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CONTRACTING ORGANIZATION: Washington State University, Pullman, WA

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14. ABSTRACT

Sleep loss and acute stress often occur simultaneously during military operations, but their combined effect on cognition – and therefore how to protect against any adverse effects – remains under-investigated. In this research project, we seek to develop a framework in which resilience to sleep loss and stress can be investigated separately and jointly. In a laboratory-based study, healthy young adults are assigned to one of four conditions: sleep deprivation only, stress only, combined sleep deprivation and stress, or control (no sleep deprivation or stress). Subjects' vigilant attention, working memory, cognitive flexibility, and dynamic risk awareness are tested twice: once immediately following a sham stress task during well-rested baseline, and again 24 h later, immediately following either a stress or sham stress task when subjects are either in a 39 h sleep deprivation or rested control condition. During this report period, we conducted eight study runs and completed data collection on 12 study participants. This work will allow us to develop a framework for the systematic investigation of the effect of sleep loss and stress on military operations, which will enable the development of targeted interventions that increase resilience against operational performance impairment. Further, this research project will help to improve the safety and

15. SUBJECT TERMS
sleep deprivation, stress, performance impairment, attentional control, cognitive flexibility, mission success, resilience

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1. INTRODUCTION

Sleep loss and acute stress are common during military operations, resulting in impaired situational awareness and decision making. Performance deficits due to sleep loss are increasingly understood to be the result of changes in the ability to adjust attentional control in fast-paced, dynamically changing circumstances. In contrast, less is known about the effect of stress on cognition or its combined effect with sleep loss. Despite the fact sleep loss and stress often co-occur during military operations, their combined effect on cognition – and therefore how to protect against any adverse effects – remain under-investigated. In this research project, we seek to develop a framework in which resilience to sleep loss and stress can be investigated separately and jointly. In a laboratory-based study, healthy young adults are assigned to one of four conditions: a sleep deprivation only condition, a stress only condition, a combined sleep deprivation and stress condition, or a control (no sleep deprivation or stress) condition. To investigate the separate and joint effects of sleep loss and stress on performance, subjects are tested on tasks specifically developed for this study that assess their vigilant attention, working memory, cognitive flexibility, and dynamic risk awareness. These tasks are administered twice: once following a sham stress task (i.e., a non-stressful variation on the stress task) while all subjects are at their well-rested baseline, and again 24 h later, following either the stress task or the sham stress task while half the subjects are assigned to a 39 h sleep deprivation condition and the other half are assigned to a well-rested control condition. By providing a framework for systematic investigation of the effect of sleep loss and stress on military operations, this research project will enable the development of targeted interventions that increase resilience against operational performance impairment. Further, this research project will help to improve the safety and success of millions of Americans, including US military personnel, who are frequently exposed to sleep loss and stress.

2. KEYWORDS

Sleep deprivation, stress, performance impairment, attentional control, cognitive flexibility, mission success, resilience

3. ACCOMPLISHMENTS

What were the major goals of the project?

Specific Aim 1: Test the prediction of the DAC framework that SD without stress induction spares WM capacity, but compromises (a) the establishment of choice outcome associations and (b) the binding and interference management processes needed for CF	**Timeline**	**Site 1**
Study Preparations	Months	
Development of standard operating procedures for participant screening and enrollment, a detailed study protocol, and standard operating procedures for cognitive task and stress test administrations	1-10 completed	Dr. Van Dongen Dr. Whitney Dr. Hinson Dr. Honn
WSU IRB review	1-6 completed	Dr. Van Dongen Dr. Honn
USAMRMC HRPO review	1-10 completed	Dr. Van Dongen Dr. Honn
Milestone(s) Achieved: Procedures documented and IRB/HRPO approvals obtained	10 completed	
Data Collection		
Subject consent and enrollment (total # human subjects: 32)	11-42 in progress	Dr. Van Dongen Dr. Honn Dr. Kurinec
Data collection: subjects complete a 4-day, 3-night in-laboratory study. Aim 1 includes 32 (of the total 64) subjects who are randomly assigned to the sleep deprivation condition (16) or the no sleep deprivation or stress condition (16). In the sleep deprivation condition, subjects have a baseline night, a 38h sleep deprivation period, and a recovery night. Subjects in the no sleep deprivation or stress condition have sleep opportunities on all 3 nights.	11-42 in progress	Dr. Van Dongen Dr. Honn Dr. Kurinec
Administration of a cognitive battery to assess elements of the DAC framework at baseline and after sleep deprivation or control (during laboratory experiment)	11-42 in progress	Dr. Van Dongen Dr. Whitney Dr. Hinson Dr. Honn Dr. Kurinec
Milestone(s) Achieved: Aim 1 data collection completed from 32 subjects (16 in a sleep deprivation condition and 16 in a no sleep deprivation and no stress condition)	42	
Data Analysis		
Process and analyze cognitive battery data with pairwise comparisons between the sleep deprivation condition and the no sleep deprivation or stress condition	12-45	Dr. Van Dongen Dr. Honn Dr. Kurinec
Milestone(s) Achieved: Aim 1 analyses completed	45	
Specific Aim 2: Test how the attentional control processes specified in the DAC framework are affected by stress induction without SD		
Data Collection		

