Fiscal Year:	FY 2019	**Task Last Updated:**	FY 09/28/2018
PI Name:	Brainard, George C. Ph.D.		
Project Title:	Testing Solid State Lighting Countermeasures to Improve Circadian Adaptation, Sleep, and Performance During High Fidelity Analog and Flight Studies for the International Space Station		
Division Name:	Human Research		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	HUMAN RESEARCH--Behavior and performance		
Joint Agency Name:		**TechPort:**	Yes
Human Research Program Elements:	(1) **HFBP**:Human Factors & Behavioral Performance (IRP Rev H)		
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:	19107-5083	**Congressional District:**	1
Comments:			
Project Type:	FLIGHT	**Solicitation / Funding Source:**	2013-14 HERO NNJ13ZSA002N-BMED Behavioral Health & Performance
Start Date:	12/01/2014	**End Date:**	11/30/2019
No. of Post Docs:	0	**No. of PhD Degrees:**	
No. of PhD Candidates:	3	**No. of Master' Degrees:**	
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	
No. of Bachelor's Candidates:	0	**Monitoring Center:**	NASA JSC
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Flight Program:	ISS		
Flight Assignment:	Flight Definition NOTE: End date changed to 11/30/2019 per NSSC information (Ed., 10/11/18) NOTE: End date changed to 11/30/2018 per NSSC information (Ed., 12/13/17) NOTE: Element change to Human Factors & Behavioral Performance; previously Behavioral Health & Performance (Ed., 1/17/17)		
Key Personnel Changes/Previous PI:	October 2015: No changes.		

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Grant/Contract No.:	NNX15AC14G
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Task Description:	This research addresses the NASA Research Announcement (NRA) NNJ13ZSA002N-BMED: Behavioral Health and Human Performance: "Evaluation of the Neurobehavioral Effects of a Dynamic Lighting System on the ISS." This NRA solicited both "Ground Based and Flight-Definition" research with the specific instructions that the "ground study serves as a precursor to the flight study, therefore the ground study should take place in an analog with high fidelity to the ISS. The SSLAs should be studied in a high fidelity ground analog environment, then implemented on ISS to evaluate individual crewmember outcomes related to circadian physiology, sleep, behavioral health and performance using sensitive and validated measures that are feasible in the spaceflight environment." Currently, the International Space Station (ISS) uses General Luminaire Assemblies (GLAs) that house fluorescent lamps for illuminating the astronauts' working and living environments. NASA has determined that, beginning in 2016, the GLAs would be replaced with Solid-State Light Assemblies (SSLAs) containing Light Emitting Diodes (LEDs). Engineers at Kennedy Space Center developed a prototype Solid-State Lighting Assembly (SSLA) that was successfully installed onboard the ISS during ISS Expedition 18. The Principal Investigator and Co-Principal Investigator of the intended research worked with engineers, scientists, and managers from Johnson Space Center (JSC) to revise the SSLA specifications so that the new lighting units would have dual capacity to: 1) provide illumination for crew members' working and living quarters, and 2) serve as a lighting countermeasure for crewmembers' circadian and sleep disruption. NASA ordered and received for a set of SSLAs intended to have this dual capacity. This research is comprised of a multidisciplinary collaboration between Thomas Jefferson University, Brigham and Women's Hospital, and JSC to complete a ground-based study in a high fidelity analog of the crew sleeping quarters and daily living environment of the ISS. Specifically, standardized psychometric, physiological, and neurobehavioral measures are testing the efficacy of light from the SSLAs to improve vision, circadian regulation, sleep, and performance in healthy astronaut-aged subjects. In addition, the initial SSLA was installed on ISS in 2016. Since then, a total of 51 SSLAs have been installed on ISS, bringing the total retrofit to 60% replacement of GLAs on the US portion of ISS. Since the onset of the SSLA retrofit, the investigators have started the inflight ISS study to assess the acceptability, use, and impact of deployment of a dynamic lighting schedule aboard the ISS during operational flight missions on astronaut vision, sleep, alertness, circadian rhythms, and general well-being. Sleep, performance, and circadian rhythm data will be compared to those collected by their team and others during previous flight missions aboard ISS, in addition to surveillance of medical and psychological health in collaboration with mission flight surgeons. This project will generate quantitative data and knowledge for the benefit of crew health, habitability, environment, and human factors in the design of future human spaceflight vehicles and habitats. The project also will provide guidance for flight surgeons, flight psychologists, and astronauts to help optimize sleep and circadian regulation during space exploration missions. This research addresses NASA's Program Requirements Document (PRD) Risk: "Risk of Performance Errors due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness and Work Overload" and Integrated Research Plan (IRP) Gap Sleep5: "We need to identify environmental specifications and operational regimens for using light to prevent and mitigate health and performance decrements due to sleep, circadian, and neurobehavioral disruption, for flight, surface, and ground crews, during all phases of spaceflight operations." The results of this research also specifically address other high priority risks of the Human Factors and Behavioral Performance Element, including the Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders, and the Risk of an Incompatible Habitat Design. Appropriately designed lighting systems will serve as a countermeasure to mitigate such risks in future Exploration missions. Importantly, this work will lead to advances in new lighting systems for civilian applications in work places and homes.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	The sleep deficits experienced by astronauts during spaceflight along with risk of incompatible habitat design can be considered threats to the success of space missions (NASA Human Research Program Integrated Risk Plan, 2018). The resulting physiological and behavioral changes caused by sleep and circadian disruption can lead to diminished alertness, cognitive ability and psychomotor performance (Dijk et al., Amer. J. Physiol., 2001; Human Health and Performance Risks of Space Exploration Missions. McPhee and Charles, eds., 2010). As a measure to counteract sleep disruptions, crewmembers report using sleep promoting drugs: 71% on space shuttle flights and 75% during ISS expeditions (Barger et al., Lancet Neurology, 2014; Flynn-Evans et al., 2016). A significant portion of the global population suffers from chronic sleep loss and/or circadian-related disorders. Evidence for disease occurring due to a disruption of circadian homeostasis has mounted significantly in the past several years. In the United States, nearly 22 million Americans do shift work that interferes with a biologically healthy nocturnal sleep cycle (US Bureau of Labor Statistics, 2007). It has been shown that shift workers are more likely to suffer from a wide variety of ailments, including cardiovascular disease, metabolic disorders, gastrointestinal distress, and cognitive and emotional problems. Development of an in-flight lighting countermeasure that helps resolve circadian and sleep disruption in astronauts is likely to help optimize the use of light therapy for patient populations with affective, circadian and sleep disorders. References Dijk DJ, Neri DF, Wyatt JK, Ronda JM, Riel E, A. R-D, Hughes RJ, Elliott AR, Prisk GK, West JB and Czeisler CA (2001) Sleep, performance, circadian rhythms, and light-dark cycles during two space shuttle flights. Am J Physiol

