Slow Wave Sleep and Long Duration Spaceflight

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OBJECTIVES

- Review literature on slow wave sleep (SWS) in long duration space flight, and the broader literature on SWS, particularly with respect to analogous environments such as the Antarctic.
- Review the evidence related to the impact of reduced SWS.
- Explore how SWS could be measured within the International Space Station (ISS) context with the aim to utilize the ISS as an analog for future extra-orbital long duration missions.

INTRODUCTION

While ground research has clearly shown that preserving adequate quantities of sleep is essential for optimal health and performance, changes in the progression, order and /or duration of specific stages of sleep is also associated with deleterious outcomes.

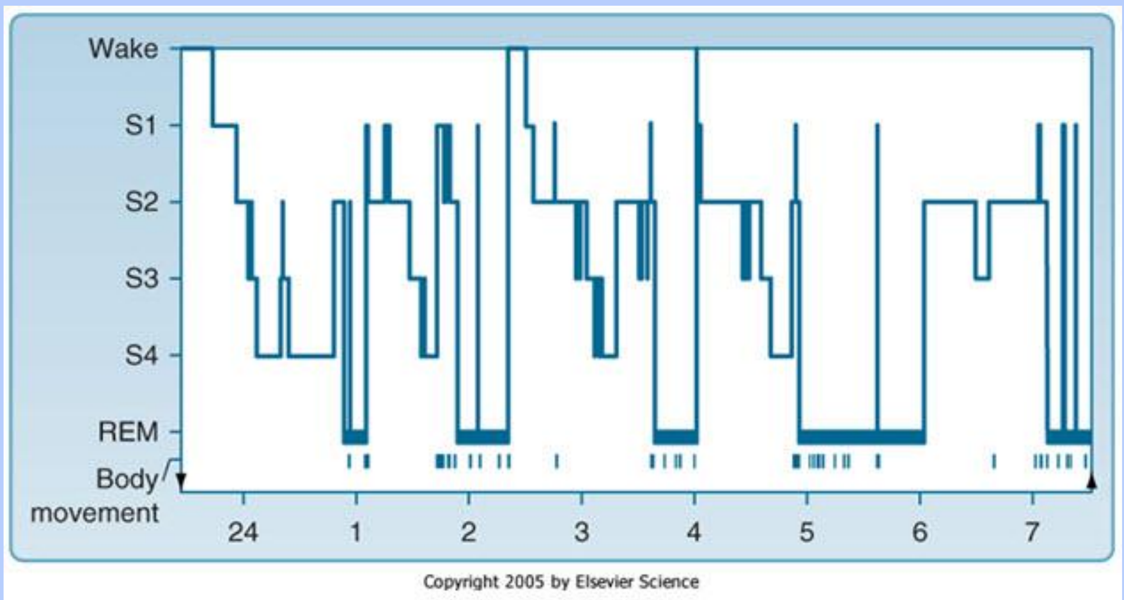

Figure 1. Progression of sleep stages across a single night in a young adult

As seen in Figure 1, in healthy individuals, REM and Non-REM sleep alternate cyclically, with stages of Non-REM sleep structured chronologically. In the early parts of the night, for instance, Non-REM stages 3 and 4 (Slow Wave Sleep, or SWS) last longer while REM sleep spans shorter; as night progresses, the length of SWS is reduced as REM sleep lengthens. This process allows for SWS to establish "precedence", with increases in SWS seen when recovering from sleep deprivation.

SWS is indeed regarded as the most 'restorative' portion of sleep. During SWS, physiological activities such as hormone secretion, muscle recovery, and immune responses are underway, while neurological processes required for long term learning and memory consolidation, also occur.

- The structure and duration of specific sleep stages may vary independent of total sleep duration, and changes in the structure and duration have been shown to be associated with deleterious outcomes. Individuals with narcolepsy enter sleep through REM as opposed to stage 1 of NREM .Disrupting slow wave sleep for several consecutive nights without reducing total sleep duration or sleep efficiency is associated with decreased pain threshold, increased discomfort, fatigue, and the inflammatory flare response in skin. Depression has been shown to be associated with a reduction of slow wave sleep and increased REM sleep.
- Given research that shows deleterious outcomes are associated with changes in sleep structure, it is essential to characterize and mitigate not only total sleep duration, but also changes in sleep stages.