Subject consent and enrollment (total # human subjects: 32, with 16 being the same participants as in aim 1 no sleep deprivation or stress condition)	11-42 in progress	Dr. Van Dongen Dr. Honn Dr. Kurinec
Data collection: subjects complete a 4-day, 3-night in-laboratory study. Aim 2 includes 32 (of the total 64) subjects who are randomly assigned to the stress only condition (16) or the no sleep deprivation or stress condition (16). In the stress only condition, subjects will complete the MAST at 13:00 on study day 3, immediately before taking the DAC cognitive battery. Subjects in the no sleep deprivation or stress condition take the sham version of the MAST immediately before taking the DAC cognitive battery.	11-42 in progress	Dr. Van Dongen Dr. Honn Dr. Kurinec
Administration of a cognitive battery to assess elements of the DAC framework at baseline and after stress induction (MAST) or no stress induction (sham MAST) (during laboratory experiment)	11-42 in progress	Dr. Van Dongen Dr. Whitney Dr. Hinson Dr. Honn Dr. Kurinec
Milestone(s) Achieved: Aim 2 data collection completed from 32 subjects (16 in a stress condition and 16 in a no sleep deprivation and no stress condition)	42	
Data Analysis		
Process and analyze cognitive battery data with pairwise comparisons between the stress only condition and the no sleep deprivation or stress condition	12-45	Dr. Van Dongen Dr. Whitney Dr. Hinson Dr. Honn Dr. Kurinec
Milestone(s) Achieved: Aim 2 analyses completed	45	
Specific Aim 3: Determine how the joint effects of acute stress and SD impact attentional control, CF, and risky decision making		
Data Collection		
Subject consent and enrollment (total # human subjects: 48, with 16 being the same participants as in aim 1 sleep deprivation condition, 16 being the same participants as in aim 2 stress only condition, and 16 additional participants in a combined sleep deprivation and stress condition)	11-42 in progress	Dr. Van Dongen Dr. Honn Dr. Kurinec
Data collection: subjects complete a 4-day, 3-night in-laboratory study. Aim 3 includes 48 (of the total 64) subjects who are randomly assigned to the sleep deprivation only condition (16), the stress only condition (16), or the combined sleep deprivation and stress condition (16). In the combined condition, subjects will have no sleep opportunity during the second night in the lab (for a 38-hour sleep deprivation period) and will complete the MAST at 13:00 on study day 3, immediately before taking the DAC cognitive battery, when they have been awake for approximately 29 hours.	11-42 in progress	Dr. Van Dongen Dr. Honn Dr. Kurinec
Administration of a cognitive battery to assess elements of the DAC framework at baseline and after stress induction (MAST) or no stress induction (sham MAST) in sleep-deprived and well-rested subjects (during laboratory experiment)	11-42 in progress	Dr. Van Dongen Dr. Whitney Dr. Hinson Dr. Honn Dr. Kurinec
Milestone(s) Achieved: Aim 3 data collection completed from 48 subjects (16 in a sleep deprivation condition; 16 in a stress	42	

condition; and 16 in a combined sleep deprivation and stress condition)		
Data Analysis		
Process and analyze cognitive battery data with a test of interaction represented by a dual pairwise comparison of the sleep deprivation only and stress only conditions to the combined sleep deprivation and stress condition	12-45	Dr. Van Dongen Dr. Whitney Dr. Hinson Dr. Honn Dr. Kurinec
Milestone(s) Achieved: Aim 3 analyses completed	45	
Final Report Preparation		
Compilation of analyses from aims 1–3 and drafting of report and briefing	46-48	Dr. Van Dongen Dr. Whitney Dr. Hinson Dr. Honn Dr. Kurinec
Presentation of study results to the DoD	48	Dr. Van Dongen
Milestone(s) Achieved: study completed	**48**	

What was accomplished under these goals?

During Year 3, the major activities to be completed to achieve the goal milestones were:

- Continued ethical review of the study procedures by the Washington State University IRB and the DoD's HRPO – completed.
- A minor IRB amendment was submitted and approved to make adjustments to study procedures and COVID-19 precautions (Aims 1-3) – completed.
- Screened over 180 potential participants; 64 passed the telephone screening, 30 completed in-person screening, and 20 have been scheduled for study runs (Aims 1-3) – completed.
- Conducted 8 study runs for a total of 14 participants (Aims 1-3) – completed.
- Applied for and received a 12-month no-cost extension.

Summary of the laboratory study protocol:

Carefully screened, healthy young adults are randomized to one of four conditions (target N = 16 in each condition): a sleep deprivation only condition; a stress only condition; a combined sleep deprivation and stress condition; or a control (no sleep

deprivation and no stress) condition (see Table 1). Subjects are in the laboratory for four days/three nights continuously, under constant observation and physiological monitoring. In either of the two sleep deprivation conditions (sleep deprivation only or combined sleep deprivation and stress), subjects have one night with 9 h time in bed for baseline sleep, then undergo 39 h of total sleep deprivation (equivalent to missing one night of sleep), and finally are given one recovery night with 9 h time in bed for sleep. Those in the stress only or control conditions have 9 h in bed for sleep on all three nights. Subjects' sleep is recorded polysomnographically and actigraphically during all scheduled sleep periods.

Subjects are tested on a range of cognitive performance tasks at baseline, and 24 h later after sleep deprivation (or well-rested control). Of central importance to the goals of the study is the completion of a cognitive task battery following the administration of sham or acute stress that assesses vigilant attention, working memory, cognitive flexibility, and dynamic risk awareness. At baseline, all subjects complete the battery of tasks following a sham version of a stress test. Following the night of either sleep deprivation or rest, those in the two stress conditions (stress only or combined sleep deprivation and stress) complete the battery of tasks following a stress test. Those in the other two conditions again complete the battery following the sham version of the stress test. During the sham or real version of the stress test and subsequent task battery, subjects' heart activity is recorded using a Holter monitor with leads attached to the chest; skin conductance responses (SCR) are also recorded using disposable self-adhesive electrodes attached to the non-dominant hand on the intermediate phalange of the index and middle fingers. Saliva samples are collected approximately every 15 minutes from the beginning of the stress or sham stress test to the end of the task battery and approximately every 2-3 h throughout the study. Additionally, venous whole blood is collected from each subject after the completion of the battery. The cognitive tests and physiological measures obtained during the study will serve to test the prediction of the Dynamic Attention Control (DAC) framework that sleep deprivation without stress induction spares working memory capacity, but compromises (a) the establishment of choice outcome associations and (b) the binding and interference management processes needed for cognitive flexibility; test how the attentional control

processes specified in the DAC framework are affected by stress induction without sleep deprivation; and determine how the joint effects of acute stress and sleep deprivation impact attentional control, cognitive flexibility, and risky decision making.

