not an issue often. With 6 hours, you might see you only have 2 more hours, you don’t take another one. There was probably a couple of times, got 8 hours so I’d take another one if there was first 3 or 4 more hours to go."

"I think maybe the Ambien wearing off. I think that was kind of a trigger—it seemed to wear off at around 4 hours and then I was ready for the next dosage of something. The finite duration of the Ambien. Honestly, I would wake up in the middle of the night for absolutely no reason. It was just bang, and I’d say, it’s 4 hours after I took the Ambien isn’t it?" I’d check my watch, Yep, 4 hours after I took the Ambien. That happened every night. I don’t know [why that is]."

"Either Ambien wearing off or just part of my normal sleep pattern."

**Conclusion: Unexplained Wake-Up and Medication Wearing Off**

The survey instrument did not pose questions related to unexplained awakenings or medication wearing off. Whether these types of awakenings are similar to experiences on Earth is unknown. Future assessments may seek to characterize the effects of medications on the ground compared to those in flight.

Additionally, responses that indicate awakenings for no apparent reason may suggest that, even with medications, sleep remains disturbed on orbit. A simple explanation could be that some crewmembers awaken because they are in a spaceflight vehicle. Or these disturbances may be due to aspects of the environment and the mission and are just not attributed to those
causes. Other environmental factors may be playing a part. As previously noted, several crewmembers (as well as flight surgeons and others at NASA) suspect that high CO$_2$ levels may be leading to interrupted sleep. Additionally, the effects of microgravity on sleep stages have not been evaluated to date.

**Conclusion: Staying Asleep in Space**

The findings and recommendations detailed below are based on the accumulated evidence shared by the Shuttle flyers who participated in this study. We have summarized in this section what these astronauts said about staying asleep in space.

Staying asleep in space is harder for those who

- perceive a more demanding mission schedule and workload,
- have a tendency to think about work,
- have noisy crewmates,
- experience back pain during the night, and/or
- need to use the WCS.

Responses to the interviews also revealed

- awakenings for unknown reasons and
- awakenings attributed to medications wearing off.

Ground-testing medications may help prepare crewmembers for such abrupt awakenings.

A crewmember who cannot stay asleep may wish to follow these recommendations:

- Prepare for the next day's activities, including writing down concerns before going to bed.
- Wear earplugs.
- Use restraints to pull knees up into a fetal position.
- Limit liquids later in the day, and use the WCS before sleep.
- Take a sleeping pill.

The interview data further indicated that several crewmembers experienced sleep medications wearing out and unexplained awakenings. Participants recommended that medications be ground-tested to determine which ones will enable sleep for a few more hours before morning, and to determine whether sleep medication use is related to awakenings on Earth.
Outcome 3: Sleep Quality Over the Mission
Participants were asked to indicate their level of agreement with the items “The quality of my on-orbit sleep generally improved with subsequent days on orbit” and “As the mission progressed, my sleep quality got worse,” on a five-point Likert scale. The possible responses were “strongly disagree,” “disagree,” “neither agree nor disagree,” “agree,” and “strongly agree.” The second item was reverse coded to ensure that responses were scaled consistently. For the analysis below, responses indicating “strongly disagree” and “disagree” were combined into one “disagree” category, and responses indicating “strongly agree” and “agree” were combined into one “agree” category.

Many crewmembers agreed that their sleep quality generally improved over the course of the mission. While 4 participants (6%) disagreed that their sleep improved over the course of the mission, 34 (52%) agreed that their sleep improved. Notably, 27 participants (42%) neither agreed nor disagreed with this statement.

Likewise, many crewmembers—46, or 72%—disagreed that their sleep quality got worse as the mission progressed. Four participants (6%) stated that they agreed that their sleep quality worsened, while 14 (22%) indicated they neither disagreed nor agreed with the statement.

Interestingly, the responses to these items were not significantly correlated ($r = 0.14$, ns). In other words, those that responded one way on the first item did not respond similarly on the second item. Although both items were essentially attempting to characterize the assessment of sleep over time, they may have been perceived differently. Perhaps the negatively slanted second item “As the mission progressed, my sleep quality got worse” created some confusion.

