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| **Fiscal Year:** | FY 2021 | **Task Last Updated:** | FY 05/05/2021 |
| **PI Name:** | Petersen, Lonnie M.D., Ph.D. | | |
| **Project Title:** | Mobile Gravity Suit (an Integrative Countermeasure Device) | | |
| **Division Name:** | Human Research | | |
| **Program/Discipline:** | | | |
| **Program/Discipline--Element/Subdiscipline:** | | | |
| **Joint Agency Name:** | | **TechPort:** | Yes |
| **Human Research Program Elements:** | (1) **HHC**:Human Health Countermeasures | | |
| **Human Research Program Risks:** | (1) **SANS**:Risk of Spaceflight Associated Neuro-ocular Syndrome (SANS) | | |
| **Space Biology Element:** | None | | |
| **Space Biology Cross-Element Discipline:** | None | | |
| **Space Biology Special Category:** | None | | |
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| **Organization Name:** | University of California, San Diego | | |
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| **City:** | La Jolla | **State:** | CA |
| **Zip Code:** | 92037-1337 | **Congressional District:** | 52 |
| **Comments:** | | | |
| **Project Type:** | Ground | **Solicitation / Funding Source:** | 2017 HERO 80JSC017N0001-Crew Health and Performance (FLAGSHIP1, OMNIBUS). Appendix A-Flagship1, Appendix B-Omnibus |
| **Start Date:** | 10/04/2018 | **End Date:** | 10/01/2022 |
| **No. of Post Docs:** | 0 | **No. of PhD Degrees:** | |
| **No. of PhD Candidates:** | 2 | **No. of Master' Degrees:** | |
| **No. of Master's Candidates:** | 1 | **No. of Bachelor's Degrees:** | |
| **No. of Bachelor's Candidates:** | 20 | **Monitoring Center:** | NASA JSC |
| **Contact Monitor:** | Brocato, Becky | **Contact Phone:** | |
| **Contact Email:** | becky.brocato@nasa.gov | | |
| **Flight Program:** | | | |
| **Flight Assignment:** | NOTE: End date changed to 10/1/2022 per NSSC information (Ed., 9/19/21)<br>NOTE: End date changed to 10/3/2021 per NSSC information (Ed., 8/21/20)<br>NOTE: End date changed to 10/3/2020 per NSSC information (Ed., 10/28/19) | | |
| **Key Personnel Changes/Previous PI:** | Change (FY2021 report): Co-I Alan Hargens is no longer affiliated with this project. | | |
| **COI Name (Institution):** | Levine, Benjamin M.D., Ph.D. ( University of Texas Southwestern Medical Center at Dallas ) | | |
| **Grant/Contract No.:** | 80NSSC19K0020 | | |
| **Performance Goal No.:** | | | |
| **Performance Goal Text:** | | | |

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| **Task Description:** | Because all parts of human physiology are affected by microgravity, an integrative countermeasure strategy is needed. Loss of muscle and bone mass along with deconditioning of the heart and vessels are well described effects of microgravity. More recently structural and functional changes of the eye, experienced by some astronauts during long-term missions, have been described and summarized in the Spaceflight Associated Neuro-ocular Syndrome (SANS). While the exact etiology of SANS remains unknown, the microgravity induced headward fluid shift is likely part of the pathophysiology and countermeasures that can reverse this fluid shift are prioritized.<br>Based on our experimental data from short-term microgravity by parabolic flights and 24-hour simulated microgravity, we suggest that fluid redistribution in space may not give rise to a pathological increase in intracranial pressure, but rather the lack of diurnal fluctuations in intracranial volume and pressures may be responsible for the remodeling of the eye. In ambulatory neurosurgical patients with pressure sensors inserted in the brain tissue, we therefore demonstrated the feasibility of lower body negative pressure to reduce intracranial pressure as means of re-introducing diurnal pressure variability. Extending on this, in a recent 3-day, 6° head-down tilt bedrest trial we applied lower body negative pressure (LBNP) for 8 hours every day, to demonstrate safety and efficacy to significantly reduce long-term swelling at the back of the eye believed to be early symptoms of SANS.<br><br>At the Aerospace Physiology Lab at University of California San Diego (UCSD) we have developed and tested a mobile "Gravity Suit" comprised of pressurized-trousers and attached vest. The suit simulates the effects of gravitational stress by application of low-levels lower body negative pressure to re-introduce an Earth-like fluid shift while at the same time inducing a ground reaction force at the bottom of the feet and a mechanical load along the entire body axis. Preliminary tests involving healthy human subjects in simulated microgravity have demonstrated the efficacy of 20 mmHg lower body negative pressure within the suit to reduce internal jugular vein cross-sectional area by some 45% and induce mechanical load of 57% bodyweight.