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Task Progress:

Grant Establishment: Three institutions are collaborating on this multidisciplinary research: Thomas Jefferson University (TJU) in Philadelphia, Brigham and Women's Hospital (BWH) in Boston, and Johnson Space Center (JSC) in Houston. The start date for the grant was December 1, 2014. Subcontracts were then established between TJU, BWH, and Lockheed Martin. The aim is to complete a ground-based study in a high fidelity analog of the crew sleeping quarters (CQ), and an in-flight study in the daily living environment of the ISS.
Ground Based Analog Study: This study aims to test the efficacy of lighting protocols for daily operations using Solid State Lighting Assemblies (SSLAs) in ISS CQs installed in laboratories at TJU. In a controlled 5-day inpatient study using astronaut-aged volunteers, we are testing the hypotheses that compared to the static, daily lighting of General Illumination only, the Dynamic Lighting Schedule protocol for a typical ISS work day (18 h wake: 6 h sleep) will improve visual performance, circadian entrainment, onset of melatonin production, sleep onset, sleep duration as well as morning alertness and performance. Separate human use protocols were submitted and approved by the Institutional Review Boards (IRBs) at TJU and NASA. Previously, NASA and National Space Biomedical Research Institute (NSBRI) funded the Principal Investigator (PI) and Co-PI to develop a high fidelity, in-laboratory analog environment to study the visual, biological, and behavioral effects of the SSLAs. Specifically, a high-fidelity replica of the ISS Crew Sleeping Quarters (CQ) was developed with precise replication of CQ volume, geometry, and surface reflectance with an SSLA providing illumination. Astronaut-aged study subjects were able to be upright in this CQ and work, read, or use a computer just as crewmembers do onboard the ISS. In addition, a second CQ was developed that allows subjects to be semi-recumbent during wakefulness in SSLA lighting or fully recumbent when sleeping in darkness. Data from controlled studies in these high fidelity in-laboratory analog conditions represent the only published ground-based human data on the efficacy of the SSLAs to date (Brainard et al., Acta Astronaut., 2013; Brainard et al., Curr. Opin. Pulm. Med., 2016). In that earlier work, however, only a single subject could be studied at a time in the facility. In the current work, a second high-fidelity recumbent CQ was built and installed in the test facility enabling us to study up to two subjects at a time, to improve our speed for acquiring data in the analog facility. The SSLAs were each adjusted for their spectral output to be as close as possible to the NASA's vendor requirements for ISS (NASA Revision C, S684-13489, 2013). These specifications include Correlated Color Temperature (CCT or K) and luminance in candelas (cd) for three basic settings: 1) General Illumination: 4500 K SSLA white light, 210 cd; 2) Phase Shift/Alertness: 6500 K SSLA (blue-enriched) white light, 420 cd; 3) Pre-Sleep: 2700 K SSLA (blue-depleted) white light, 90 cd.

