All photographs courtesy NASA

NASA's Sleep Doc

Smith L. Johnston, MD, is known as the most engaged NASA flight surgeon in the area of sleep research.

By Franklin A. Holman

The sleep of astronauts on board the final space flight of Atlantis was interrupted by an alarm telling the space crew that one of the main computers had failed. The astronauts were able to quickly fix the glitch but not without having to face a frequent problem in space—disturbed sleep. Disrupted sleep on space missions has long been on the radar of NASA. Now, with the retiring of the shuttle program, sleep researchers, under the leadership of Smith L. Johnston, MD, are looking forward to a new era of investigations aimed at unlocking the secrets of sleep in space.

"As a flight physician, Smith has been very much at the front line of trying to identify how to manage sleep in an effective way in spaceflight," says David F. Dinges, PhD, professor and chief of the Division of Sleep and Chronobiology, Department of Psychiatry, University of Pennsylvania. "I think most of us see him as one of the, if not the most, engaged flight doctors in the area of trying to ensure astronauts get healthy sleep before, during, and after spaceflight."

Serving as medical officer and flight surgeon for NASA Johnson Space Center over the past 17 years, Johnston says, "It's my job to ensure that individuals in space are healthy. In terms of sleep, it's my responsibility to use everything in our armamentarium to make sure astronauts can sleep and shift while in orbit."

Astronauts are up against a number of factors when trying to sleep in space. For one, every time astronauts orbit the earth, there is a 90-minute light/dark cycle, meaning during spaceflight the crew experiences approximately 16 "sunsets" per day. Because of this light/dark schedule, astronauts' circadian rhythms can be thrown off.

"Circadian rhythms can become misaligned when you have these 90-minute light/dark cycles sending inappropriately timed signals to the clock in the brain," says Laura K. Barger, PhD, instructor in medicine, Harvard Medical School. "Because of this, astronauts may not be able to maintain alignment with the 24-hour day. If your circadian rhythms aren't synchronized to the external environment, you have difficulty sleeping," says Barger, who is also associate physiologist, Division of Sleep Medicine, Department of Medicine, Brigham and Women's Hospital, Boston.

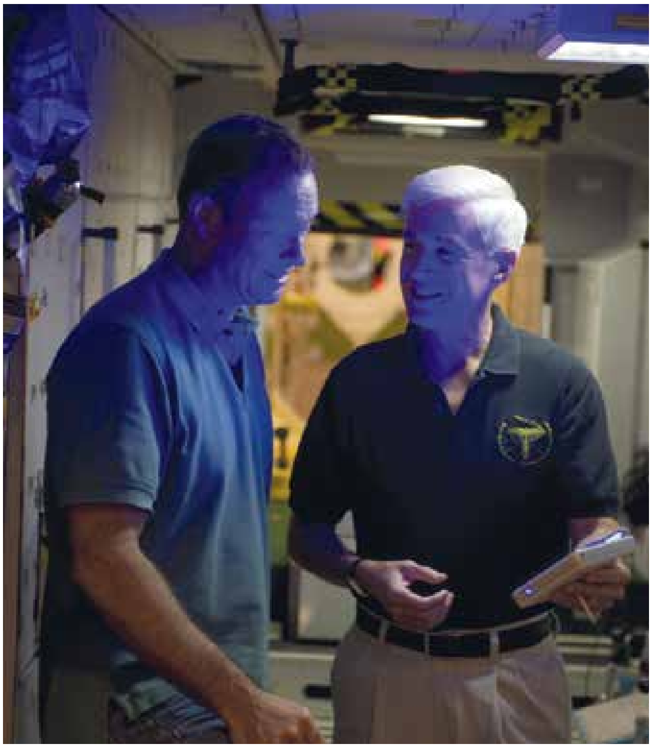
The physical sleeping environment is also a challenge. Since there is no gravity and astronauts would be floating otherwise, they are velcroed to the wall during sleep. "Having to sleep in a bag velcroed to the wall, which is essentially what happens, is the physical environment," says Steven W. Lockley, PhD, assistant professor of medicine, Harvard Medical School. "There's often a lot of noise, it's often quite hot, and there's often a lot of extraneous light, so the physical environment is quite difficult for people to sleep in," adds Lockley, who is also associate neuroscientist, Division of Sleep Medicine, Department of Medicine, Brigham and Women's Hospital.

