Fiscal Year:	FY 2010	**Task Last Updated:**	FY 05/21/2010
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Project Title:	Designing Individual Countermeasures to Reduce Sleep Disruption and Improve Performance and Alertness in Space		
Division Name:	Human Research		
Program/Discipline:	NSBRI		
Program/Discipline--Element/Subdiscipline:	NSBRI--Human Factors and Performance Team		
Joint Agency Name:		**TechPort:**	No
Human Research Program Elements:	(1) **BHP**:Behavioral Health & Performance (archival in 2017)		
Human Research Program Risks:	(1) **BMed**:Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders (2) **Sleep**:Risk of Performance Decrements and Adverse Health Outcomes Resulting from Sleep Loss, Circadian Desynchronization, and Work Overload		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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Zip Code:	02115-5804	**Congressional District:**	8
Comments:			
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Contact Monitor:		**Contact Phone:**	
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Task Description:

Objective neurobehavioral performance, subjective alertness, and sleep are critically important to astronaut and ground-based crew health and to ensure the success of space missions. Neurobehavioral performance and alertness are affected by changes in circadian rhythms, homeostatic sleep/wake regulation and sleep inertia, and the interactions of these processes. During space missions, circadian rhythms and sleep are disrupted, both for those in space and for those on Earth. Problems with sleep, circadian rhythms and performance have been reported in astronauts, and NASA data indicate that sleeping pills are among the most commonly used drugs in space. Therefore, it is imperative that schedules and countermeasures are designed to optimize individual performance, alertness, and sleep quality relative to operational requirements. Our approach to designing countermeasures is to develop new scheduling techniques and software that use mathematical models to describe the underlying physiology of internal timing, performance and sleep.
We have developed and validated a mathematical model of the human circadian pacemaker that includes the key processes of circadian rhythms, sleep/wake homeostasis and sleep inertia, and is able to predict the effects of sleep/wake and circadian phase on performance and alertness. The software implementing this model has been used by NASA and consultants when designing light countermeasures for astronaut pre-launch schedules as well as for designing in-flight schedules. To further improve this mathematical model and this method for optimal design of countermeasures, our specific aims are to: (1) Replace the current assumption that an individual sleeps when scheduled to sleep, with probabilities of sleep and wake during those times; (2) Improve daily assessment of sleep and sleep disruption using actigraphy data; (3) Add statistical features including confidence limits to the predictions; (4) Update the software per astronaut and ground crew requests for specific features and reports. The basic mathematical work will focus on individual, rather than group, predictions and use novel non-linear mathematical and statistical measures. These projects address NASA's objectives to improve the design of individual countermeasures to reduce sleep disruption and improve performance and alertness in space and on Earth. Our current progress is as follows:

The major advance in the last year was the publication of a novel scheduling algorithm called Shifter in PLoS Computational Biology. The algorithm automatically designs optimal light countermeasures for user-defined NASA related schedules. These light interventions have been demonstrated to minimize fatigue, improve performance, and improve sleep in experimental and field studies. Developing Shifter required several mathematical and computational advances, including the development of a novel schedule representation and scheduling algorithm. Shifter for the first times allows individuals who are not circadian experts to design schedules and light interventions. Using Shifter, schedules are produced within a minute; previous design of light interventions, such as for the Mars Day protocol, took approximately two weeks with multiple iterations of CPSS and other software. The scheduling framework has also been designed to be applicable to work schedules including shift-work and transmeridian travel. To this end, we have begun applying our methods to the design of schedules for medical residents, so as to provide schedules that predict optimal performance while meeting new guidelines for restricted physician hours.

We are extending our current models and developing new methods to refine the scheduling algorithm for predicting individual differences in circadian phase and performance. To achieve this, we are individualizing predictions based on easily collected trait information (e.g., age, chronotype), and developing a statistical framework for building individual models. Experimental evidence demonstrates changes in physiology are well correlated with age and specialized questionnaire results (e.g., habitual sleep time is highly correlated with circadian phase). This is important because circadian phase correlates with intrinsic circadian period, which we have shown to be the most important input to generating accurate individualized predictions. Further work will involve identifying other demographics which can be used as proxies for physiological parameters.

The use of sleep aids during NASA missions is indicative of the difficulties astronauts face in sleeping during space flight. To assess the ability of individuals to conform to scheduled work hours, we are integrating the circadian and performance model with a model of the physiological mechanisms which control sleep-wake transitions. This combined model dynamically predicts wake/sleep state across a simulated protocol, allowing predictions of sleep efficiency, and likelihood of falling asleep during scheduled wake periods.

Integral to successfully using these methods in space is the ability to assess physiological state, and make individualized predictions. Since sleep is a core issue in space, we are targeting use of actigraphy, which is an inexpensive and less intrusive alternative to polysomnography. Our current work allows us to predict sleep state, circadian phase and performance directly from actigraphy.

Our plan is to use this information as input to our scheduling algorithm, resulting in individualized countermeasure predictions in real-time. The key benefit of these new methods is the ability to investigate different schedules, and to adaptively respond to changes that are unavoidable, such as launch rescheduling due to inclement weather. Our NSBRI-funded work is broadly applicable to diverse work environments, ranging from NASA missions to industries such as aviation, transportation, and the military.