Table 1. Matrix of study conditions.

		Sleep Deprivation?	
		Yes	No
Stress?	Yes	**N=16** Sleep Dep + Stress	**N=16** Stress Only
	No	**N=16** Sleep Dep Only	**N=16** Neither (control)

Stated goals not met:

Due to delays and laboratory closures caused by the COVID-19 pandemic in year 1, we began year 2 considerably behind schedule, and these study delays have persisted into year 3. Further, human subject recruitment following re-opening has been slower than anticipated, due to the pandemic's ripple effects on society and ensuing shortages in the labor market, which has ongoing impact on recruitment for in-residence studies across the country. This has limited the number of participants who could be screened for eligibility in the study. Additionally, by necessity, availability of the laboratory has been shared with another DoD-funded in-laboratory study, which has also been delayed by the pandemic. Together, these pandemic-related constraints have left us behind schedule for studying subjects in the laboratory (Aims 1–3). As expected, we have requested and received a 1-year no-cost extension to complete the project.

What opportunities for training and professional development has the project provided?

The project provides significant opportunities for graduate education and professional development:

- A Ph.D. student in the Experimental Psychology graduate program at Washington State University, Amanda Hudson, has been involved in this project to develop and program novel cognitive tasks to assess performance changes during sleep deprivation and/or stress. She is currently receiving training in recording of sleep (polysomnography); recording and processing of galvanic skin conductance; developing and programming of cognitive performance tasks in E-Prime software; and data reduction and statistical analysis. The graduate student is involved in the project under the direct mentorship of one of the Co-PIs of the project, Dr. Kimberly Honn, and training and experience has been gained on a daily basis. During Year 3, the graduate student worked with the investigators to fine-tune the study procedures, train research assistants on study procedures, and ensure data quality.

- A Master's student in the Experimental Psychology graduate program at Washington State University, Emily Moslener, was involved in this project to develop and program novel cognitive tasks to assess performance changes during sleep deprivation and/or stress. She received training in recording and processing of galvanic skin conductance; developing and programming of cognitive performance tasks in E-Prime software; and data reduction and statistical analysis. The graduate student was involved in the project under the direct mentorship of one of the Co-PIs of the project, Dr. Kimberly Honn. During Year 3, the graduate student worked with the investigators to fine-tune the study procedures and tasks for the study and had her research related to this project presented at a military health conference (conference abstract currently unpublished).

- A Ph.D. student in the Experimental Psychology graduate program at Washington State University, Kirsie Lundholm, has been involved in this project to help develop the study procedures involved in the stress task and the associated saliva samples

and processing. She is receiving training in saliva sampling and processing; blood sampling and processing; developing and programming of cognitive performance tasks in E-Prime software; stress test implementation; protocol development; data reduction; and statistical analysis. Training and experience has been gained on a daily basis. During Year 3, the graduate student worked with the investigators to fine-tune the study and saliva procedures for the study, train research assistants on saliva collection and other task procedures, and presented her research related to this study at a national sleep conference.

How were the results disseminated to communities of interest?

The results were shared with relevant military and civilian communities through presentations at the 2023 SLEEP conference as well as the 2023 Military Health System Research Symposium (MHSRS).

What do you plan to do during the next reporting period to accomplish the goals?

Now that the study is actively collecting data and a 1-year no-cost extension has been obtained, year 4 will be fully focused on subject recruitment, screening, and data collection in the laboratory experiment. Our goal is to have completed data collection by the end of Year 4. However, the consequences of pandemic-related delays and its impact on subject recruitment may eventually necessitate another 1-year no-cost extension, and we are carefully monitoring our expenditures to make sure sufficient resources will be available to finish the project in that instance. That being said, we are increasing our study advertising efforts and continue working to accelerate the pace of subject recruitment. Since the beginning of Year 3, we have made great strides in improving recruitment and screening and hope to continue this trend into Year 4.

Some of the data collected during Year 4 of the study will be available for preliminary analyses, which will be used in training opportunities for graduate students and post-baccalaureate trainees and presented at national conferences for dissemination.

4. IMPACT

What was the impact on the development of the principal discipline(s) of the project?

As data collection began, we performed analyses of archival data related to the project to keep the relevant science moving forward. In a paper published in the journal *Sleep Advances*, we showed that contrary to expectations, increasing the density of stimuli on the Psychomotor Vigilance Test (PVT) by shortening the inter-trial interval did not result in increased impairment during sleep deprivation. This new information provides important insight into the underlying processes involved in the PVT that make it the gold standard for detecting changes in alertness due to sleep loss.

In a paper published in the journal *Frontiers in Neuroscience*, we laid out a framework to guide research on sleep loss and memory. We outline the limitations of the current approach of focusing on the detrimental effects of sleep loss on encoding and propose using the lessons learned from the amnesia literature to guide predictions of preserved and impaired aspects of memory during sleep loss. This paper is relevant to research efforts to understand the effects of sleep loss on memory and can be used to guide work relevant to populations that are expected to learn and remember information under conditions of sleep loss, to include military personnel.