Adding to these disturbances is the unusual shift patterns that astronauts may work while in space, which would result in the same problems that shift workers have on earth. Astronauts frequently face slam shifts—severe shifts in sleep/wake patterns due to docking or having to perform a critical operation. Such shifts force crew members to remain alert even though their circadian rhythms are signaling that it is time to sleep. "Although avoiding slam shifts is preferred, a crew may have a slam shift when the shuttle docks with the International Space Station (ISS) and then have to be on that time and then have to be on another slam shift when the shuttle leaves," says Johnston.

All of these factors add up, increasing the potential for sleep loss and for mission errors. Ground-based research has shown that in less than 1 week of 4 to 6 hours of sleep per day (which is typically what astronauts experience), impairment and performance deficits start to occur.[1]

Another study from Dinges' laboratory by Van Dongen et al[2] showed that cognitive performance and working memory declined after subjects slept only 4 or 6 hours per day for multiple, consecutive days. Participants who slept only 4 hours were impaired in 6 days and considered severely impaired in 11 days. Participants who slept 6 hours were impaired in 7 days.

Smith L. Johnston, MD (right), analyzes actigraphy data with astronaut Michael E. Lopez-Alegria. The data provided by an actigraph can be used to assess an astronaut's sleep time prior to performing a critical task.



Light therapy can be used to help astronauts adjust their circadian rhythms. Smith L. Johnston, MD (right), explains the benefits of light therapy to astronaut Michael E. Lopez-Alegria.

Astronauts Thomas D. Jones and Mark L. Polansky, STS-98 mission specialists, are photographed during their sleep shift in the Destiny laboratory on the International Space Station (ISS).

Studies have also equated performance after sleep deprivation to performance while intoxicated. Researchers have shown that performance after limiting sleep to 4 to 5 hours per night for 7 days or staying awake for 17.7 to 19.7 hours was equivalent to performance with a blood alcohol level of 0.1%.[3]

In order to minimize sleep loss and its impact on space missions, Johnston works with a group of sleep researchers who specialize in a variety of sleep medicine disciplines to help NASA understand sleep in space and implement sleep health practices for shuttle missions and while on board the International Space Station.

CHRONOBIOLOGY RESEARCHERS

Two of those researchers are David F. Dinges and Hans Van Dongen, PhD, research professor and assistant director, Sleep and Performance Research Center at Washington State University. Van Dongen and Dinges developed the Astronaut Scheduling Assistant—software based on a mathematical model of sleep and circadian effects on performance, to make predictions of when performance will change and in what direction, from worse to better, based on the interaction of the homeostatic drive for sleep and the circadian system.

"It's important that we not wait until someone is extremely fatigued, extremely sleep deprived, or very tired and having trouble performing," Dinges says. "In fact what we really want to do is find ways to use models and prevention strategies like prophylactic sleep, in conjunction with detection technologies, to determine when fatigue is present in space, and then institute acute interventions to mitigate it."

Many tools similar to the Astronaut Scheduling Assistant developed by Van Dongen and Dinges are being applied in varied degrees, but more research is necessary before models that predict astronaut performance relative to fatigue and circadian desynchronization are applied in space. "Additional validation of the mathematical models is needed, but they're certainly a very promising avenue of technology for trying to help manage fatigue in environments like spaceflight," Dinges says.

FATIGUE MANAGEMENT RESEARCHERS

Besides mathematical scheduling tools, researchers are also using actigraphy to study the impact of spaceflight on sleep. At the early stages of sleep research in spaceflight, standard polysomnography was employed. While conducting such research was possible, it was expensive and time-consuming. Using standard polysomnography also limited the amount of data that could be collected on astronauts and therefore made it difficult for researchers to draw conclusions. Results found using standard polysomnography were also interpreted as mission dependent. Due to these factors, researchers and NASA decided to employ actigraphy to maximize the amount of data gathered while minimizing cost and time.

