Fiscal Year:	FY 2010	**Task Last Updated:**	FY 10/05/2010
PI Name:	Cavanagh, Peter R. Ph.D., D.Sc.		
Project Title:	Monitoring Bone Health by Daily Load Stimulus Measurement during Lunar Missions		
Division Name:	Human Research		
Program/Discipline:	NSBRI		
Program/Discipline--Element/Subdiscipline:	NSBRI--Musculoskeletal Alterations Team		
Joint Agency Name:		**TechPort:**	No
Human Research Program Elements:	(1) **HHC**:Human Health Countermeasures		
Human Research Program Risks:	(1) **Bone Fracture**:Risk of Bone Fracture due to Spaceflight-induced Changes to Bone (2) **Osteo**:Risk Of Early Onset Osteoporosis Due To Spaceflight		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
PI Email:	cavanagh@u.washington.edu	**Fax:**	FY 206-685-3139
PI Organization Type:	UNIVERSITY	**Phone:**	206-221-2845
Organization Name:	University of Washington		
PI Address 1:	Department of Orthopaedics and Sports Medicine		
PI Address 2:	School of Medicine		
PI Web Page:			
City:	Seattle	**State:**	WA
Zip Code:	98195-6500	**Congressional District:**	7
Comments:	PI moved from Cleveland Clinic to University of Washington in June 2008 (8/08)		
Project Type:	Ground	**Solicitation / Funding Source:**	2007 Crew Health NNJ07ZSA002N
Start Date:	10/01/2008	**End Date:**	09/30/2012
No. of Post Docs:	1	**No. of PhD Degrees:**	0
No. of PhD Candidates:	1	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	3	**Monitoring Center:**	NSBRI
Contact Monitor:		**Contact Phone:**	
Contact Email:			
Flight Program:			
Flight Assignment:			
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Lang, Thomas (University of California, San Francisco) Grodsinsky, Carlos (ZIN Technologies, Inc.) Gilkey, Kelly (NASA Glenn Research Center)		
Grant/Contract No.:	NCC 9-58-MA01603		
Performance Goal No.:			
Performance Goal Text:			

Task Description:

One of the key questions that remain unanswered as we prepare for prolonged lunar sojourns is the degree to which living and exercising on the lunar surface will provide an osteoprotective stimulus to prevent the loss of bone mineral density (BMD) that has been observed in microgravity. The concept of daily load stimulus is useful in this regard since it has the potential to estimate the "dose" of load to the lower extremities that will maintain skeletal integrity even in the setting of concurrent therapeutic drug and exercise countermeasures. Most observers believe that some form of supplementary exercise will be required during lunar activity, but this will need to be optimized to provide the most efficient use of crew time. Cavanagh et al. (J. Biomech., 2010) have recently published reports that on average, only 43 minutes of of the ~150 minutes assigned for exercise during a day resulted in loaded, osteoprotective exercise. Given the continued loss of (BMD) observed in crewmembers after long-duration flights, this amount of loaded exercise is not enough to preserve an acceptable amount of bone strength.
The original Project Objectives were to, namely:

1) Allow quantification of a crew health risk and.

2) Develop technologies to monitor a health risk.

The original Specific Aims of the project include:

1) To develop hardware based on Micro Electro Mechanical Systems technology (MEMS) that can unobtrusively monitor the accelerations applied to the body and interface with an ambulatory monitor.

2) To extend the Daily Load Stimulus Algorithm to account for recent developments in bone mechanobiology, to incorporate accelerometric signals, and to write software to perform this analysis in real-time.

3) To demonstrate the feasibility and validity of the approach in 1g, in 1/6g in the eZLS, and in the 1/6g lunar bed rest analog.

4) To integrate the hardware and software into a package suitable for flight development.

To date, the following goals and objectives have been met:

The wireless Daily Load Sensor has been designed, manufactured, and tested in a series of studies. The Daily Load Stimulus Algorithm has been extended to account for recent developments in bone mechanobiology, particularly the issue of stimulus saturation. The sensor system has been tested in 1g, 1/6g, and 3/8g environments. NASA HRP has decided to not utilize the lunar bed rest model, and as such the system has not been tested in that analog. A large data collection period has been completed at the end of Project Year 2, and initial data analysis is starting to reveal potential crew health risks to bone health maintenance in reduced gravity environments.

