Sleep Disruption Medical Intervention Forecasting (SDMIF) Module for the Integrated Medical Model

B. E. Lewandowski[1], J. E. Brooker[1], S. R. Hursh[2], M. M. Mallis[2], J. L. Caldwell[3], and J. G. Myers[1]

[1]NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, OH 44135,
[2]Institutes for Behavioral Resources, Inc., 2104 Maryland Ave., Baltimore, MD 21218, and
[3]Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

INTRODUCTION

The NASA Integrated Medical Model (IMM) assesses the risk, including likelihood and impact of occurrence, of all credible in-flight medical conditions. Fatigue due to sleep disruption is a condition that could lead to operational errors, potentially resulting in loss of mission or crew. Pharmacological consumables are mitigation strategies used to manage the risks associated with sleep deficits. The likelihood of medical intervention due to sleep disruption was estimated with a well validated sleep model and a Monte Carlo computer simulation in an effort to optimize the quantity of consumables.

METHODS

The key components of the model are the mission parameter program, the calculation of sleep intensity and the diagnosis and decision module. The mission parameter program was used to create simulated daily sleep/wake schedules for an ISS increment. The hypothetical schedules included critical events such as dockings and extravehicular activities and included actual sleep time and sleep quality. The schedules were used as inputs to the Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) Model (IBR Inc., Baltimore MD), which calculated sleep intensity. Sleep data from an ISS study was used to relate calculated sleep intensity to the probability of sleep medication use, using a generalized linear model for binomial regression. A human yes/no decision process using a binomial random number was also factored into sleep medication use probability.

RESULTS

These probability calculations were repeated 5000 times resulting in an estimate of the most likely amount of sleep aids used during an ISS mission and a 95% confidence interval.

CONCLUSIONS

These results were transferred to the parent IMM for further weighting and integration with other medical conditions, to help inform operational decisions. This model is a potential planning tool for ensuring adequate sleep during sleep disrupted periods of a mission.
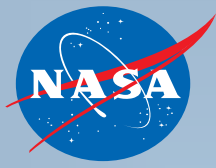
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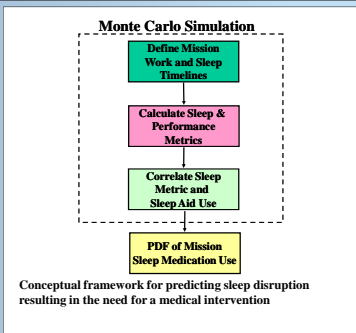[3]Air Force Research Laboratory, Wright-Patterson AFB, OH

BACKGROUND

NASA's Integrated Medical Model

- A probabilistic, simulation-based tool used to predict the rate of occurrence of in-flight medical events
- Used to help determine the relative risk of medical events that could occur in space
- Used to help optimize mitigation tools, such as the in flight medical kit
- Probabilistic risk assessment methods are utilized in combination with the best available spaceflight data , evidence and relevant terrestrial databases

### Sleep Disruption on the International Space Station (ISS)

- Difficulties with sleep affect more than half of all US crews on ISS
- Mitigation strategies of sleep disruption impact the mass and volume of vehicle consumables and the mission timeline
- The SDMIF tool estimates the occurrence of sleep disruption and need for medical interventions

Monte Carlo Simulation

Define Mission Work and Sleep Timelines → Calculate Sleep & Performance Metrics → Correlate Sleep Metric and Sleep Aid Use → PDF of Mission Sleep Medication Use

Conceptual framework for predicting sleep disruption resulting in the need for a medical intervention

METHODS

Mission Work and Sleep Timelines

- Generated realistic ISS mission schedules of sleep and wake times derived from historical planned and actual ISS mission schedules
- The sleep/wake schedules included shifting events: Shuttle, Soyuz and Progress Dockings and Extra Vehicular Activities (EVA)
- The actual amount of sleep obtained during a sleep opportunity was predicted
- The quality of sleep, dependent on the frequency and quantity of wakefulness, or interruptions was modeled

Graphical example of a sleep/wake schedule for a simulated ISS mission. Black areas represent wakefulness, white areas represent sleep opportunities.