Sleep Quality Over the Mission and Earth Sleep. There were no specific items regarding Earth sleep. However, whether an astronaut felt well-rested when waking from sleep on Earth was related to both the improvement ($r = .25, p = .05$) and worsening ($r = -.28, p = .03$) of sleep over the duration of a mission. Astronauts who wake well-rested on Earth are likely to see an improvement and not a worsening in the quality of their sleep over the duration of their mission, suggesting that perhaps some individuals—in this instance, those who reported restful sleep on Earth—are more likely to adapt to the spaceflight environment than others.

Factors Related to Sleep Quality Over the Mission: Overview of Survey Results
Different aspects of the spaceflight scenario may contribute to changes in sleep quality over the duration of the mission, for some individuals. The survey and interview included items related to various potential stressors: mission characteristics, such as schedules and work-related concerns; environmental factors, such as noise and light; crew factors, such as commander policies; and individual factors, such as use of stimulants. The items were categorized into four primary topics, each composed of two or three factors (Figure 22). Notably, each of the factors that were significant (marked with bold type and *) relate to the individual.
The interviews did not include items that specifically addressed changes in sleep over the duration of the mission. Some of the participants, when discussing other issues, discussed them in the context of mission duration.

The relationship between each of the survey constructs and the outcome “sleep quality over the mission” was evaluated; results are reported below. Where significant correlations existed, related interview data will be listed.

**Survey Results: Use of Stimulants and Sleep Quality Over the Mission**

Survey analysis showed that stimulant use was not related to an improvement in sleep quality over the course of a mission \( (r = -0.01, \text{ns}) \). However, use of stimulants was related to worsening sleep quality \( (r = 0.31, p = 0.01) \). We do not know whether those who experienced worsening sleep quality opted to use stimulants, or if the consumption of stimulants led to worsening sleep quality. As often seen on Earth, the relationship between stimulants and sleep loss is probably iterative.

**Interview Results: Use of Stimulants and Sleep Quality Over the Mission**

No questions were specific to stimulant use over the duration of the mission. As previously shown, a total of 12 participants out of 75 (16%) stated that they used alertness medications during their mission. When discussing the use of stimulants on orbit \( (n = 11) \), 5 (55%)
respondents indicated that they used stimulants in preparation for a task such as extravehicular activity (EVA), rendezvous, or landing; 3 respondents (27%) specified Provigil as a means to offset sleep debt or fatigue.

"On an earlier flight where we had just an incredible load of payload activities and we’re working well beyond the normal day and getting up early to get ready for the activities, there was accumulative fatigue function, but not on this most recent flight."

"I did have Provigil available for if I didn’t have a good night sleep. I think one of the nights, I can’t remember for what reason, but I probably was closer to 4 and a half hours of sleep and I had an EVA the next day, so I took a Provigil before going out. I had tried Provigil before the flight one day, and it seemed to work fine, and it seemed to help with any fatigue or sleepiness. So I tried it the once on the ground and then I used it the once in the EVA so I didn’t notice any effect. That’s the one thing I would recommend to folks is the Provigil."

"Launch and landing I take Fendex; otherwise, none of that, and I don’t do sleep meds because I didn’t find any of the sleep meds on Earth to be effective for me."

Stimulant use may result in worsening sleep quality and increased fatigue; conversely, for some crewmembers, as sleep loss and fatigue accumulate, stimulant use may increase.

Survey Results: Fatigue and Sleep Quality Over the Mission

Those astronauts who reported the quality of their sleep worsening over the duration of the mission also reported increased fatigue as the mission progressed ($r = .26, p = .04$).

Interview Results: Fatigue and Sleep Quality Over the Mission

No questions were specific to fatigue over the duration of the mission, but when crewmembers were asked how fatigue affected their mission, of the 29 (43%) who indicated they felt effects, 6 (21%) stated they felt cumulative effects of fatigue toward the end of their mission. As previously mentioned, some crewmembers discussed adverse effects related to fatigue. Other comments are listed below:

"I didn’t think that’s ever been a Shuttle mission this intense in terms of content. I personally think that there must been a limit to which you subject, even performance folks, to intense focus, concentrated, don’t you dare make a mistake type of environment. There must be a limit to the number of days that you can do that with people without them eventually having some degradation in performance. By Flight Day 12, 13, everybody was tired. Mentally fatigued, tired, but not that there is degradation in performance, but you are starting to see that things are a little slipping here, there, inconsequential."
"I don’t think I had any fatigue that affected me during the mission. I think by the end of mission, we were all tired, because you had this build up of sleep deficit, but I don’t think that – but it was not a pace that you could keep up indefinitely."