Preliminary results of a study using actigraphy have estimated that while in flight the shuttle crew sleeps an average of approximately 6 hours nightly and approximately 7 hours +/- 1 hour in the first week after flight.[4] Early findings involved an analysis of 23 astronauts over nine missions. Using actigraphy, baseline data is collected for 2 weeks 90 days before a shuttle launch. Data is then collected from 11 days before the shuttle lifts off until launch, in flight, and for 1 week after the shuttle lands.

Employing actigraphs, researchers have also found that sleep quality is hampered when the shuttle crew is faced with a critical mission such as an extravehicular activity (EVA). By analyzing data on nine crew members from five missions who were involved in such a task, they found that average total sleep time the night before the critical mission was 5.6 hours +/- 1.1 hours.[4]

Using actigraphy, results can even be relayed to the ISS crew so they can factor in their sleep when performing EVAs. "We've found it to be very helpful," Barger says about actigraphy. "In fact, we've gotten information down from the station and sent it back up to the astronauts, via the crew surgeons, to give them feedback on how much sleep they're getting before some critical tasks like the space walks or EVAs."

Johnston has referred to actigraphy as being able to monitor an "additional vital sign." Plans to make actigraphy an operational requirement are in the works. Along with sleep logs, actigraphy can help researchers determine trends in disturbed sleep in order to implement countermeasures such as light therapy.

Backdropped by a colorful Earth, including land masses that make up part of New Zealand, astronaut Robert L. Curbeam, Jr, (left) and European Space Agency (ESA) astronaut Christer Fuglesang, both STS-116 mission specialists, participate in the mission's first of three planned sessions of extravehicular activity (EVA) as construction resumes on the International Space Station.

CIRCADIAN PHOTORECEPTION RESEARCHERS

Astronauts are not necessarily at the mercy of the circadian rhythm disruptions inherent in space travel. Although studies of circadian desynchronization are limited and findings about the amount of circadian desynchronization experienced while in flight have varied, a number of studies have demonstrated that circadian desynchronization impacts at least some crew members.[5] Circadian desynchronization is in part influenced by the lighting in the shuttle and the International Space Station.

In the past, space crews have documented issues with lighting on the ISS. The suboptimal, dim lighting was the result of the incandescent and fluorescent light bulbs on the station experiencing burnout; there was also difficulty shipping up a new stock of lights.[4] After the problem was mainly addressed with a reshipment in 2005, the issue was put on the back burner.[4] However, in 2010 lighting garnered new attention with a report outlining how replacement lighting on the International Space Station should be implemented.[6] A team at NASA headed by Lauren Leveton, PhD, found that "maintaining current brightness levels limits visual acuity, work space, and the use of light as a countermeasure for improving circadian entrainment, hastening phase shifting, evoking acute alertness, and enhancing performance." These factors led researchers to conclude that lighting needed to be revised on the ISS.[6]

Researchers like Steven Lockley and George Brainard, PhD, are studying how different colors of light have the ability to preferentially shift astronauts' clocks or alert the brain in order to eventually develop smart lighting systems that are properly attuned, so they can mediate the photoreceptors' responses to light. Researchers are trying to target those photoreceptors and implement efficient lighting to make sure astronauts can shift their body clocks quickly, or are alert when they need to be.

"The lighting on the space station will eventually have to be replaced," says Lockley. "New technology such as solid state lighting or light emitting diodes, for example, gives the potential to have lights that are smart and can produce different colors or different intensities, different durations or patterns of light, which the fluorescent lights that are currently on the station are not capable of doing. So new technology, alongside this new science and understanding of how light affects our physiology, can come together to help produce smarter, more energy-efficient, and better lighting systems to help maintain circadian rhythms in space, and also to alert people when they need to be working at a higher level."

With supplies of fluorescent lights on the International Space Station estimated to be exhausted by 2015, sleep researchers have their work cut out for them with plans to provide optimal light to crews on the space station.

While Atlantis has returned home and the NASA shuttle program has ended, sleep research will continue, and its applications will be employed on future space missions to the International Space Station utilizing the Russian Soyuz and a new generation of space exploration advanced by private entrepreneurs. This new era of space exploration will require closer global cooperation and pose new opportunities where researchers like Smith Johnston and his team will collaborate to pose new questions and explore new findings that could result in one better sleep for mankind. **SR**

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References available with the online version.

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