<br><br>The intravehicular suit is comfortable enough to wear 8-10 hours a day and flexible enough to be combined with daily activity and even exercise with the overall aim to provide an integrative countermeasure. As an overall long-term aim, we suggest that use of the Gravity Suit will 1) re-introduce the diurnal variability of intracranial pressure and volume to help prevent development of SANS; 2) stimulate the cardiovascular system to maintain cardiac muscle mass and vascular compliance; 3) counteract loss of postural muscle mass and bone density; 4) finally, the axial loading may preserve curvature of the spine, paraspinal muscle, and disc morphology to both ameliorate in-flight back pain, and reduce risk of post-flight disc herniation.<br><br>Within the scope of this proposal, we will finalize and further test our prototype by integrating vacuum- and monitoring systems within the waist-belt to increase safety and allow for free and un-tethered movement. Comfort, range of motion, and gait will be assessed during relevant activities simulating daily work tasks on the International Space Station (ISS) and in combination with resistive exercise device relevant for cislunar and deep space missions. High levels and/or prolonged exposure to lower body negative pressure can potentially compromise blood flow to the brain; however, activity and use of the muscle pump increases orthostatic tolerance. To establish a safe range and optimize the user scenario, we will test cardiovascular responses and cerebral perfusion during graded lower body negative pressure with and without a combined ground reaction force and in combination with rowing exercise. Successful funding of this proposal will bring our Gravity Suit to Countermeasure Readiness Level 7. |
| **Rationale for HRP Directed Research:** | |
| **Research Impact/Earth Benefits:** | While designed as a countermeasure for use in space, LBNP may hold benefits for life on Earth. One specific example is reduction of pressure inside the brain which may hold potential for patients on Earth with elevated intracranial pressure. |
| | Ongoing Work and Scope of Second Year of Funding<br>The focus of ongoing work is to further investigate any potential physiological differences in response between classic LBNP and LBNP including ground reaction forces (GRF). The bulk of available literature includes “classic” LBNP (no GRF) which seems promising as a countermeasure for SANS (Lawley et al. Daily Generation of a Footward Fluid Shift Attenuates Ocular Changes Associated with Head-Down Tilt Bedrest. J Appl Physiol. 129(5), 1220-1231, 2020). With the second year of the omnibus project, I aim to further investigate potential differences in LBNP response when GRF are allowed. Since GRF include activation of the muscle pump and a potentially a myriad of other reflexes from proprioceptor and vestibular-cardio reflexes, it is possible that the cardiovascular response to LBNP+GRF is modulated. Furthermore, we will continue the development of the GravitySuit, particularly focusing on the vacuum and safety systems.<br><br>COVID UPDATE: UCSD closed down early in 2020 and has, regrettably, not fully opened up yet. Aerospace Physiology lab (Petersen lab) submitted and was approved for on-site research ramp-up; however, all work has been under significant restrictions and 6 feet distance has to be maintained at all times. Thus, research with human subjects has been close to impossible and I have focused efforts that were possible; therefore, significant technical advances have been made while some experimental data was collected.<br><br>Technical Progress: Based on feedback from HRP (NASA's Human Research Program), we have updated the battery system and vacuum system. Additionally, much experimental work has gone into material selection both for the soft-shell and the structure framework. Mobility across the individual joint has also been a focus and we have created a knee design that allows for full mobility without contact with the skin. We are currently evaluating materials for the structural support of the knee joint.<br><br>Experimental procedure arm: I was able to include nine subjects in the experimental arm of the extension grant. Please find abstract summarizing method and data below:<br><br>Title: LOWER BODY NEGATIVE PRESSURE AS INTEGRATIVE COUNTERMEASURE DURING SPACEFLIGHT<br><br>INTRODUCTION: Because most aspects of human physiology are affected by microgravity, an integrated countermeasure strategy is warranted. Deconditioning of the cardiovascular and musculoskeletal system are well described consequences of long-tern spaceflight and more recently the Spaceflight-Associated Neuro-ocular Syndrome (SANS) has been identified and classified as a major risk factor. While exact mechanisms are incompletely understood, combined effects of altered fluid distribution and lack of diurnal intracranial pressure (ICP) variability are likely key |