In a conference abstract presented at the SLEEP 2023 conference, we found that sleep deprivation differentially affects how two physiological systems respond to repeated stressors. This work has relevance to military operations, as it is likely individuals will experience repeated stressors and sleep loss in high OPTEMPO settings. This work underscores the importance of capturing measures of both physiological systems when investigating the relationship between sleep loss and stress.

Our other conferences abstracts presented at SLEEP 2023 investigated aspects relevant to individual objective and subjective resilience to sleep loss. First, we found that there are no significant differences in slow wave sleep before or after sleep

deprivation regardless of whether sleep prior to sleep deprivation was extended or restricted. While the amount of slow wave sleep is relatively conserved even following a week of sleep restriction, this conservation did not provide resilience to a night of sleep deprivation in terms of cognitive performance or subjective sleepiness. This work suggests that slow wave sleep is unlikely to mediate resilience to sleep loss.

Second, we found that individuals with self-reported higher trait emotion reactivity, or sensitivity to emotion-evoking stimuli or events, report greater negative mood during sleep deprivation than those with lower self-reported trait emotion reactivity. However, level of trait emotion reactivity did not predict positive mood during sleep deprivation. These findings suggest that individual differences in how people experience events may predict their subjective experience during sleep loss.

What was the impact on other disciplines?

Nothing to Report.

What was the impact on technology transfer?

Nothing to Report.

What was the impact on society beyond science and technology?

In both military and civilian environments, sleep loss and stress increase the chances of errors and accidents, increasing the likelihood of injury and death and undermining the chances of mission success. Although there have been advances in understanding how sleep loss affects the mechanisms underlying effective performance, situational awareness, and decision making, it remains to be determined how stress impacts these abilities, as well as what the joint effects of stress and sleep loss may be. This project will provide a single framework for explaining the separate and joint effects of sleep loss and stress on decision making in dynamic environments, which will serve to guide the development of future countermeasures.

5. CHANGES/PROBLEMS

Changes in approach and reasons for change

Nothing to Report.

Actual or anticipated problems or delays and actions or plans to resolve them

We have incurred considerable delays due to the COVID-19 pandemic, which forced us to shut down our laboratory from March 2020 until September 2021. Furthermore, availability of the laboratory has had to be shared with another DoD-funded in-laboratory study, which has also been delayed by the pandemic. Consequently, we are behind schedule with regard to subject enrollment for the in-laboratory study of this project. Now that we have been able to reopen our laboratory and resume research activities, we have intensified our efforts to conduct this study and have seen a promising increase in subject recruitment. However, due to the aforementioned delays, we requested and obtained a 1-year no-cost extension to be able to fully meet our objectives, and it is anticipated that we may need to request another 1-year no-cost extension should subject recruitment remain below pre-pandemic levels.

Changes that had a significant impact on expenditures

Due to the impact of COVID-19 and the associated laboratory closure and study recruitment delays, we are behind schedule with regard to studying subjects in the laboratory. Expenditures are therefore lagging compared to the original budget. We expect that the difference will dissipate as we accelerate the pace of the study to complete data collection. We have been carefully monitoring our funding and pacing expenditures so as to be able to finish the project during the 1-year no-cost extension and will continue to do so should another 1-year no-cost extension be needed.

Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents

Nothing to Report.

Significant changes in use or care of human subjects

Nothing to Report.

Significant changes in use or care of vertebrate animals.

Nothing to Report (Not Applicable).

Significant changes in use of biohazards and/or select agents

Nothing to Report (Not Applicable).

6. PRODUCTS

Publications, conference papers, and presentations

Journal publications

Honn, K. A., & Van Dongen, H. P.A. Paradoxical effects from stimulus density manipulation provide new insight into the impact of sleep deprivation on PVT performance. *Sleep Advances*, 2022; 4(1): zpac045, published. Acknowledgement of federal support: yes.

Whitney, P., Kurinec, C. A., & Hinson, J. M. Temporary amnesia from sleep loss: A framework for understanding consequences of sleep deprivation. *Frontiers in Neuroscience*, 2023; 17, published. Acknowledgement of federal support: yes.

Books or other non-periodical, one-time publications

Ph.D. dissertations:

Nothing to Report.

Conference abstracts:

Kurinec, C., Proctor, M., Stenson, A., Whitney, P., Hinson, J., & Van Dongen, H. Trait emotion reactivity predicts change in negative but not positive affect during total sleep deprivation. *Sleep*, 2023, 46 (Supplement 1), A64-A65, published. Acknowledgement of federal support: yes.

Lundholm., K., Delane, S., James, S., Honn, K., Hansen, D., Van Dongen, H. P.A., & Satterfield, B. Sleep deprivation alters two physiological systems' responses to repeated stressors differentially. *Sleep*, 2023, 46 (Supplement 1), A59-A60, published. Acknowledgement of federal support: yes.

Skeiky, L., Honn, K., Satterfield, B., & Van Dongen, H. P.A. Conservation of prior slow wave sleep does not provide resilience to neurobehavioral impairment during total sleep deprivation. *Sleep*, 2023, 46 (Supplement 1), A93, published. Acknowledgement of federal support: yes.

Other publications, conference papers, and presentations

Invited lectures:

Van Dongen, H. P.A. *Sleep's impact on fatigue, safety, errors, and risks*. Preparedness Division, Bureau of Reclamation; Spokane, Washington, July 2023.

Van Dongen, H. P.A. *Local sleep, cognitive impairment, and inter-individual differences*. Research Symposium in Honor of JM Krueger's Research, Washington State University; Pullman, Washington, August 2023.