"You can see people starting to wear down towards the end of the mission, especially people with a lot of high stress events going on during the mission. You could just see them the last few days just starting to drag. I don’t think it affected the mission. We got everything done, but they were living better through chemistry as well. They were taking either Ambien to get to sleep or Provigil to get themselves awake, but that can only take you so far and you can see people starting to slow done, but the mission was slow done at the same time. We were undocking and getting ready to come home."

"I think later in the flight, when people let their guard down and you can start getting a little more, you know, back to your usual smartass comments and that kind of stuff, nothing really bad. Yeah, I think people get – I mean, you get to know your crewmembers, you know, your crewmates so you can see if you don’t get your rest, you can start getting cranky. So it’s normal. The same thing happens in space."

In light of ground studies demonstrating the potential deleterious outcomes related to cumulative sleep loss and/or fatigue, if sleep quality worsens, crewmembers should consider the possibility of fatigue-related performance effects.

**Survey Results: Physical Discomfort and Sleep Quality Over the Mission**

Astronauts who reported worsening sleep quality also reported that their sleeping position affected their ability to sleep (r = −.31, p = .01). The interview yielded a variety of responses related to sleep positions, including these:

"I think as the mission went on, that became less important. Feeling like you’re pushed up against something -- I think as the mission went on, I used less and less bungees. Then the Nada chair was occasional. Sometimes I used it, sometimes I didn’t. I think a lot of that depended on how my back was feeling, because that helps your back as well. I think it was necessary early on to just try and find some form of normalcy, because I sleep on my side with my knees up. So, you can’t do that in space unless you have something pulling your knees up, which these devices did."

"I would put the strap around my knees. The reason I didn’t [free float] like that was more of a privacy issue...I was better just going into the sleeping bag as much as I could get – cover myself up from, you know, getting hit by something that might go floating by or – I psychologically, it’s got to be psychological – felt better going all the way down to the sleeping bag and having all this part covered up back here, and really the only thing showing, in fact, what I did sometimes is I would sleep where my face was facing the ceiling. And if I was on my side, I could kind of have something in front of my face so I wasn’t just out there where something could go floating by, and I think that was totally
psychological. It was a conscious decision."

"I thought I would sleep on the ceiling this time because I thought that would be cool, and I tried that, but I couldn’t get it off my mind that I was sleeping on the ceiling and it kind of freaked me out. So I said, “The hell with this,” and I moved to the floor. Then we installed the exercise bike next day, so I couldn’t sleep on the floor anymore. So then I went to the wall. I found that it took me really a couple of days to kind of be okay with – I think for me, before the spacewalks."

"I would, in my sleeping bag in space, kind of go to my side even though there was nothing different. Although, I would feel sort of the sensation of the pillow on the side of my head, and that felt good."

"Well, for me, and it’s different for everybody, but I find you can actually nap by simply closing your eyes. So I could be sitting on this, floating freely in space and you just close your eyes, your arms are out in front of you, your knees are bent, your hips are flexed, and you just nap. And you float around. I’ve done that before in the Lab and it’s pretty cool to be able to do. I’m lucky in a sense that it seems like I can sleep in a wide different number of environments in 0 G and it’s not an issue."

"What it does is changes your position of your spine. It’s not the legs, it’s the spine which after a couple of hours—not a couple of hours—4 or 5 hours being in one position that maybe is correlated to reasons why you wake up after 4 or 5 hours, I need to move my spine; and that’s what I did. Tucked in the knees, put it under the band and was good for the rest—I only needed the two positions. I never switched back and forth, I might have once or twice, but basically, there was one switch in the position every night."

**Conclusion: Sleep Quality Over the Mission**

The findings and recommendations detailed below are based on the accumulated evidence shared by Shuttle flyers who participated in the study. We have summarized what these astronauts said about sleep over the duration of the mission.

Sleep quality over the mission, whether it improved or worsened, was largely affected by characteristics of the individual rather than by aspects of the mission, Shuttle, or fellow crewmembers.

Sleep quality over the mission improved for those who

- feel well-rested when waking from sleep on Earth.

Sleep quality over the mission worsened for those

- who used stimulants,
whose sleeping position affected their ability to sleep, and
who felt more fatigue as the mission progressed.

VI. Discussion

The goal of this study was to identify strategies that will help crewmembers improve their sleep quality during spaceflight missions. The specific aims of the study are listed below, with a discussion regarding how these aims were addressed.