Based on published and unpublished data, the Co-PIs have determined that the 90 cd luminance at crewmember's eye level inside of a CQ would be too bright to serve as an effective Pre-Sleep countermeasure. This issue was discussed with our project management team at JSC on several occasions. It was determined that in spaceflight, the SSLA luminance could be lowered from 90 cd using a combination of SSLA dimming buttons and a cloth shade system that is currently used on the fluorescent lighting system in the CQs onboard ISS. Based on a series of SSLA lighting measures and our prior pilot study in the CQs, we chose a Pre-Sleep luminance of 7.7 cd (20 lux at eye level) for our Pre-Sleep setting.

This study includes male and female volunteers in good physical and mental health with normal color vision. Volunteers are selected in the age range of astronauts (range 26-54 years). Prior to admission to the laboratory, subjects are asked to maintain a regular 8:16 h, sleep:wake schedule and wear a wrist-borne, non-invasive activity and light monitor for at least 10 to 14 days. In August 2015, study recruitment was initiated. Over 550 subjects expressed interest in participating in this study. Approximately half of those individuals were not eligible based on phone interviews. Among those who were potentially eligible, 70 signed consent paperwork. Twenty-eight of those subjects completed the screening process and were randomly assigned into a lighting condition of either dynamic (N=16) or static (N=12) lighting. Among those subjects, 19 were male and 9 were female (age range 26 - 53 years). Twenty-five of these subjects successfully completed the entire five day study.

The data gathered from this first study run include successful collection of complete pre-study actigraphy, and inpatient study actigraphy from each subject. A total of 268 neurocognitive and performance tests were collected from each subject across the five day inpatient study (over 6,700 total). In addition, 95 Karolinska sleepiness scales (KSS) were collected from each subject across the inpatient study (2,375 total). Complete sets of blood, saliva, and urine samples were collected from each subject for the measurement of melatonin and 6-sulfatoxymelatonin. Melatonin contents of 548 plasma samples from 25 participants who completed a full study run have been analyzed. Polysomnography (PSG) was used to monitor sleep states and wakefulness using electrodes placed on the scalp, face, chin, and chest. Electrodes were positioned according to the International 10-20 System. The actigraphy, neurocognitive, and performance tests and urinary 6 sulfatoxymeltonin measures match similar or identical tests that will be used onboard ISS during the flight study. Subject recruitment and enrolling has been stopped at this time. Data analysis is in process on the numerous dependent variables from the 5-day study. Portions of data from this study have been uploaded to the NASA Large File Transfer service.

The testing of visual performance and color vision under different SSLA light settings has been done separately from the five day studies. Two separate cohorts of 8 healthy male and female, astronaut-aged subjects have completed within-subjects study designs that test their visual performance and color vision. The data from each of these studies is being analyzed.

ISS Flight Study: Compared to the analog study, the flight study is at an earlier stage. The aims of this study are to test the efficacy of lighting protocols for daily operations using SSLAs for inflight crewmembers onboard ISS missions. Specifically, we will assess the acceptability, use and operational impact of deployment of the Dynamic Lighting Schedule protocol on astronaut vision, sleep, alertness, circadian rhythms, and general well-being during ISS flight missions. This inflight study will test the hypotheses that, compared to current static daily fluorescent lighting of

General Illumination only, the Dynamic Lighting Schedule protocol will maintain acceptable visual performance and color discrimination for operational tasks, improve circadian entrainment, improve circadian adaptation following a sleep shift challenge such as a 'slam-shift', improve sleep duration and efficiency, and enhance wake-time alertness and cognitive performance.

Ethical approvals have been obtained from NASA and Partners Healthcare for the flight study. The flight study successfully went through an ISS Medical Project (ISSMP) feasibility assessment on 8/8/15. Subsequently, the Human Research Program (HRP) Science Management Panel selected this study for flight on 9/3/15. The first ISSMP teleconference was held on 9/30/15 involving representatives from JSC's ISSMP, BWH, and TJU. Currently, this teleconference is held monthly. To date, seven crew members have consented to participate in the flight study. The first three astronauts have completed pre-flight, in-flight, and post-flight testing. The other four consented crewmembers are in process in various phases of pre-flight, in-flight, and post-flight testing. Fifty-one SSLAs have been successfully installed in the ISS.