Oral presentations at conferences:

Lundholm., K., Delane, S., James, S., Honn, K., Hansen, D., Van Dongen, H. P.A., & Satterfield, B. Sleep deprivation alters two physiological systems' responses to repeated stressors differentially. Oral presentation at the SLEEP 2023 conference (Indianapolis, IN). June 2023.

Website(s) or other Internet site(s)

Nothing to Report.

Technologies or techniques

Nothing to Report.

Inventions, patent applications, and/or licenses

Nothing to Report.

Other Products

Nothing to Report.

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Name:	*Hans P.A. Van Dongen, Ph.D.*
Project Role:	*PI*
Researcher Identifier:	*ORCID ID: 0000-0002-4678-2971*
Nearest person month worked:	*2*
Contribution to Project:	*Dr. Van Dongen oversaw the project and coordinated all personnel activities and tasks.*
Funding Support:	

Name:	*Kimberly A. Honn, Ph.D.*
Project Role:	*Co-PI*
Researcher Identifier:	*ORCID ID: 0000-0001-8911-6277*
Nearest person month worked:	*2*
Contribution to Project:	*Dr. Honn oversaw the development of study procedures and the hiring and training of staff and assisted with obtaining informed consent and overseeing the laboratory study.*
Funding Support:	

Name:	*Paul Whitney, Ph.D.*
Project Role:	*Co-PI*
Researcher Identifier:	*ORCID ID: 0000-0003-1973-5261*
Nearest person month worked:	*1*
Contribution to Project:	*Dr. Whitney contributed key expertise on the development of measures in the cognitive task batteries.*
Funding Support:	

Name:	*John M. Hinson, Ph.D.*
Project Role:	*Co-PI*
Researcher Identifier:	*ORCID ID: 0000-0002-5012-5974*
Nearest person month worked:	*1*
Contribution to Project:	*Dr. Hinson contributed critical expertise the development of measures in the cognitive task batteries as well as the development of the stress task.*
Funding Support:	

Name:	*Courtney A Kurinec, Ph.D.*
Project Role:	*Senior Research Coordinator*
Researcher Identifier:	*ORCID ID: 0000-0001-5800-1610*
Nearest person month worked:	*4*
Contribution to Project:	*Dr. Kurinec assisted with the development of study procedures, contributed to the development of measures in the cognitive task batteries, and assisted with scheduling research assistants, obtaining informed consent, and overseeing the laboratory study.*
Funding Support:	

Name:	*Devon Hansen, Ph.D., LMHC*
Project Role:	*Assistant Professor*
Researcher Identifier:	*Washington State University ID: 10064965*
Nearest person month worked:	1
Contribution to Project:	*Dr. Hansen assisted with hiring and management of staffing for the laboratory study.*
Funding Support:	

Name:	*Brieann Satterfield, Ph.D.*
Project Role:	*Assistant Research Professor*
Researcher Identifier:	*ORCID ID: 0000-0002-8688-2416*
Nearest person month worked:	1
Contribution to Project:	*Dr. Satterfield assisted with participant recruitment and enrollment, and oversight of staffing for the laboratory study.*
Funding Support:	

Name:	*Matthew E. Layton, M.D., Ph.D.*
Project Role:	*Physician of Record*
Researcher Identifier:	*ORCID ID: 0000-0002-3287-9203*
Nearest person month worked:	*1*
Contribution to Project:	*Dr. Layton served as medical director for the study and implemented procedures for the participant screening.*
Funding Support:	

Name:	*Dawn DePriest, Ph.D., FNP-C*
Project Role:	*Medical Oversight*
Researcher Identifier:	*Washington State University ID: 11458230*
Nearest person month worked:	*1*
Contribution to Project:	*Together with Dr. Layton, Dr. DePriest performed medical exams during screening and oversaw subject health and well-being in the laboratory study.*
Funding Support:	

Name:	*Sue Weeks, MN, FNP-C, PMHNP-BC, DNP*
Project Role:	*Medical Oversight*
Researcher Identifier:	*Washington State University ID: 11458230*
Nearest person month worked:	*1*
Contribution to Project:	*Together with Dr. Layton, Dr. Weeks performed medical exams during screening and oversaw subject health and well-being in the laboratory study.*

Funding Support:	

Name:	*Naomi Teeter, M.S.*
Project Role:	*Research Coordinator*
Researcher Identifier:	*Washington State University ID: 11792273*
Nearest person month worked:	*1*
Contribution to Project:	*Ms. Teeter assisted with scheduling research assistants, obtaining informed consent, and overseeing the laboratory study.*
Funding Support:	

Name:	*Myles Finlay, RPSGT*
Project Role:	*Registered Polysomnographic Technologist*
Researcher Identifier:	*Washington State University ID: 11546225*
Nearest person month worked:	*2*
Contribution to Project:	*Mr. Finlay oversaw sleep monitoring in the laboratory study, including assessment of baseline sleep to verify inclusion criteria. He also trained research assistants and graduate students on sleep recording procedures.*
Funding Support:	

Name:	*Amanda Hudson, M.A.*
Project Role:	*Ph.D. Student*
Researcher Identifier:	*ORCID ID: 0000-0002-1641-1782*
Nearest person month worked:	*4*
Contribution to Project:	*Ms. Hudson developed study procedures and implemented performance testing for the study. She also trained research assistants and graduate students on study procedures and worked to fine-tune and troubleshoot cognitive tasks.*
Funding Support:	

Name:	*Anthony Stenson, M.A.*
Project Role:	*Ph.D. Student*
Researcher Identifier:	*ORCID ID: 0000-0002-2405-0649*
Nearest person month worked:	*1*
Contribution to Project:	*Mr. Stenson assisted with the development of measures in the cognitive task batteries.*
Funding Support:	*National Science Foundation award #1840192*