Rationale for HRP Directed Research:

The development of (1) mathematical models of circadian rhythms, sleep, alertness and performance, and (2) software based on these models that aid in schedule design, can improve performance and alertness and thereby effectiveness and public safety for people who work at night, on rotating schedules, on non-24-hr schedules or extended duty schedules (e.g., pilots, train and truck drivers, shift workers, health care workers, public safety officers). Attempting to sleep at adverse circadian phases is difficult, resulting in poor sleep efficiency. Similarly, attempting to work at adverse circadian phases and/or after a long time awake, results in poor worker performance and productivity, and increased errors. For example, the accidents at the Chernobyl and Three Mile Island nuclear reactors and the Exxon Valdez grounding were all partially attributed to employees working at adverse circadian phases. The mathematical models and the available software implementing these models can be used to simulate and quantitatively evaluate different scenarios of sleep/wake schedules and light exposure to predict the resulting circadian phase and amplitude, subjective alertness and performance. Our software has been requested by members of academia, government and industry, including airline, safety, medical, and military applications. Its use could help produce improved work schedules for both astronauts and ground-crew.
The recent incorporation of actigraphy as input to the mathematical model as a tool to record sleep has improved the confidence levels on the daily assessment of sleep when compared to the use of sleep logs. The interface between actigraphy and the Circadian Performance Simulation Software enables faster and possibly more accurate predictions of circadian phase and performance parameters. The software now also includes optimal countermeasure design, so that countermeasures can be planned for times of predicted poor performance and alertness. The schedule/countermeasure

Research Impact/Earth Benefits:	design program allows users to interactively design schedules and implement mathematically optimal light countermeasures (including intensity, duration and placement) to minimize worker fatigue. This scheduling software will be valuable to those who work at night, on rotating schedules, on non-24-hr schedules or extended duty schedules. The software allows individuals to design countermeasures for their assigned work schedules so that their sleep and wake rhythms will be adjusted for optimal performance at desired times, both with respect to scheduled work events and circadian phase. Improving sleep duration and quality can also decrease the risk of accidents and errors, as well as decrease the long-term risks of cardiovascular, metabolic, immune and psychological pathologies. Mathematical modeling has been used for basic scientific research. Inclusion of mathematical models in the planning process to optimize measures to be studied in experimental protocols enables more efficient use of research resources and directs new research. If the modeling of existing experimental data is found to be unsatisfactory, then model assumptions may need to be revised. This revision may include identification of a new physiological process not previously described. As an example, an additional component (non-linear response to ocular light stimuli) was added to our mathematical model to describe data collected in our clinical research facilities, even before the anatomic and physiologic basis of this component was found. Later experiments validated this mathematical prediction. The proposed mathematical model, based on behavioral experimental findings, had uncovered previously unknown additional physiological processes at the cellular level. The mathematical modeling efforts and software have also been used in educational programs and in the popular press to teach students and teachers about circadian rhythms and sleep and their effects on alertness and performance.
Task Progress:	Specific Aim 1 (predicting sleep-wake within scheduled sleep): We are integrating the existing circadian/performance model with a physiological model of sleep/wake transitions. This integrated model will predict whether individuals will be able to conform to enforced work schedules, including estimated likelihood of insomnia during scheduled sleep periods or difficulty remaining awake during working hours. In the current year of this project, we have been validating this integrated model against human data from a variety of sleep/wake schedule protocols. Specific Aim 2 (actigraphy): We have integrated the output from actigraphy data with the input required to run our Circadian Performance Simulation Software (CPSS), which utilizes our mathematical model of the human circadian pacemaker, performance and alertness, that includes the key processes of circadian rhythms, sleep/wake homeostasis and sleep inertia as well as the effects of light on circadian rhythms. Pre-processing tools have been developed to generate the sleep/wake schedule and light levels from raw or processed actigraphy data. The sleep/wake and lighting schedule thus generated may be used as input to CPSS. Specific Aim 3 (Statistical modeling of individual circadian, sleep, performance and alertness parameters): We have concentrated on statistical modeling of individual circadian parameters of our circadian, performance and alertness models. By fitting the model to individual, rather than grouped data, we obtain a set of parameters for the performance and alertness models unique to each individual. We can then use other data collected from the individual, such as age, gender, habitual sleep time, morningness/eveningness preference, etc. to determine correlations between model parameters and individual characteristics. Specific Aim 4 (Work with NASA and NSBRI personnel to revise features of our current software to meet their specifications for administratively scheduling sleep, wake and countermeasure design to minimize fatigue and performance issues.): We have had discussions with NASA and NSBRI personnel to revise features of our current software to meet their specifications for administratively scheduling sleep, wake and countermeasure design to minimize fatigue and performance issues, as well as incorporating the models into other modeling work performed by NASA. As one example, we developed Shifter, a novel scheduling algorithm that automatically designs optimal light countermeasures for user defined schedules. Appropriate light interventions have been demonstrated to minimize fatigue, improve performance, and improve sleep in experimental and field studies. Developing Shifter required several mathematical and computational advances, including the development of a novel schedule representation and scheduling algorithm. The scheduling framework has also been designed to be applicable to work schedules including shift-work and transmeridian travel.
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