This ISS flight study on crewmembers is a sophisticated human photobiological study. All photobiological studies, whether in spaceflight or on Earth, rely on precise characterization of the independent variable of the study: light. For this study, the relevant light stimulus is light emitted by the new SSLAs and the current ISS fluorescent lighting system. A spectrophotometer/irradiance meter is an essential tool for ensuring that consistent emission of light spectrum and light intensity are maintained during the inflight ISS research. The key measures for this flight study are light irradiance, illuminance, and spectral power distribution of the four settings of the SSLAs, as well as the single setting of the current fluorescent lights. Working with the study collaborators, ISSMP has selected and purchased the meter that is being used for the flight study. To date, 23 sets of lighting measures have been taken by crewmembers and transmitted from ISS to the study team on Earth.

Considerable work between the study collaborators and the hardware group of ISSMP has gone into making flight worthy versions of visual performance and color vision tests. These tests are now complete and are being used on the ISS. The Lanthony Desaturated 15-Hue test is the method to be used for testing crewmember color discrimination under the different SSLA light settings compared to that of the current fluorescent lighting on ISS. Additional planning for the flight study is ongoing with regular meetings with NASA personnel. Historical data of actigraphy, sleep logs, cognitive testing, and urine samples have been identified from previous flight studies that will act as the control data in the flight study. Discussions are ongoing about data sharing for these historical data.

References

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Bibliography Type:	Description: (Last Updated: 10/30/2023)
Abstracts for Journals and Proceedings	Brainard G, Hanifin J, Warfield B, Jasser S, Kemp J, Disoke F, Ayers F, Glodjo T, Panepinto L, Vadalia S, Kanumilli S, Nelson N, Hasher D, Balaicuis J, Byrne B, Pineda C, Gerner E, Clark T, Maida J, Johnston S, Moomaw R, Barger L, Czeisler C, St. Hilaire M, Rahman S, Lockley S. "Testing solid state lighting countermeasures to improve circadian adaptation, sleep and performance during high fidelity analog and flight studies for the International Space Station." Presented at the 2018 NASA Human Research Program Investigators’ Workshop, Galveston, TX, January 22-25, 2018. 2018 NASA Human Research Program Investigators’ Workshop, Galveston, TX, January 22-25, 2018. , Jan-2018
Abstracts for Journals and Proceedings	Glodjo TZ, Disoke F, Kemp J, Warfield B, Hanifin J, Lockley S, Brainard G. "Testing solid state lighting countermeasures to improve circadian adaptation, sleep and performance during high fidelity analog studies for the International Space Station: Vision Testing." Presented at the Thomas Jefferson University Sigma Xi Student Research Day, Philadelphia, Pennsylvania, April 10, 2018. Thomas Jefferson University Sigma Xi Student Research Day, Philadelphia, Pennsylvania, April 10, 2018. , Apr-2018
Abstracts for Journals and Proceedings	Lockley S, Rahman S, St Hilaire M, Clark T, Hanifin J, Barger L, Czeisler C, Brainard G. "Lighting protocols for exploration – HERA campaign." Presented at the 2018 NASA Human Research Program Investigators’ Workshop, Galveston, TX, January 22-25, 2018. 2018 NASA Human Research Program Investigators’ Workshop, Galveston, TX, January 22-25, 2018. , Jan-2018
Articles in Peer-reviewed Journals	Pattison PM, Tsao JY, Brainard GC, Bugbee B. "LEDs for photons, physiology and food." Nature. 2018 Nov;563(7732):493-500. https://doi.org/10.1038/s41586-018-0706-x ; PubMed PMID: 30464269 [Note: reported originally in Sept 2018 as "in press"] , Nov-2018
Articles in Peer-reviewed Journals	Weaver MD, Barger LK, Malone SK, Anderson LS, Klerman EB. "Dose-dependent associations between sleep duration and unsafe behaviors among US high school students." JAMA Pediatr. 2018 Dec 1;172(12):1187-9. PubMed PMID: 30285029; PubMed Central PMCID: PMC6366445 , Dec-2018
Awards	Brainard GC. (George C. Brainard) "Exemplary Service and Support Award. Illuminating Engineering Society, Standards and Research Department, Boston, MA, August 2018." Aug-2018