(1) Obtain, from a representative sample of current astronauts who have flown short-duration STS missions, and analyze subjective data on their sleep behaviors and sleep quality on Earth, during training periods, and during Shuttle missions.

The investigators accomplished this aim by recruiting current astronauts who have flown short-duration STS missions, collecting data through surveys and interviews, and analyzing the data and presenting findings in this report. In all, 74 current astronauts participated in the study; of these, 64 completed an interview and a survey, and 10 completed the interview only. This sample of individuals includes almost the entire population of current astronauts (as of March 2010) and more than exceeds our original goal of 30 or more participants.

The focus of the analysis is largely on sleep behaviors during Shuttle missions, with factors relating to ease of falling asleep in space, staying asleep in space, and sleep quality over the course of the mission. Some of the analysis does compare sleep behaviors on Earth to those in space, particularly regarding sleep medication use. Although the study provides insight into sleep behaviors on Earth, the items included in the survey and in the interview did not specifically focus on training periods. Reports indicate that for long-duration missions, the training can be more stressful and fatiguing than the spaceflight mission itself. Hence, while these were not specifically analyzed in this effort, an assessment of training practices and optimal countermeasure strategies for ISS astronauts should be conducted.

(2) Use the results of analysis of these data to identify and recommend to current and future astronauts specific strategies for ensuring sleep quality and quantity during spaceflight missions.

We accomplished this aim by identifying and recommending specific strategies to current and future astronauts through this report as well as a slide presentation that summarizes our primary findings, and a one-page document highlighting strategies developed from the investigation to be presented to remaining crewmembers preparing for upcoming Shuttle missions. The study therefore fulfilled its aim of providing
recommendations to crewmembers for promoting sleep quality and quantity during their Shuttle mission.

Unfortunately, the analysis from the study was completed as the Space Shuttle Program was winding down. For this reason the number of crewmembers that were given these recommendations was limited. The findings, however, are considered relevant to those preparing for an ISS mission, and has provided a generous number of “lessons learned” for a similar assessment of the sleep and workload experience from ISS missions.

Additionally, findings from the investigation can inform future short-duration and long-duration spaceflight missions. The experiences of the Shuttle flyers captured in this report provide evidence regarding environmental contributors (such as lighting and crowdedness), mission contributors (e.g., schedules and workload), crew-related factors (e.g., crewmember noisiness), and individual contributors (e.g., stimulant use, back pain). These findings can inform future habitat designers, mission planners, and crew surgeons, as well as future astronauts, about sleep-related concerns—and possible mitigation strategies—for future missions.

(3) Provide recommendations for flight rules and requirements and for crew health and habitability standards, for the purpose of managing problems in spaceflight related to fatigue caused by sleep loss.

In addition to supporting current crewmembers, findings from the study address BHP gaps, and, subsequently, flight rules and requirements and crew health and habitability standards.

As previously noted, the findings help to inform Sleep Gap2: “How is performance in spaceflight affected by fatigue due to sleep loss, circadian desynchronization, extended wakefulness and work overload?” and Sleep Gap 7: “Does sleep loss, circadian desynchronization, work overload and extended wakefulness as it is experienced in spaceflight affect well-being, crew interaction, and performance? If so, how?”

When asked about fatigue effects during their mission ($n = 63$), over half of the crewmembers indicated they perceived no effects. Close to half of the crewmembers, however, mentioned they were aware of fatigue during their mission. Of the responses given, 8% mentioned making fatigue-related mistakes and 14% indicated that they noticed cognitive slowing. Twenty-one percent of the astronauts responding stated that their performance would have improved if they hadn’t been fatigued.

When asked about fatigue effects on the crew ($n = 63$), one-third of the crewmembers indicated it had no impact, whereas the rest discussed effects that were present during the mission but were mostly managed. Some crewmembers elaborated on psychosocial effects of fatigue, noting increased irritability, tenseness, anger, impatience.
Importantly, despite the lack of sleep and intense workload experienced by many, crewmembers successfully completed their tasks and their mission. Maintaining such a pace beyond 2 weeks, however, could yield deleterious performance and psychosocial outcomes.

Although this investigation is limited in that it presents a retrospective, subjective assessment of sleep in flight, anecdotal reports from crewmembers helped to characterize the risk of performance and behavioral decrements related to fatigue.

