Investigating Sleep Quality Under Elevated Atmospheric CO2 in a Simulated Space-Analog Environment

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Elevated atmospheric CO2 (atmCO2) is a persistent operational challenge in human spaceflight, where crew exhalation and limited ventilation lead to CO2 accumulation within the cabin. As a result, astronauts usually report mild hypercapnia-related symptoms along with frequent sleep disruption, posing risks to cognitive performance and mission safety. This study investigated associations between fluctuating atmCO2 levels and sleep quality in a simulated space-analog center replicating realistic mission confinement over seven days. A six-member crew lived and worked inside the facility, enabling assessment of sleep alongside continuous in situ atmCO2 monitoring via an extensive 146 sensor network capturing CO2 buildup driven by crew metabolic activity. Daily physiological measures included end-tidal CO2 assessed by handheld capnography, wrist-worn actigraphy, subjective sleep quality using the Pittsburgh Sleep Quality Index (PSQI), NASA-TLX workload, mood and symptoms. The results showed that atmCO2 levels remained moderately elevated during the mission (mean=1,120 parts per million [ppm]) and rose further during wakefulness. There was inter-crew variability in sleep and duration (3.2-7.8 h/night), with progressive sleep debt across the mission. Paradoxically, higher atmCO2 was associated with improved sleep quality (PSQI -1.25 per 100 ppm increase), earlier awakening (-0.6 hours per 100 ppm increase), poorer mood (-2.6 per 100 ppm increase), along with increased fatigue and headache. These results suggest that moderately elevated atmCO2 may induce somnolence, while concurrently disrupting sleep duration and mood, possibly masking reduced restorative sleep. This has implications for defining safe atmCO2 thresholds and developing countermeasures for future space missions.

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