Soyuz event

Soyuz relocation event

(A) STS slam shift event, (B) STS gradual shift event

(A) EVA slam shift event, (B) EVA gradual shift event

(A) Progress slam shift event, (B) Progress gradual shift event

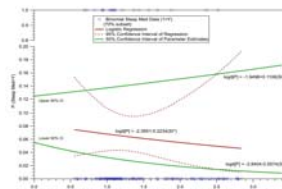## METHODS (Con't)

Sleep & Performance Metrics

- The Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) Model is an accepted sleep model used to determine the effects of sleep timing and duration and the influence of time of day (circadian effects)
- SAFTE accurately reflects the degrading effects of sleep fragmentation or sleep interruptions
- SAFTE input is mission schedule and astronaut parameters
- SAFTE output is effectiveness, sleep reservoir and sleep intensity
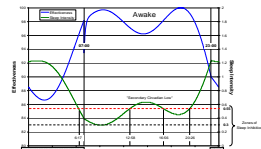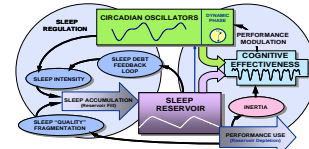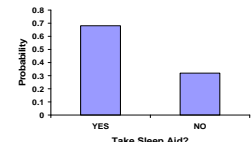

The Sleep Activity, Fatigue, and Task Effectiveness (SAFTE™) Model (IBR, Inc)

SAFTE Output

Sleep Metric and Sleep Aid Use

- The underlying premise was that below a particular sleep intensity threshold, pharmaceutical intervention is likely
- A logistic regression was used to correlate sleep intensity calculated with SAFTE to reported incidences of intervention, obtained from the Sleep-Wake Actigraphy and Light Exposure During Spaceflight study (NCC9-119, PI Charles A. Czeisler, M.D., Ph.D., Co-I Laura K. Barger, Ph.D.)
- The regression coefficients were used in the model equation that translated sleep intensity to probability
- A human yes/no decision process was also incorporated with a binomial random number

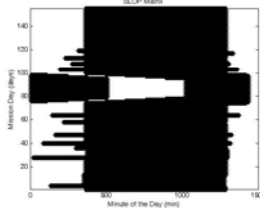Logistic regression of SAFTE output with data from NRA NCC9-119
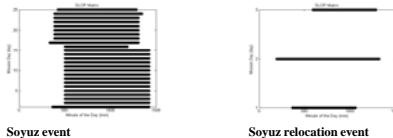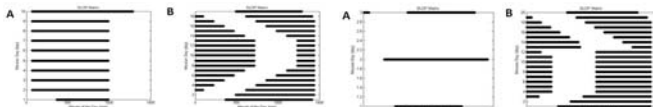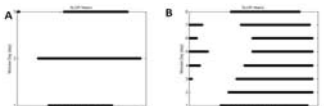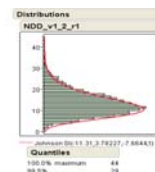

Human yes/no decision

RESULTS

Estimated Number of Sleep Aids Used During an ISS Mission

- Estimate based on 5000 trials
- Result was 13 ± 5.5 (mean $\pm$ standard deviation) sleep aids per mission with a 95% confidence interval of 4 – 25

Results showing number of sleep meds taken per crew per increment, and associated uncertainty (JMP output)

DISCUSSION

Model Limitations

- Mission work and sleep timelines were based on ISS increments 1 – 12. The average number of data points in each parameter distribution was 10 ± 7, which is a fairly small sample, accuracy could be improved with additional data from additional increments.

- The sleep intensity threshold was found using SAFTE model values of sleep intensity, which is a calculated, rather than physiological measure.

- The p-value of the logistic regression used to find the sleep intensity threshold was 0.6427 indicating that the model fit is no better than when a fixed response rate across the whole sample is used.

- The above result highlights that medication use may be a multi-factor problem and that the model may not capture environmental and physiological factors that are major factors in medication use.

- Future models should attempt to utilize a sleep model more tailored to space flight conditions.

- Future estimates of sleep intensity, used to perform the correlation with flight data, should use the actual sleep structure over the length of the ISS increment.

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