Regarding **Sleep Gap 3**: “Does sleep loss continue in spaceflight or is there adaptation?” most crewmembers seemed to report that they maintained about the same amount of sleep throughout the mission or improved it. Astronauts who reported the quality of their sleep worsening over the duration of the mission also reported increased fatigue as the mission progressed ($r = -.26$, $p = .04$). This subjective assessment, therefore, showed that many crewmembers reported adapting to sleep in space, but fatigue effects were felt by those who continued to lose sleep.

Answers to questions about sleep and adaptation to spaceflight will be largely enhanced by objective data recently collected on the Sleep-Wake Actigraphy investigation (Flynn-Evans et al., 2012). The tempo and workload on Shuttle missions likely varies from the tempo on a long-duration mission like those on the ISS, which may be more suitable for studying adaptation. This gap should be addressed through other investigations, including those that utilize objective measures and those that assess long-duration stays in space. Additionally, we do not know if sleep structure remains intact in microgravity (with and without sleep medication).

Findings from the study further inform **Sleep Gap 6**: “How can individual crewmembers use sleep and alertness medications prior to and during spaceflight?” As previously mentioned, sleep medications are regularly used during Shuttle missions – yet, sleep remains reduced. In this investigation, crewmembers discussed their subjective assessment of the advantages and disadvantages of hypnotics. Various medications affected individual crewmembers interviewed in this study differently, and this is why the current effort from Space Medicine Division/BHP to ground-test sleep medication effects on individual astronauts is supported.

Additionally, the investigation demonstrates that additional education about alertness medications is needed. Twelve of the 75 participants had used Provigil, and eleven additional crewmembers had Provigil with them during their mission in case they opted to use it. Several crewmembers, however, had concerns about the medication, and others said they simply did not know enough about it.

Regarding **Sleep Gap 9**: “What are the countermeasures needed to treat/recover from chronic partial sleep loss, work overload, and/or slam sleep shifting?” Please note that Shuttle crewmembers, despite regular medication use, are attaining only around 6
hours of sleep per night (Flynn-Evans et al., 2012). Although medications may help some crewmembers with sleep onset, sleep continues to be reduced, and other mitigations are needed.

Importantly, findings from the study revealed that task- and mission-related concerns and anxiety inhibited the ability to fall asleep. Therefore, methods for managing work stress should be included as part of astronaut training. Training and education on the effects of sleep loss could also be implemented to help crewmembers become more aware of their own limitations, as well as understand how to support their peers who may have different sleep needs. As previously mentioned, some crewmembers indicated that to mitigate fatigue effects on performance, the team remained vigilant of one another’s fatigue levels and covered one another accordingly. Awareness training and methods through which to support each other through fatigue may be warranted.

Additionally, several crewmembers mentioned high CO₂ levels as a possible contributor to headaches, fragmented sleep, and cognitive impairments, echoing the suspicions of flight surgeon and researchers at NASA. Thus, an assessment of CO₂ levels in flight and objective measures of sleep duration are recommended.

Findings from the investigation have also informed **Sleep Gap 10: What flight rules and requirements improve sleep, circadian desynchronization, fatigue and work overload?**, which also serves as the third aim of the study. Flight rules pertain to issues such as scheduling. The current investigation provides evidence that time is needed specifically for pre-sleep setup, as well as wind-down. BHP is therefore working with the Space Human Factors and Habitability group to define a minimum duration of pre-sleep and post-sleep times for future space missions.

BHP is also participating in an effort to define standards for future space habitats specific to recent Design Reference Missions. The current investigation provided evidence that general noise from other crewmembers caused nighttime awakenings, and therefore substantiated the need to provide private sleep quarters regardless of the habitable volume. Additionally, some crewmembers discussed the length of time it took to set up for sleep, lending further voice to the need for permanent, individual sleep quarters.

BHP has also informed standards for minimum lighting levels for future spaceflight missions. Laboratory investigations have provided evidence that melatonin suppression can occur at night even under very low levels of light (Brainard et al., 2001). The current investigation revealed that even minimal light leakage can hinder sleep onset for some crewmembers.

*(4) Assess the feasibility of implementing the full survey instrument, or portions of it, as a standardized operational measure for all spaceflight missions and of capturing the information in the LSAH.*
The implementation of this study has demonstrated that surveying astronauts as an operational procedure is in fact feasible. Lessons learned from this study can help to inform future efforts.