Name:	*Emily Moslener, M.S.*
Project Role:	*M.S. Student*
Researcher Identifier:	*ORCID ID:* 0000-0002-8034-3139
Nearest person month worked:	*3*
Contribution to Project:	*Ms. Moslener developed study procedures and implemented performance testing for the study.*
Funding Support:	

Name:	*Kirsie Lundholm, M.S.*
Project Role:	*Ph.D. Student*
Researcher Identifier:	*ORCID ID:* 0000-0002-8191-2508
Nearest person month worked:	*4*
Contribution to Project:	*Ms. Lundholm developed study procedures and oversaw training on saliva collection and processing. She also assisted with the development of the stress task procedures and minute-by-minute study protocol. She assisted with blood draws during screening and study procedures, blood and saliva processing, and laboratory study data collection.*
Funding Support:	

Name:	*Lillian Skeiky, M.S.*
Project Role:	*Ph.D. Student*
Researcher Identifier:	*Washington State University ID: 11656455*
Nearest person month worked:	*4*
Contribution to Project:	*Ms. Skeiky assisted with blood draws during screening and study procedures, blood and saliva processing, and laboratory study data collection.*
Funding Support:	

Name:	*Rachael Muck, B.S.*
Project Role:	*Ph.D. Student*
Researcher Identifier:	*Washington State University ID: 11441657*
Nearest person month worked:	*4*
Contribution to Project:	*Ms. Muck assisted with blood draws during screening and study procedures, blood and saliva processing, and laboratory study data collection.*
Funding Support:	

Name:	*Sofia Fluke, B.S.*
Project Role:	*Ph.D. Student*
Researcher Identifier:	*Washington State University ID: 11726590*
Nearest person month worked:	*2*
Contribution to Project:	*Ms. Fluke assisted with laboratory study data collection.*
Funding Support:	

Name:	*Sara Delane*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11622588*
Nearest person month worked:	*2*
Contribution to Project:	*Ms. Delane was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study. She also assisted with screenings and preparations for the study.*
Funding Support:	

Name:	*Anthony Scholes*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11812127*
Nearest person month worked:	*2*
Contribution to Project:	*Mr. Scholes was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study. He also assisted with recruitment, screenings, and study preparations.*
Funding Support:	

Name:	*Rebecca Simmons*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11792459*
Nearest person month worked:	*2*
Contribution to Project:	*Ms. Simmons was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study. She also assisted with recruitment, screenings and study preparations.*
Funding Support:	

Name:	*Sean Hovland*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 011870426*
Nearest person month worked:	*2*
Contribution to Project:	*Mr. Hovland was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study. He also assisted with recruitment, screenings, and study preparations.*
Funding Support:	

Name:	*Sofia Novochekhova*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 011821945*
Nearest person month worked:	*1*
Contribution to Project:	*Ms. Novochekhova was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study. She also assisted with screenings and preparations for the study.*
Funding Support:	

Name:	*Jiayi Ena Wang*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11696023*
Nearest person month worked:	*1*
Contribution to Project:	*Ms. Wang was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study. She also assisted with screenings and preparations for the study.*
Funding Support:	

Name:	*Mariana Pacheco-Arcaya*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11803213*
Nearest person month worked:	1
Contribution to Project:	*Ms. Pacheco-Arcaya was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study. She also assisted with screenings and meal preparations for the study.*
Funding Support:	

Name:	*Tye Arrington-Fox*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11791760*
Nearest person month worked:	1
Contribution to Project:	*Mr. Arrington-Fox was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study. He also assisted with sleep recordings.*
Funding Support:	

Name:	*Anthony Bennett*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11814077*
Nearest person month worked:	*1*
Contribution to Project:	*Mr. Bennett was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Ashlyn Kovacevich*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11819440*
Nearest person month worked:	*1*
Contribution to Project:	*Ms. Kovacevich was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Shen Tsao*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11513719*
Nearest person month worked:	*1*
Contribution to Project:	*Ms. Tsao was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Freya Fanson*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11821629*
Nearest person month worked:	1
Contribution to Project:	*Ms. Fanson was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Braden Bell*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11829377*
Nearest person month worked:	1
Contribution to Project:	*Mr. Bell was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Lindsey Bell*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11686355*
Nearest person month worked:	1
Contribution to Project:	*Ms. Bell was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	Claire Sparano
Project Role:	Research Assistant
Researcher Identifier:	Washington State University ID: 11829384
Nearest person month worked:	1
Contribution to Project:	*Ms. Sparano was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Isabelle Howard*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11829384*
Nearest person month worked:	1
Contribution to Project:	*Ms. Howard was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Shelda Salomon*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11672053*
Nearest person month worked:	1
Contribution to Project:	*Ms. Salomon was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Tayler Clifton*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11828903*
Nearest person month worked:	1
Contribution to Project:	*Ms. Clifton was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Gwen Jaramillo*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11830381*
Nearest person month worked:	1
Contribution to Project:	*Ms. Jaramillo was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Payton Moore*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11870795*
Nearest person month worked:	1
Contribution to Project:	*Ms. Moore was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Evan Busch*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11616248*
Nearest person month worked:	1
Contribution to Project:	*Mr. Busch was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Grace Olsen*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11871396*
Nearest person month worked:	1
Contribution to Project:	*Ms. Olsen was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Name:	*Sadie Kruger*
Project Role:	*Research Assistant*
Researcher Identifier:	*Washington State University ID: 11847621*
Nearest person month worked:	1
Contribution to Project:	*Ms. Kruger was part of the group of research assistants providing around-the-clock staffing and carrying out the research protocol for the laboratory study.*
Funding Support:	

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

Grants started:

Army Research Office / Multidisciplinary University Research Initiatives Program (subcontract under University of Michigan), “Understanding and Predicting Cognitive Fatigue across Multiple Timescales, Distinct Aspects of Cognition, and Different Individuals with Multiscale Whole Cortex Models” (PI: Forger D), September 2022–September 2025.

