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Editorial

Sleep in space as a new medical frontier: the challenge of preserving normal sleep in the abnormal environment of space missions

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ABSTRACT

Space agencies such as the National Aeronautics and Space Administration of the United States, the Russian Federal Space Agency, the European Space Agency, the China National Space Administration, the Japan Aerospace Exploration Agency, and Indian Space Research Organization, although differing in their local political agendas, have a common interest in promoting all applied sciences that may facilitate man's adaptation to life beyond the earth. One of man's most important adaptations has been the evolutionary development of sleep cycles in response to the 24 hour rotation of the earth. Less well understood has been man's biological response to gravity. Before humans ventured into space, many questioned whether sleep was possible at all in microgravity environments. It is now known that, in fact, space travelers can sleep once they leave the pull of the earth's gravity, but that the sleep they do get is not completely refreshing and that the associated sleep disturbances can be elaborate and variable. According to astronauts' subjective reports, the duration of sleep is shorter than that on earth and there is an increased incidence of disturbed sleep. Objective sleep recordings carried out during various missions including the Skylab missions, space shuttle missions, and Mir missions all support the conclusion that, compared to sleep on earth, the duration in human sleep in space is shorter, averaging about six hours. In the new frontier of space exploration, one of the great practical problems to be solved relates to how man can preserve "normal" sleep in a very abnormal environment. The challenge of managing fatigue and sleep loss during space mission has critical importance for the mental efficiency and safety of the crew and ultimately for the success of the mission itself. Numerous "earthly" examples now show that crew fatigue on ships, trucks, and long-haul jetliners can lead to inadequate performance and sometimes fatal consequences, a reality which has caused many space agencies to take the issue of sleep seriously.

'A man's reach should exceed his grasp, or what's heaven for?'—Robert Browning

There is no limit to human potential nor to what one would wish for or hope to conquer. Certainly this attitude drives the thought and imagination of those who are closely involved in the technical challenges of space travel [3]. Space agencies such as the National Aeronautics and Space Administration (NASA) of the United States, the Russian Federal Space Agency (FKA or RKA), the European Space Agency (ESA), the China National Space Administration (CNSA), the Japan Aerospace Exploration Agency (JAXA), and Indian Space Research Organization (ISRO) are in the forefront of aerospace research, whatever their local political agendas may be. At their core however the basic mission of these various

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agencies remains consistent: to grapple with the significant problems that man will confront in adjusting to life in space. In the new frontier of space exploration, one of the great problems to be solved relates to sleep. After spending millions of years evolving to survive on a planet that turns on its axis once every 24 h, all living animals have adapted to the pull of gravity towards the center of the Earth and humans have not escaped the requirements of this challenge. The question is, how will humans adapt to living in outer space where some of earth's environmental time-keepers have been removed or drastically changed?

Anthropological evidence suggests that man's lifespan was initially much shorter than it is today. During the Paleolithic and early Neolithic periods, the average human only lived about 30–40 years [25]. This is not surprising in view of the harsh and frigid conditions that often prevailed in man's immediate environment. The uncertainties of food supplies and natural resources frequently drove our primitive ancestors to seek better opportunities for survival by exploring new lands beyond the areas in which they found themselves. Humans ventured out of Africa around 125,000 years ago, and then spread out across Asia about 75,000 years ago [26]. Eventually they traveled on to new continents and islands and ultimately populated most of the regions of this planet. Evolution of the human species has been through small physical changes to the body but accompanied by huge changes in the human brain and intelligence. The great theme of wanting to explore new frontiers has always been an enduring *leitmotif* of man's nature. Even ancient civilizations seem to have used '*Vimāna*', a mythological flying craft or chariot described in Hindu texts and Sanskrit epics. What we thirst for most is not to conquer the world… but to go beyond and even escapes the earth's pull! In modern times this aspiration has turned our attention toward the heavens. Thus, while venturing into the frontier of space was at one time thought to be an impossible dream, the driving force of this idea has provided the technology to bring this dream into the realm of the possible!

Over the last decade there has been an unprecedented growth in many areas of science, technology, and medicine. We have seen again and again in the newspapers and media what a particular country has accomplished on an annual basis. The next frontier is to travel to Mars. Agencies such as NASA have prioritized research that will elucidate the strategies and skills humans will require meeting the challenges of long-duration spaceflight [18]. Similar strategies have been either adopted or are under development in by various space agencies. Accompanying the high aspirations of many nations to explore new worlds is an awareness of the equally challenging practical difficulties that would be posed by such an undertaking. One of the major questions is whether human crews will be up to the task of piloting space vehicles over the great distances involved in reaching other planets. Numerous "earthly" examples now show that crew fatigue on ships [11,20], trucks [21], and long-haul jetliners [24] can lead to inadequate performance and sometimes fatal consequences [15], a reality which has caused many of the space agencies to take the issue of sleep seriously.

Human space travel is often challenging for various reasons. First, the crew is subjected to long periods of enforced wakefulness, which in turn poses a risk for the health and safety of self, the crew members, and the entire mission. Sleep loss, subsequent fatigue and sleepiness can cause errors in judgment and impairments to memory and cognition. The consequence is that performance of critical tasks is impaired in an environment with/where there is not too much outside help available. The interdependency of many on-board tasks means that the consequences of individual failure at carrying out one task component is multiplied and could potentially compromise the entire mission. In certain circumstances, these errors can produce huge economic losses or even loss of life.