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| **Task Progress:** | factors. Lower body negative pressure (LBNP) simulates the beneficial effects of gravity by re-introducing foot-ward fluid shift and generating mechanical loading. In ground-based trials we have demonstrated the dose-response relationship between LBNP and ICP and determined 20-30 mmHg as recommended level counteract cephalic congestion without impairing cerebral perfusion (Petersen et al. 2018) and when applied for 8-hours daily during slight head-down tilt bedrest LBNP ameliorated choroidal engorgement and other early signs of SANS (Lawley et al. 2020). AIM: To increase feasibility of LBNP during spaceflight we have developed and validated a wearable, flexible, and mobile LBNP: GravitySuit (Petersen et al. 2019). Application of LBNP in a weightless environment differs from that of ground-based in that the subject cannot rely on friction forces (1GX) to prevent them from being displaced into the device. Therefore, subject must push off against the bottom of the device and LBNP-induced ground-reaction forces (GRF) between subjects' feet and device are inevitable. This project investigated if LBNP with and without GRF induce similar physiological responses.<br><br>METHOD AND RESULTS: Nine healthy young volunteers (5/4 female/male) were included in a randomized cross-over trial and incremental LBNP from 0 to 40 mmHg was applied for 2 min either with use of a foot-board for subjects to push off against (+GRF) or with use of a saddle to prevent any mechanical forces (-GRF). Cardiovascular parameters (Nexfin) and internal jugular venous cross-sectional area (IJVa) were recorded.<br><br>We found no statistical difference in blood pressure responses, cardiac stroke volume or cardiac output between +GFR and -GFR at any level of LBNP. Importantly, IJVa was reduced to the same extend by incremental LBNP with and without GRF: from a baseline of 1.1 +/- 0.4 cm2 to 0.4 +/- 3.3 cm2 at 40mmHg without GRF; and from 1.1 +/- 0.6 cm2 to 0.4 +/- 0.3 cm2 with GRF (mean +/- SD; P>0.05). The increase in heart rate at every level of LBNP was trended to be smaller when GRF were allowed compared to no GRF but failed to reach statistical significance.<br><br>DISCUSSION: Volumetric values responded in a similar fashion during short term application of LBNP with and without GRF. Heart rate trended toward a blunted LBNP-induced increase when GRF were included. LBNP +GRF more closely simulates a normal upright standing posture, which usually does not induce syncope to the same extend as passive head-up tilt or LBNP without GRF. GRF introduces a host of compensatory mechanisms including the muscle venous pump and orthostatic cardiovascular reflexes. Potential differences in effect during long-term LBNP application remain unknown. We recommend future ground-based analogue trials investigating LBNP as a countermeasure considers not only duration of application but also the method including +/- GRF. The mandatory GRF when LBNP is applied in weightlessness is a limitation for considerations of applying LBNP during sleep.<br><br>References<br><br>Petersen LG, Lawley JS, Lilja-Cyron A, Petersen JCG, Howden EJ, Sarma S, Cornwell WK, Zhang R, Whitworth LA, Williams MA, Juhler M, Levine BD. Lower Body Negative Pressure to Safely Reduce Intracranial Pressure. J Phys 597:237-248, 2018<br><br>Lawley JS, Babu G, Janssen SLJE, Petersen LG, Hearon Jr. CM, Dias KA, Sarma S, Williams MA, Whitworth LA, Levine BD. Daily Generation of a Footward Fluid Shift Attenuates Ocular Changes Associated with Head-Down Tilt Bedrest. J Appl Physiol. 129(5), 1220-1231, 2020<br><br>Petersen LG, Hargens A, Bird E, Ashari N, Saalfeld J, Petersen JCG. Mobile Lower Body Negative Pressure Suit as an Integrative Countermeasure for Spaceflight. Aerospace Medicine and Human Performance. 1;90(12):993-999, 2019 |
| **Bibliography Type:** | Description: (Last Updated: 03/21/2025) |
| **Articles in Peer-reviewed Journals** | Harris KM, Petersen LG, Weber T. "Reviving lower body negative pressure as a countermeasure to prevent pathological vascular and ocular changes in microgravity." npj Microgravity. 2020 Dec 17;6(1):38. https://doi.org/10.1038/s41526-020-00127-3 ; PMID: 33335101; PMCID: PMC7746725 , Dec-2020 |
| **Articles in Peer-reviewed Journals** | Ogoh S, Washio T, Paton JFR, Fisher JP, Petersen LG. "Gravitational effects on intracranial pressure and blood flow regulation in young men: a potential shunting role for the external carotid artery." J Appl Physiol (1985). 2020 Oct 1;129(4):901-8. Epub 2020 Aug 20. https://doi.org/10.1152/japplphysiol.00369.2020 ; PMID: 32816640 , Oct-2020 |
| **Articles in Peer-reviewed Journals** | Roberts DR, Petersen LG. "Studies of hydrocephalus associated with long-term spaceflight may provide new insights into cerebrospinal fluid flow dynamics here on Earth. [Editorial comment on Lee et al. Spaceflight-associated brain white matter microstructural changes and intracranial fluid redistribution. JAMA Neurol. 2019 Apr 1;76(4):412-9. https://doi.org/10.1001/jamaneurol.2018.4882 ]" JAMA Neurology. 2019 Apr;76(4):391-2. https://doi.org/10.1001/jamaneurol.2018.4891 ; PubMed PMID: 30673794 , Apr-2019 |
| **Papers from Meeting Proceedings** | Harris K, Petersen LG, Damann V, Scott J, Weber T. "Effects of Lower-body Negative Pressure on Fluid Distribution During Gravitational Unloading." 70th International Astronautical Congress (IAC), Washington, DC, October 21-25, 2019.<br>70th International Astronautical Congress (IAC), Washington, DC, October 21-25, 2019. Paper IAC-19,A1,4,1149136. , Oct-2019 |