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Sleep and cognitive function of crewmembers and mission controllers working 24-h shifts during a simulated 105-day spaceflight mission

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ABSTRACT

The success of long-duration space missions depends on the ability of crewmembers and mission support specialists to be alert and maintain high levels of cognitive function while operating complex, technical equipment. We examined sleep, nocturnal melatonin levels and cognitive function of crewmembers and the sleep and cognitive function of mission controllers who participated in a high-fidelity 105-day simulated spaceflight mission at the Institute of Biomedical Problems (Moscow). Crewmembers were required to perform daily mission duties and work one 24-h extended duration work shift every sixth day. Mission controllers nominally worked 24-h extended duration shifts. Supplemental lighting was provided to crewmembers and mission controllers. Participants' sleep was estimated by wrist-actigraphy recordings. Overall, results show that crewmembers and mission controllers obtained inadequate sleep and exhibited impaired cognitive function, despite countermeasure use, while working extended duration shifts. Crewmembers averaged 7.04 ± 0.92 h (mean $\pm$ SD) and 6.94 ± 1.08 h (mean $\pm$ SD) in the two workdays prior to the extended duration shifts, 1.88 ± 0.40 h (mean $\pm$ SD) during the 24-h work shift, and then slept 10.18 ± 0.96 h (mean $\pm$ SD) the day after the night shift. Although supplemental light was provided, crewmembers' average nocturnal melatonin levels remained elevated during extended 24-h work shifts. Naps and caffeine use were reported by crewmembers during ~86% and 45% of extended night work shifts, respectively. Even with reported use of wake-promoting countermeasures, significant impairments in cognitive function were observed. Mission controllers slept 5.63 ± 0.95 h (mean $\pm$ SD) the night prior to their extended duration work shift. On an average, 89% of night shifts included naps with mission controllers sleeping an average of 3.4 ± 1.0 h (mean $\pm$ SD) during the 24-h extended duration work shift. Mission controllers also showed impaired cognitive function during extended duration work shifts.

These findings indicate that extended duration work shifts present a significant challenge to crewmembers and mission support specialists during long-duration space mission operations. Future research is needed to evaluate the efficacy of alternative work schedules and the development and implementation of more effective countermeasures will be required to maintain high levels of performance.

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1. Introduction

Long-duration space missions beyond low earth orbit represent the future of human space exploration. The success of a long-duration mission critically depends on the ability of the crew and the controllers who support them to be alert and maintain high levels of cognitive function while monitoring and operating complex, technical equipment. As the space program moves from low earth orbit missions to exploration missions and then to asteroids, Mars and beyond, technology limitations and communication delays may limit the systems monitoring that can be done by flight controllers here on Earth. Therefore, crewmembers may likely be required to perform more of these tasks themselves.

Crew schedules will necessarily evolve to fit the needs of the mission, including 24-h monitoring of complex technical equipment. Providing continuous cover 24 h per day, 7 days per week with limited crewmembers will therefore require night shift operations and may include long work weeks and/or extended duration shifts. Rotating shift work may also be required or division of crews into day work and night work teams, as occurred on some of the early Space Shuttle missions.

Optimal human health, performance and safety during spaceflight require adequate sleep duration and synchrony between the circadian pacemaker—which regulates the timing of sleep, endocrine function, alertness and performance—and the timing of the imposed sleep–wake schedule and required mission operations. Night shift operations and extended duration shifts can lead to insufficient sleep opportunities and circadian misalignment.

It has been well documented in laboratory and field studies that working extended duration work shifts that include work during the night results in impaired performance, reduced alertness and mood, and increased sleepiness and risk of accidents [1,2]. Shift workers, particularly night shift workers who invert their normal sleep/wake schedule, suffer for several reasons. When working the night shift, the timing of work and sleep are out of phase with the normal phase of the circadian timing system that is entrained to the environmental light–dark cycle. This circadian misalignment, induced by a mismatch between scheduled work time and the environmental light–dark cycle, leads to a substantial loss of sleep duration during (daytime) sleep episodes [3], independent of, and in addition to, social and environmental obstacles to sleep (e.g., family events, noise) that are present during the daytime hours when most are awake. Misalignment of circadian phase coupled with sleep loss results in the deterioration of alertness and impairment of performance during night work [4].

Spaceflight analog missions are unique opportunities that allow evaluation of sleep, and cognitive function of crewmembers and support staff when scheduled to conditions proposed for extended duration spaceflight missions. We therefore evaluated the sleep and cognitive function of crewmembers and mission controllers during a 105-day operational spaceflight analog simulation that included instruction in the use of fatigue countermeasures during extended work shifts. Specifically, we aimed to test light exposure as a night shift fatigue countermeasure. Non-image forming responses to light include effects on the circadian system, including melatonin suppression, and on brain arousal [5]. These non-image responses to light are most sensitive to exposure to short-wavelengths [6–8]. Therefore, we hypothesized that alertness, performance and mood of crewmembers and external mission controllers exposed to shorter wavelength light (with a peak wavelength between 485 and 525 nm) during the night shift will be significantly better than the alertness, performance and mood of those same crewmembers when they are exposed to intermediate wavelength light (with a peak wavelength of either 545–555 nm or longer wavelength light 620–690 nm) during the night shift. As exposure to light at night, including the light intensities tested [8,9], has been shown to reduce nighttime melatonin levels and such reduction in melatonin levels has been associated with improved performance [5] we also examined salivary melatonin levels during the night shift of the crewmembers.

2. Material and methods

The Institute of Biomedical Problems (IBMP), located in Moscow, Russia, conducted a 105-day operational spaceflight simulation study from March 31, 2009 to July 14, 2009. The mission was designed as a feasibility pilot in preparation for a subsequent 520-day study mimicking the isolation associated with a long-duration spaceflight. Six male crewmember participants (four Russian, one French, and one German) aged 25–40 (32.8 $\pm$ 5.6 years; mean $\pm$ SD) lived and worked in the IBMP isolation facility that included a medical module, a habitable module, a Mars landing module simulator and a storage module. Each crewmember had individual sleeping quarters.

Crewmembers were required to perform mission operations daily throughout the 105-day study composed of daily work operations and an extended duration 24-h work shift every sixth day. Crewmembers were scheduled to sleep between 24:00 and 08:00 h daily, except during the extended 24-h work shift, after which time they were scheduled recovery sleep from 08:00 to 16:00 h and again from 24:00 to 08:00 h. Crewmembers participated in a variety of research studies in addition to the current sleep and cognitive function protocol [10]. Cognitive function of crewmembers was assessed on four consecutive days of the six-day work cycle: morning and afternoon of the day prior to the 24-h shift (day 1), morning and afternoon, evening (baseline) of the 24 h shift at ~22:30 h, and four times during the overnight portion of the 24 h shift at ~01:00, 03:00, 05:00 and 07:00 h (day 0), and afternoon of the day immediately following the 24-h shift and the morning and afternoon of the subsequent day following the 24-h shift (day +2). Nineteen Russian mission controllers (nine females), composed of eight engineers and 11 medical personnel, also participated and were scheduled to work periodic 24-h shifts in support of the mission. Mission controllers were employees of IBMP who lived at home and continued their work responsibilities when not scheduled to 24-h shifts for the mission simulation. Mission controllers completed cognitive function tests three times during the evening/nighttime hours of the 24-h work shift at ~18:00, 00:30 and 07:30 h. The protocol was approved by IBMP, the