Fiscal Year:	FY 2020	**Task Last Updated:**	FY 11/07/2019
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:	None		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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Zip Code:	92037-1337	**Congressional District:**	52
Comments:			
Project Type:	GROUND	**Solicitation:**	2017 HERO 80JSC017N0001-Crew Health and Performance (FLAGSHIP1, OMNIBUS). Appendix A-Flagship1, Appendix B-Omnibus
Start Date:	10/04/2018	**End Date:**	10/03/2020
No. of Post Docs:	0	**No. of PhD Degrees:**	
No. of PhD Candidates:	2	**No. of Master' Degrees:**	
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	
No. of Bachelor's Candidates:	9	**Monitoring Center:**	NASA JSC
Contact Monitor:	Norsk, Peter	**Contact Phone:**	
Contact Email:	Peter.norsk@nasa.gov		
Flight Program:			
Flight Assignment:	NOTE: End date changed to 10/3/2020 per NSSC information (Ed., 10/28/19)		
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Hargens, Alan Ph.D. (University of California, San Diego) Levine, Benjamin M.D., Ph.D. (University of Texas Southwestern Medical Center at Dallas)		
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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.
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.

At the University of California San Diego we have developed and tested a fully 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.

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 will 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.

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.

Task Progress:

Introduction: Because all aspects of human physiology are affected by microgravity, an integrated countermeasure approach is warranted. The aim of this proposal is to finalize and further validate our prototype of an intravehicular mobile countermeasure suit, which consists of lower body negative pressure (LBNP) trousers and vest to reproduce the effects of gravitational stress during spaceflight. This mobile “Gravity Suit” aims to be: 1) Comfortable enough to allow for use for several hours per day, which entails monitoring and some form of regulation of the internal environment (temperature and humidity); 2) Not interfere with everyday in-flight activities, which entails being slim enough to allow for movement around the station and to be mobile and un-tethered, i.e., to have a mobile battery-operated vacuum system; 3) be flexible enough to be combined with some forms of exercise and movement, which entails ability to flex the knee and hip to at least 90 degrees.
Background: LBNP was used as early as the Apollo program through Skylab and Mir (Hoffler et al. 1977, Iwasaki et al. 2007). Currently the Russian LBNP device (“Chibis”) is available on International Space Station (ISS). Several indications point to beneficial multi-system effects. To make LBNP feasible as a countermeasure, we created a wearable, untethered, mobile, and flexible device.

Aim: To test that the suit induces caudal fluid shift as know from “classic rigid LBNP” devices (Petersen et al. 2019) and in addition to that it provides mechanical loading of the body which could potentially be beneficial for the musculoskeletal system.

Materials and Methods: We have designed and built a wearable LBNP device consisting of a set of trousers that can be pressurized with a seal created at the iliac crest and attached “boots” that support ground reaction forces. The mechanical loads are carried to the shoulders by means of the attached vest to provide mechanical loading to the entire axial length of the body. Negative pressure is generated by a portable vacuum powered by a rechargeable battery. Following Institutional Review Board (IRB) approval 8 healthy subjects were included in initial testing. Mechanical loading was quantified as ground reaction forces (GRF) under the sole of each foot using force sensors (Tekscan, USA) and on the shoulders under the vest. Caudal fluid shift was assessed from the reductions in internal jugular venous cross-sectional area (IJVa) using ultrasounds (treason t3200, treason, USA). Continuous cardiovascular profile was recorded using the volume-clamp method from a finger cuff (Nexfin, BMeye, The Netherlands) and presented as 1 min average following 5 minutes of rest at each condition. Range of motion was recorded as maximum comfortable angle of flexion of the hip and knees from the normal position. Incremental LBNP from 0 to 40 mmHg at increments of 10 mmHg were applied while subjects were resting in a suspended supine position. Following completion of the incremental protocol, LBNP was set at 20 mmHg and range of motion at this level was recorded.

Results: Relative to normal body weight (BW) when standing upright, increments of 10 mmHg LBNP from 0 to 40 mmHg whilst supine generated incremental axial mechanical loading of the body with around 35 mmHg generating close to one bodyweight. Caudal fluid displacement was indicated by the significant reduction of IVJa while cardiovascular parameters were well maintained ($P > 0.05$) with the exception of stroke volume (SV) which decreased at 40 mmHg, and which was accompanied by a non-significant increase in heart rate (HR). Mean arterial blood pressure (MAP) was maintained throughout the incremental LBNP protocol. Range of motion across the hip and knee joints was measured and confirmed to reach 90 degrees.

Discussion: LBNP is a potential countermeasure to reverse the cranial fluid shift associated with weightlessness. In the first year of this omnibus project, we have demonstrated that a caudal fluid shift and mechanical loading can be achieved using a wearable mobile LBNP suit.

Limitations: An important limitation is the restricted dimensions of the suit which only allowed for inclusion of subjects with a limited waist-, hip-, and leg-circumference and length of the legs. Ongoing efforts are directed toward including subjects of varying size and further investigating the effects of LBNP in combination with GRF.

References

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Bibliography Type:	Description: (Last Updated: 02/11/2020)
Abstracts for Journals and Proceedings	Petersen LG. "Effects of Gravity and Spaceflight on Fluid Shifts and Neuro-ocular Impairment: Countermeasures." Presented at 39th International Society for Gravitational Physiology (ISGP) & European Space Agency (ESA) Life Sciences Meeting, Noordwijk, Netherlands, June 18-22, 2018. Abstracts. 39th International Society for Gravitational Physiology (ISGP) & European Space Agency (ESA) Life Sciences Meeting, Noordwijk, Netherlands, June 18-22, 2018. , Jun-2018
Abstracts for Journals and Proceedings	Petersen LG, Hargens A, Levine B. "Mobile Negative Pressure Suit as an Integrative Countermeasure." Poster, 2019 NASA Human Research Program Investigators' Workshop, Galveston, TX, January 22-25, 2019. Abstracts. 2019 NASA Human Research Program Investigators' Workshop, Galveston, TX, January 22-25, 2019. , Jan-2019
Abstracts for Journals and Proceedings	Petersen LG. "Mobile Lower Body Negative Pressure Suit as an Integrative Countermeasure." Presented at 89th Aerospace Medicine Association Meeting, Las Vegas, NV, May 5-19, 2019. Aerospace Medicine and Human Performance. 2019 Mar;90(3). , Mar-2019
Articles in Peer-reviewed Journals	Petersen LG, Ogoh S. "Gravity, intracranial pressure, and cerebral autoregulation." Physiol Rep. 2019 Mar;7(6):e14039. https:// ; PubMed PMID: 30912269; PubMed Central PMCID: PMC6434070 , Mar-2019
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Awards	Petersen LG. "1st Place Aerospace Medical and Human Performance, AMSRO Scientific Paper Award. 89th Aerospace Medicine Association Meeting, Las Vegas, NV, May 5-19, 2019." May-2019