After validation in the enhanced Zero Gravity Locomotion Simulator (eZLS) at NASA Glenn Research Center, a deliverable of this project will be a system, the Daily Load Sensor, including a foot-mounted and a waist-mounted unit that will wirelessly transmit signals to a portable data logger that could potentially be used to collect data on other physiological systems simultaneously. Onboard software with visual feedback will determine how much additional exercise is required each day to maintain bone homeostasis. This high Technology Readiness Level (TRL=7) project combines theory, experimentation and hardware development to produce a device that will be a critical component in the effort to maintain bone health during lunar missions. The project is a collaborative effort between the University of Washington, the Exercise Countermeasures Laboratory at NASA Glenn Research Center, ZIN Technologies and the University of California, San Francisco.

Key findings to date include:

• Foot forces suggest IVA lunar and Martian locomotion (walking, running, loping, hopping) alone may not be osteoprotective.

• Foot forces suggest that a simulated lunar EVA (body weight plus ~200 Earth lbs of suit mass) locomotion may not be osteoprotective.

• Foot forces suggest that a simulated Martian EVA (body weight plus ~200 Earth lbs of suit mass) locomotion may provide adequate loading under some locomotion conditions to be osteoprotective depending on the duration of the activities.

• Lunar and Martian hopping and loping result in higher foot forces than walking. Running provides the highest foot forces in any one environment as compared to other locomotor activities.

• The eZLS provides simulation of reduced gravity environments and capability to utilize gravity replacement loads, similar to the treadmills in use on ISS.

• An Artificial Neural Network can precisely recognize lunar locomotor activity, which is useful during remote monitoring scenarios.

During year three of the project, we plan to achieve the following:

• Enhance the Activity Recognition library to include automated detection of additional mission critical tasks such as ladder climb, rock translation, platform jump down, squat exercise, and obstacle avoidance.

• Test the interface between our wireless sensors and the BioNet software framework in the laboratory setting, for future automated data management aboard the International Space Station (ISS).

• Determine feasibility of flight integration with hardware in current configuration, and asses need for modification to allow utilization aboard the ISS.

• Develop an ambulatory data logging system that is capable of communicating with the wireless sensors and the BioNet software framework.

• Instrument subjects who are participating in an on-going bed rest campaign conducted by our laboratory examining treadmill exercise countermeasures against bone demineralization.

Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Accurate and detailed ambulatory activity monitoring with the added benefit of software predicting bone health is a tool that would be highly sought after by athletic communities, the aging population, osteoporotic patients, and elderly care personnel. This project has the potential to produce a NASA spinoff that would benefit the mentioned populations through personal bone health monitoring systems. In 2005, osteoporosis-related fractures in the US were responsible for an estimated $19 billion in medical expenses. This estimate is expected to rise to $25.3 billion by 2025. The personal monitoring system being developed under this grant can help individuals manage their bone health based on personal exercise goals and real-time feedback. Use of this hardware could help significantly decrease medical costs related to osteoporotic fracture.
Task Progress:	Year two of the MBH project has focused on the following: 1) Hardware Design Review and Maintenance, 2) Data Collection & Analysis, 3) eZLS Facility Maintenance, and 4) IRB modifications. At the end of year two we have made significant progress on each item, as described below. 1) HARDWARE DESIGN REVIEW AND MAINTENANCE: The Hardware Design Review was held at the beginning of Year 2. At that time, it was decided that the foot sensor would be encapsulated in a hard epoxy resin. The sampling rates of the waist and foot sensors were set to 256HZ and 1024Hz, respectively. ZIN Technologies continued to support hardware maintenance over Year 2 of the project, providing additional sensors upon request and re-calibration of the sensors half-way through the study. A software update was also performed to increase the resolution of the timestamp. Sensor battery chargers were replaced periodically throughout the study. 2) DATA COLLECTION & ANALYSIS: A total of 38 subjects were screened and consented for this study. A total of 25 subjects were enrolled in the study. Subjects were asked to perform a variety of mission critical tasks while positioned in the eZLS. These activities were performed in either shoes or boots, and at 1g, 1/6g, or 3/8g simulated gravity environments and included walking (1MPH), running (6MPH), loping (2MPH), hopping (2MPH), ladder climb, platform jump-down, 40lb rock carry, obstacle avoidance, and squat exercise. Data collection was completed in August 2010. Initial results were presented at the American Society of Biomechanics Annual Meeting and focused on locomotor activities (walking, running, loping, hopping). 3) EZLS FACILITY MAINTENANCE: NASA Glenn Research Center houses the enhanced Zero-gravity Locomotion System (eZLS) on which our hardware was tested. Specialty hardware needs were identified and engineers were tasked with the fabrication and integration of the ladder step, jump-down platform, obstacle avoidance hardware, and 40lb rock load. A customized passive pneumatic Subject Load Device (PP-SLD) was installed for Phase II of this study (See attached report for detailed description; Appendix B). The force plate on the instrumented treadmill was conditioned for low-gravity load usage, and the controller software was updated to include a reset zero function (See attached report for detailed description; Appendix B). All eZLS instrumentation was calibrated before the study began. 4) IRB MODIFICATIONS: Following full board approval from both the University of Washington IRB and the NASA CPHS, a number of modifications were requested and approved in Year 2 of the project, which included: 1) Increased subject recruitment numbers from 30 to 47. 2) Increased data sharing capability. 3) Record subject leg length for calculation of the Froude Number. 4) Decreased walking speed from 3MPH to 1MPH. 5) Included the 1g squat exercises in Phase II.
Bibliography Type:	Description: (Last Updated: 03/08/2018)
Abstracts for Journals and Proceedings	Hanson A, Chmiel A, Thorndike D, Grodskinsky C, Gilkey K, Cavanagh P. "Miniaturized accelerometric device to monitor bone health during lunar missions." 2010 Aerospace Medical Association Annual Scientific Meeting, Phoenix, AZ, May 9-13, 2010. Aviation, Space, and Environmental Medicine 2010 Mar;81(3):234. , Mar-2010
Abstracts for Journals and Proceedings	Hanson A, Gilkey K, Thorndike D, Grodsinsky C, Rice A, Cavanagh P. "Bone stimulus and astronaut activity recognition during missions to the moon and mars." 2010 Northwest Biomechanics Symposium, Seattle, WA, May 21-22, 2010. 2010 Northwest Biomechanics Symposium, Abstract Book, May 2010. , May-2010
Abstracts for Journals and Proceedings	Hanson A, Gilkey K, Weaver A, Perusek G, Thorndike D, Kutnick G, Grodsinsky C, Rice A, Cavanagh P. "Gait characteristics of simulated lunar locomotion." 34th annual meeting of the American Society of Biomechanics, Providence, RI, August 18-21, 2010. 34th annual meeting of the American Society of Biomechanics, Abstract Book, August 2010. http://www.asbweb.org/conferences/2010/abstracts/287.pdf , Aug-2010
Abstracts for Journals and Proceedings	Hanson AM, Gilkey K, Perusek GP, Grodsinsky CM, Thorndike D, Kutnick G, Weaver AS, Lang TF, Rice AJ, Cavanagh PR. "Monitoring daily load stimulus during lunar missions." 2010 NASA Human Research Program Investigators' Workshop, Houston, TX, February 2-5, 2010. 2010 NASA Human Research Program Investigators' Workshop, Abstract Book, February 2010. , Feb-2010
Articles in Peer-reviewed Journals	Hanson AM, Gilkey KM, Perusek GP,Thorndike DA, Kutnick G, Grodsinsky CM, Rice AJ, Cavanagh PR. "Miniaturized sensors to monitor simulated lunar locomotion." Aviation, Space, and Environmental Medicine. Submitted, May 2010. , May-2010
Awards	Hanson A. "Space Camp Hall of Fame 2010 Inductee, August 2010." Aug-2010
Awards	Perusek G. "Silver Snoopy award, October 2009." Oct-2009

Awards	Perusek G. "Space Flight Awareness Award, October 2009." Oct-2009
Awards	Cavanagh P. "2010 Career Achievement Award, Biomechanics Interest Group, American College of Sports Medicine, June 2010." Jun-2010