Google LLC, “Objective Fatigue Measurement with Phone-Based Eye Tracking” (PI: Hansen DA), September 2023–September 2024.

These new projects did not stem from results obtained in the present project, and there is no overlap between the new projects and the current project. Effort on the new projects has been offset by reduced effort on completed and closed grants (see below).

Grants closed:

Naval Postgraduate School, “Circadian Entrainment and Performance Recovery” (PI: Honn KA), August 2021–August 2023. This was an in-laboratory study of the effects of a blue-enriched light intervention on circadian entrainment and performance recovery when switching from day to night schedules.

DHHS/CDC/NIOSH, “Fatigue and Cognition Scientific Advisor” (PI: Honn KA), April 2019–July 2023. This project examined the impact of heat exposure on cognitive functioning, and whether physiological parameters and personal risk factors can be used to predict declines in cognitive functioning, particularly in the context of mining operations.

What other organizations were involved as partners?

Nothing to Report.

8. SPECIAL REPORTING REQUIREMENTS

Award Chart is enclosed (see Appendices).

9. APPENDICES

The following items are enclosed:

- Award Chart for 15 Sept 2022 – 14 Sept 2023
- PDF copy of Honn & Van Dongen (2022), *Sleep Advances* publication
- PDF copy of Whitney et al. (2023), *Frontiers in Neuroscience* publication

Journal publications

Honn, K. A., & Van Dongen, H. P.A. Paradoxical effects from stimulus density manipulation provide new insight into the impact of sleep deprivation on PVT performance. *Sleep Advances*, 2022; 4(1): zpac045, published. Acknowledgement of federal support: yes.

See appendix for a PDF copy.

Whitney, P., Kurinec, C. A., & Hinson, J. M. Temporary amnesia from sleep loss: A framework for understanding consequences of sleep deprivation. *Frontiers in Neuroscience*, 2023; 17, published. Acknowledgement of federal support: yes.

See appendix for a PDF copy.

Conference abstracts

Kurinec, C., Proctor, M., Stenson, A., Whitney, P., Hinson, J., & Van Dongen, H. Trait emotion reactivity predicts change in negative but not positive affect during total sleep deprivation. *Sleep*, 2023, 46 (Supplement 1), A64-A65, published. Acknowledgement of federal support: yes.

Abstract citation ID: zsad077.0143

0143

TRAIT EMOTION REACTIVITY PREDICTS CHANGE IN NEGATIVE BUT NOT POSITIVE AFFECT DURING TOTAL SLEEP DEPRIVATION

Courtney Kurinec[1], Matteya Proctor[1], Anthony Stenson[1], Paul Whitney[1], John Hinson[1], Hans Van Dongen[1]
[1] Washington State University

Introduction: During laboratory-based, voluntary exposure to total sleep deprivation (TSD), relatively large decreases in positive mood and relatively small increases in negative mood have been observed, with the magnitudes of change varying across individuals. People differ in their trait emotion reactivity, i.e., their sensitivity to emotion-evoking stimuli or events. As higher reactivity is associated with greater difficulty regulating emotion, we hypothesized this trait could moderate mood changes during TSD.
Methods: N=96 healthy adults (ages 21-38, 47% female) participated in one of three 4-day/3-night in-laboratory TSD studies. In each study, after 10h baseline sleep, participants were exposed to 38h TSD, followed by 10h recovery sleep. Participants completed the Emotion Reactivity Scale (ERS), and their self-reported affect was assessed every 2-4h during wake using the Positive and Negative Affect Schedule (PANAS). The 11 test bouts during TSD shared across studies were included in analyses (day 2: 09:00, 13:00, 21:00, 23:00; day 3: 01:00, 03:00, 05:00, 07:00, 09:00, 13:00, 21:00). Positive and negative affect ratings were analyzed with linear mixed-effects regression with fixed effects of test bout (categorical), ERS score (continuous), and their interaction, covariates for study, sex, and age, and a random intercept over participants.
Results: Participants showed the expected decrease in positive affect as a function of test bout (time awake and time of day, $p < 0.001$), and a smaller, non-significant increase in negative affect ($p=0.17$). Higher ERS scores were associated with increased negative affect during TSD ($p=0.002$), but this effect was small, and negative affect showed a floor effect. Emotion reactivity was not a significant predictor of decreased positive affect during TSD ($p=0.97$).
Conclusion: As hypothesized, emotion reactivity predicted individual variability in negative affect during TSD, but unexpectedly it did not predict the decrease in positive affect associated with TSD. This suggests that the trait measured by the ERS may be biased toward negative affect, and/or that positive affective changes may be more difficult to predict during the low arousal state induced by TSD. Studies inducing greater variability in negative affect during TSD (e.g., through exposure to a stressor) are needed to confirm our findings.
Support (if any): NIH CA167691, ONR N00014-13-1-0302, and CDMRP W81XWH-16-1-0319 and W81XWH-20-1-0442.

Lundholm., K., Delane, S., James, S., Honn, K., Hansen, D., Van Dongen, H. P.A., & Satterfield, B. Sleep deprivation alters two physiological systems' responses to repeated stressors differentially. *Sleep*, 2023, 46 (Supplement 1), A59-A60, published. Acknowledgement of federal support: yes.