GROUND RESEARCH

Antarctica is widely regarded as an analog for an exploration long duration spaceflight mission. Several investigations have assessed sleep duration and sleep structure of individuals living in Antarctica. Several have found persistent sleep disruptions and changes in sleep structure, as outlined below.

Study	Procedure	Findings	Discussion
Joern, Shurley, Brooks, Guenter, Pierce (1970)	N=2; PSG ; measured upon arrival (First week of summer mission)	Complete loss of SWS	Authors state due in part to adaptation to decreased oxygen pressure
Natani, Shurrley, Pierce, Brooks (1970)	N=4; PSG 3 consecutive nights at 6 different data points: baseline, 4 sessions in Antarctica (spanning summer and three winter phases), upon return to US	Loss of SWS; REM decreased significantly; SWS not return 6 months following return to US	Authors state due in part to chronic hypobaric hypoxia ; extreme dark-light variation, monotony
Paterson (1975)	N=10; at regular altitude, controlled alcohol use, coffee, naps, mood disorders, adequate diet; attained regular exercise; pooled 38 nights of recordings across 9 months (April to December)	SWS reduced progressively, lowest levels in summer months (break in SWS reduction when temporary return to d/n cycle)	Extreme polar daylight may account for changes seen; may be exacerbated by altitude changes as seen in other studies
Palinkas, Houseal, Miller (2000)	*To be updated*		
Bhattacharyya , Pal, Sharma (2008)	N=6; total PSG recordings for 6 n spanned about 18 days/month	SWS showed significant variation with time - decreased significantly compared to baseline, except for November (summer month) – decreasing trend most pronounced during winter	Exercise may play a role in increasing SWS.

Various factors including changes in the day-night cycle, high altitudes, lack of exercise and increased stress may impact sleep structure; the strength of these impacts and how those manifest operationally, however, is yet to be determined.

SPACEFLIGHT RESEARCH

- Research from Shuttle indicates that, within the context of Shuttle mission and environment, and despite sleep medication usage, total sleep duration remains reduced (Barger and Czeisler, 2011). Likewise, anecdotal evidence indicates sleep remains a top concern for ISS crew members.
- Studies related to sleep structure in space however remains sparse. The few studies that have evaluated sleep stages in flight suggest changes in sleep structure may occur.

Study	Procedure	Findings	Discussion
Gundel (1997)	N=4 at baseline, prelaunch, and over various nights throughout long duration mission on Mir (only one N went beyond 30 days); PSG	Reduced sleep duration in-flight; redistribution of SWS from first to second period; latency to REM sleep shorter; one participant demonstrated significant sleep difficulties and mal-adaptation (medication use not reported)	Authors state due in part to lack of day earth-night lighting cues; individual differences in adaptation
Monk (1998)	N=7; 72-hour measurement blocks included PSG – one preflight, two in-flight (beginning and end), one post-flight	Reduced sleep duration in-flight; all participants had reduced SWS in-flight	Authors state reduced SWS of great concern for future exploration missions
Stickgold and Hobson (1999)	N=5; nightcap recorded average of 25 nights pre-mission, 24 in-mission and 14-post	Decreased sleep duration, reduced REM sleep, reduced sleep efficiency	Authors state this level of reduced sleep could lead to performance decrements
Djik(2001)	*To be updated*		
Mallis and DeRoshia(2005)	Evaluate previous literature	Stoilova et al. (2003) and Moldofsky et al. (2000) found reduced SWS in-flight	

Spaceflight research therefore suggests that changes in the structure, progression and duration of sleep stages may occur. These findings are especially of concern given the evidence that crew members often report launching sleep deprived, and under normal conditions of sleep deprivation, SWS tends to increase. Reduced and off-nominal REM stages may also pose concerns.
Long duration exploration missions will pose stressors that may affect sleep structure. Research indicates that such changes are associated with deleterious outcomes, hence, further investigations that seek to characterize sleep stages in current spaceflight, and evaluate sleep stages in response to future countermeasures (i.e. lighting protocols) are needed.

New technologies that minimize volume requirements, crew time and pose more acceptable protocols may facilitate this type of research.