These revisions include the following:

- Clarify confusing items. Some items, although they were placed in sections pertaining to spaceflight or Earth sleep, did not specify “spaceflight” or “Earth,” leaving too much room for interpretation by the participant.

- Include more items that assess the subjective experience of sleep in space. Only one item on the survey asked about falling asleep in space and one item asked about staying asleep in space. To make the instrument more robust, several items should inquire about these outcomes.

- Clarify items that are phrased in a leading manner and/or that are double barreled. Although steps were taken to minimize such items, a later review of the survey revealed that several of them remained; for instance, in an attempt to assess ability to “stay asleep,” the item read, “In space, I am rarely disturbed during my sleep and can sleep through anything.” The use of “disturbed” may inherently suggest an external interruption, which may or may not have been the case.

- Include items specifically about the training period on Earth, and about sleep on Earth outside of the training period.

- During the interview, remind participants to answer questions in regard to their most recent mission.

- Some interview questions are repetitive, or asked in slightly different ways. Revise interview questions so that they are not redundant.

- During the interview, when discussing sleep mitigation strategies, follow up with a “What effect did this have on your sleep?” (or performance, or other outcome)

- Keep a database, separate from the responses, to track the participants who agreed to be included in the study. For the current study, to ensure that the identities of the participants remained anonymous, we did not track the participants’ identifications. Although this allowed us to assure participants that their responses would remain completely anonymous, it does not allow future data-mining efforts.
• Track the ID numbers of participants in the surveys and the interviews. Do not leave it up to the participants to provide this information, as many forgot to bring their ID number to the interviews and therefore the two data sets (survey and interview) could not fully be matched.

VII. Limitations of the Findings

Subjective assessments. This investigation helps to characterize the sleep experience of Shuttle astronauts during their stays in space, but certain limitations must be kept in mind when drawing conclusions from it. The intent of the study was to gather subjective experiences, and thus it is not based on objective facts but rather perception. Certain conclusions made by participants are not substantiated in the research; for instance, claims indicating that “you adapt to sleep deprivation” are not shown in the research. In fact, as discussed in the Background Section, chronic partial sleep deprivation has been shown to lead to performance and health decrements.

Retrospective. Additionally, the study is retrospective—for some participants, weeks had passed since their Shuttle flight, and for others, several years. For some individuals, therefore, the recollection of the sleep experience on Shuttle may not be an accurate representation. More immediate and unobtrusive assessments in the spaceflight environment using validated, objective measures, in conjunction with capturing subjective perceptions, is a preferred approach for most accurately characterizing risk in flight.

Individual Differences. As noted, to maintain results as ‘completely anonymous’, individual factors related each respondent were not tracked. As a result, the analysis presented does not allow for determining whether stressors or countermeasure strategies varied relative to factors such as previous spaceflight experience or age.

VIII. Acknowledgments

The authors would like to acknowledge:
Drs. Lacey Schmidt, Kim Seaton, Daphne Peoples and Camille Shea, for their assistance with interviewing participants;
Drs. David Dinges, Smith Johnston and Walter Sipes, and Mr. Steve VanderArk, for their contributions and supportive feedback;
Ms. Susan Breeden and Ms. Monica Travis, for their assistance with editing and formatting;
And a very big thank you to Dr. Mike Barratt, for his careful review and helpful insight.
IX. References


In 2009, the NASA Human Research Program Behavioral Health and Performance (BHP) Element, in collaboration with the Space Medicine Division, implemented a study to characterize the subjective sleep experience of astronauts during Space Shuttle missions. Study participants were NASA astronauts who have flown Shuttle since the “Return to Flight” missions (STS-114) in 2005, through those on STS-130 in February 2010. A total of 64 astronauts completed both the survey and the interview; an additional 10 astronauts completed just the interview. Content of the survey relates to sleep during Shuttle missions and sleep on Earth, including factors that may inhibit sleep; and specific countermeasure strategies used and their subjective effectiveness. Follow-up interviews provided an opportunity to gather additional information on sleep stressors and countermeasures. The survey results indicated individual variability exists with regard to sleep in flight. Some factors predictive of reported sleep quality were identified. Results from this investigation will be used to provide recommendations to astronauts preparing for spaceflight missions to the International Space Station, the Soyuz, and those training for future missions. This study will also help identify gaps related to needed countermeasure development and implementation, and provide insight into the use of sleep medications in space.