Abstract citation ID: zsad077.0131

0131
SLEEP DEPRIVATION ALTERS TWO PHYSIOLOGICAL SYSTEMS' RESPONSES TO REPEATED STRESSORS DIFFERENTIALLY

Kirsie Lundholm[1], Sara Delane[1], Stephen James[2], Kimberly Honn[3], Devon Hansen[1], Hans Van Dongen[1], Brieann Satterfield[1]

[1] Washington State University, [2] Washington State University, College of Medicine, [3] Sleep and Performance Research Center, Washington State University Spokane

Introduction: The hypothalamic-pituitary-adrenal (HPA) and sympathetic-adrenal-medullary (SAM) axes activate in response to stressors. Real-world exposure to stressors often co-occurs with total sleep deprivation (TSD). The SAM response to a single stressor appears unchanged by TSD, but salivary alpha-amylase (sAA) has shown that TSD blunts the SAM response to repeated stressor exposure. Using salivary cortisol concentration (SCC), we investigated the HPA response to repeated stressors under well-rested and TSD conditions.

Methods: N=10 healthy adults (ages 28.3±5.78; 5f) completed a 4-day/3-night in-laboratory study with 38h TSD preceded and followed by 10h sleep opportunities. On day 2 (well-rested) and day 3 (TSD), participants completed two stressor sessions in a high-fidelity shooting simulator, separated by 30min. Acting as police officers, civilian participants verbally interacted with emergency response scenarios and decided whether to use (simulated) deadly force. Seven saliva samples were collected each day: pre-stressor, and 0min, 15min, and 30min after each session. Samples were assayed for SCC and normalized against each day's pre-stressor sample.

Results: Mixed-effects ANOVA showed a significant effect of sample time ($F[5,99]=19.85$, $p< 0.001$), with SCC peaking 15min after the first stressor session and steadily declining thereafter. The SCC peak was significantly blunted during TSD compared to well-rested ($t[99]=2.84$, $p=0.006$). Correlations with previously reported, simultaneously assessed sAA concentrations, which peaked right after the first stressor session, were not significant ($p>0.2$). Additionally, whereas sAA showed a second peak after the second stressor session when participants were well-rested, no second peak was found in SCC.

Conclusion: The SCC response after one stressor session with simulated emergency response scenarios was blunted during TSD, unlike the sAA response. However, while sAA peaked twice in response to repeated stressor exposure when participants were well-rested (though not during TSD), SCC continued to decline after the first stressor exposure, potentially indicating a HPA refractory mechanism or habituation. Also, over participants there was no significant relationship between the magnitude of the stressor response between SCC and sAA. Taken together, our results suggest fundamentally distinct SAM and HPA axis responsivity to repeated acute stressors, with differential impact of TSD.

Support (if any): ONR N00014-13-1-0302, PRMRP W81 XWH-20-1-0442.

Skeiky, L., Honn, K., Satterfield, B., & Van Dongen, H. P.A. Conservation of prior slow wave sleep does not provide resilience to neurobehavioral impairment during total sleep deprivation. *Sleep*, 2023, 46 (Supplement 1), A93, published. Acknowledgement of federal support: yes.

Abstract citation ID: zsad077.0210

0210

CONSERVATION OF PRIOR SLOW WAVE SLEEP DOES NOT PROVIDE RESILIENCE TO NEUROBEHAVIORAL IMPAIRMENT DURING TOTAL SLEEP DEPRIVATION

Lillian Skeiky[1], Kimberly Honn[2], Brieann Satterfield[1], Hans Van Dongen[1]

[1] Washington State University, [2] Sleep and Performance Research Center, Washington State University Spokane

Introduction: Slow wave sleep (SWS) is thought to play a critical, if not unique, role in resilience and recovery of waking function. It has been posited that if SWS is preserved, the impact of sleep restriction on subsequent neurobehavioral functioning should be minimal. In this context, we investigated the effects of a delayed and restricted sleep opportunity on SWS and on neurobehavioral impairment during a subsequent period of total sleep deprivation (TSD).

Methods: N=21 healthy adults (21–38y, 9f) underwent three separate periods of 36h TSD, each preceded by one week of prior sleep extension to 12h time in bed (TIB) per night (PSE condition, twice), or prior sleep restriction to 6h TIB per night (PSR condition, once). The last night of each condition was spent inside the laboratory. TIB for the pre-TSD night was 22:00–10:00 (PSE) or 04:00–10:00 (PSR). During each 36h TSD period, subjects completed a neurobehavioral task battery every 2h including a digit-symbol substitution test (DSST) measuring cognitive throughput and the Karolinska Sleepiness Scale (KSS) measuring subjective sleepiness. Following TSD, subjects had a 12h sleep opportunity (22:00–10:00). Sleep was recorded polysomnographically during both pre- and post-TSD nights.

Results: The pre-TSD night in the PSR condition had less total sleep time, with significant reductions ($p< 0.001$) in N1, N2, and REM durations compared to the PSE condition. There were no significant differences between the PSE and PSR conditions in SWS duration ($p=0.40$). Moreover, in the post-TSD night, there were no significant differences ($p>0.1$) between the PSE and PSR conditions in any of the sleep stages, including SWS. Neurobehavioral functioning during TSD exhibited significant effects ($p< 0.02$) of prior sleep condition on DSST throughput and KSS sleepiness, with reduced throughput and increased sleepiness in the PSR condition relative to the PSE condition.

Conclusion: SWS was remarkably conserved in delayed, restricted sleep compared to extended sleep. However, this conservation of SWS did not prevent exacerbation of DSST throughput deficits or KSS sleepiness from prior sleep restriction during subsequent TSD. As such, other aspects of sleep besides SWS are also important in mediating sleep-induced resilience and recovery.

Support (if any): NASA NAG9-1161, CDMRP W81XWH-20-1-0442, ARO W911NF2210223.