A report of the U.S. Presidential Commission on the Space Shuttle Challenger Accident cited the contribution of human error and poor judgment, which in turn may have been caused by sleep loss and shiftwork during the early morning hours [22]. The report concluded that sleep loss, irregular working hours, and extra shifts may have significantly contributed to critical errors in judgment made by experienced senior managers. In all, sleep deprivation was a contributory, if not a causal factor in the poor decisions made the night before the launch of the Space Shuttle Challenger. In another 'near-catastrophic' event related to the shuttle Columbia in 1986, operator fatigue was reported to be a major contributing factor in which the console operators at the Kennedy Space Center inadvertently drained 18,000 pounds of liquid oxygen from the shuttle's external tank within 5 min before scheduled launch [14]. The liquid oxygen loss went undetected until after the mission was canceled only 31 s before lift-off because of a secondary effect on the engine inlet temperature.

Sleep is very often considered to be a barometer of human health. Not only we do sleep better when our overall health is good, there is now considerable evidence that adequate rest at night is essential for supporting the healthy functioning of our bodies and maintaining mental alertness. Unfortunately our sleep/wake cycle is disturbed by stressors such as shiftwork and air travel. Before humans ventured into space, there was an obvious question if sleep was feasible at all in the microgravity environment of outer space. However, such doubts were subsequently resolved by the evidence of actual experience. It is now known that, in fact, space travelers can sleep once they leave the pull of the earth's gravity, but that the sleep they do get is not completely refreshing and that the associated sleep disturbances can be elaborate and variable [2].

Sleep disturbances in interplanetary missions depend on a combination of several factors including that of inter-individual differences [9]. In addition to age and gender, it has been found that a rapid succession of light–dark (LD) exposure, ambient temperature, isolation and confinement, uncomfortable postures, noise, space and motion sickness, need to void, physical restraints or changes in physical activity and/or long/unusual sleep–wake and crew shiftwork schedule (operational demands), over excitation (for example, availing a life-time opportunity, crew relationship problems or emotional stress), or other general malaise, could lead to diminished alertness, cognition, and psychomotor performance [19]. All these factors on a varying degree can pose a serious threat to crew safety as well as to the space vehicle. It is important to minimize these risks in the extreme and challenging environment of outer space. Some astronauts have reported awakening for unknown reasons. Due to logistic challenges with measuring sleep in the spaceflight environment, only few astronauts have been studied using polysomnography, which is considered to be the gold-standard method for evaluating sleep. Instead, subjective sleep diaries and actigraphy (wrist-worn accelerometer) have been used to characterize sleep among a larger population of astronauts.

Circadian misalignment is a major concern during space travel [1,8,13]. Our natural environmental light–dark cycle is the pervasive and prominent synchronizing agent for the regulation of circadian (~24 h) rhythms [4]. The circadian rhythm requires regular timing of light of sufficient intensity, wavelength, duration and timing in order to remain entrained to the imposed sleep/wake schedule [12,17]. Synchronization of the sleep/wake rhythm and rest-activity cycles with the light–dark cycle of the external environment is essential for maintaining optimal health and performance; conversely, desynchronization disrupts these cycles and leads to sleep disturbance and cognitive impairment during waking.

Circadian misalignment is apparent during spaceflight [10]. A study that was conducted in the late 90's on Russian cosmonauts at the Mir space station also showed that the sleep was much more disturbed than on Earth and that body temperature rhythms were also delayed by 2 h in space [16]. The scientific literature now shows that according to astronauts' subjective reports, sleep durations in space are shorter than on earth and that there is an increased incidence of disturbed sleep. Both subjective and objective sleep recordings carried out various missions including the Skylab missions [6,7], space shuttle missions [5], and Mir missions [16] all point to the conclusion that, compared to sleep on earth, the duration in human sleep in space is shorter, averaging about six hours. In addition to changes in the sleep/wake cycle, other changes such as neurobehavioral, physiological (changes in endocrine and thermal physiology, muscle tonicity and bone consistency) also occur [27]. Several countermeasures are in development to help improve sleep quality and duration during spaceflight including circadian friendly schedule design, short-wavelength (blue) light and sleeping pills [2,23,28].

The evidence of a number of years of scientific research has consistently pointed to the conclusion that disrupted sleep is a very common and important problem among astronauts. The associated challenges of work in an outer space environment require that astronauts to be well rested and alert and that this is essential for optimal crew performance.

The increasing recognition of the importance of sleep hygiene strongly underscores the need for generalizing the findings of this growing science to the requirements of man as he ventures into the next frontier of outer space. More specifically, in preparation for the arduous demands of space travel, behavioral and pharmacological treatments might be needed for astronauts and their families. Simulations and proper protocols need to be developed in order to overcome the potential challenges. For example, programs may be required for the training and implementation of preflight circadian adaptation countermeasures, as well as inflight sleep/wake schedules to optimize circadian adaptation and to minimize and counteract the sleep loss and sleep disruption. In order to meet these challenges, it is recommended that various stakeholder agencies should establish comprehensive sleep and biological/biomedical research programs. In addition, a human fatigue management program should be established to provide appropriate education and training for the crew and mission personnel.

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