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| **Fiscal Year:** | FY 2011 | **Task Last Updated:** | FY 10/12/2011 |
| **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<br>(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 | | |
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| **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:** | 09/30/2013 |
| **No. of Post Docs:** | 1 | **No. of PhD Degrees:** | 1 |
| **No. of PhD Candidates:** | 1 | **No. of Master' Degrees:** | 0 |
| **No. of Master's Candidates:** | 0 | **No. of Bachelor's Degrees:** | 2 |
| **No. of Bachelor's Candidates:** | 2 | **Monitoring Center:** | NSBRI |
| **Contact Monitor:** | | **Contact Phone:** | |
| **Contact Email:** | | | |
| **Flight Program:** | | | |
| **Flight Assignment:** | NOTE: End date changed to 9/30/2013 per NSBRI data submission (Ed., 3/4/2014) | | |
| **Key Personnel Changes/Previous PI:** | | | |
| **COI Name (Institution):** | Lang, Thomas ( University of California, San Francisco )<br>Grodsinsky, Carlos ( ZIN Technologies, Inc. )<br>Gilkey, Kelly ( NASA Glenn Research Center ) | | |
| **Grant/Contract No.:** | NCC 9-58-MA01603 | | |
| **Performance Goal No.:** | | | |
| **Performance Goal Text:** | | | |

**Task Description:**

1. Original project aims/objectives
One of the key questions that remains unanswered as we prepare to send humans to other planetary surfaces is the degree to which living and exercising in these reduced gravity environments 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 activity on the moon, Mars, or nearby asteroid, 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 the ~150 minutes assigned for exercise during a day resulted in loaded exercise. Given the continued loss of BMD observed in crew members after long-duration flights, this amount of loaded exercise is not enough to preserve an acceptable amount of bone strength.

The Specific Aims of the project include:

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

2) 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) Demonstrate the feasibility and validity of the approach in 1g, in 1/6g in the eZLS, and in another analog.

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

2. Key findings to date

- Foot forces suggest IVA lunar and Martian locomotion (walking, running, loping, hopping) alone may not be osteoprotective, and that a simulated lunar EVA (body weight plus ~200 Earth lbs of suit mass) locomotion may not be osteoprotective.

- Foot forces suggest that locomotion in a simulated Martian EVA (body weight plus ~200 Earth lbs of suit mass) 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, while running provides the highest foot forces in any one environment.

- The Artificial Neural Network (ANN) developed can precisely recognize lunar locomotor activity, which is useful during remote monitoring scenarios.

- An ankle mount configuration was tested in a small cohort (n=6). There is a marked decrease in signal magnitude between the ankle and in-shoe mounting. The ANN will need to be retrained with ankle mount data.

3. Impact of key findings on hypotheses, technology requirements, objectives, and specific aims of the original proposal

The wireless activity tracking device has been designed, manufactured, and tested in a series of studies in 1g, 1/6g, and 3/8g simulated environments. Initial data analysis is starting to reveal potential crew health risks to bone health maintenance in reduced gravity environments.

The sensor has been interfaced with a Smartphone to allow data collection in the field. This is an important step in moving towards flight readiness. The transition to the Smartphone interface has allowed a spin-off use of the wireless sensor system in a study aimed to reduce the rate of loading during running and ultimately reduce the rate of injury in female runners.

The NASA Human Research Program (HRP) has decided to not utilize the lunar bed rest model, and as such the system has not been tested in that analog as originally proposed. An alternative test environment such as a parabolic flight would be an ideal environment to test the system in, and the feasibility of conducting such a test is under review. The initial parabolic flight has demonstrated the system is ready for a full parabolic flight study. The study would provide the data needed to validate the system and compare to the results of the simulated reduced gravity environments test conducted in the eZLS. These tests would help to bring the activity sensor system to a high Technology Readiness Level (TRL=7). Final data analysis will help determine if additional software updates are necessary and help solidify drawings and design requirements that will be prepared for a CDR during Year 4.

4. Proposed research plan for the coming year

- Further enhance the Activity Recognition library to recognize activities collected in the ankle-mounted configuration and to include automated detection of additional mission critical tasks such as ladder climb, rock translation, platform jump down, squat exercise, and obstacle avoidance.

- Continue to 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).

- Utilize the Smartphone platform as a portable data logger that is capable of communicating with the wireless sensors and the BioNet software framework.

- Test the activity monitoring system on a parabolic flight as a validation of system operation in a simulated Martian (1 parabola), lunar (2 parabolas), and microgravity (22 parabolas) environment.

- Review results from a data-sharing arrangement with the Integrated Medical Model team at NASA Glenn who received Jump Down data from this study, and with colleague Joern Rittweger who received static hopping data to assess the loss of energy during a stiff legged hop at 1g, 3/8g, and 1/6g.

- Present data at the annual NASA Human Research Program Investigators' Workshop and other scientific meetings.

- Prepare manuscripts for publication to peer reviewed journals.

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| **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.<br>The small wireless sensors developed in this study have been useful in other research efforts. Attached to the ankle, the sensor is currently being used in a study examining gait characteristics of female runners engaged in regular, long-distance training programs who are prone to injury. The goal is to reduce the rate of loading during running. A program has been developed to provide real-time feedback from the sensors as displayed on a screen in front of the runner. The runner can adjust their gait to a desirable data point in real-time, or take a portable data logger with them into the field and analyze the data post-run to see how the in-lab training has helped to re-train their running gait. Additional work has been proposed to use the sensors to assess the trade-off between hardware complexity and information density in comparing activity data from patients with bilateral osteoarthritis of the knee and unilateral trans-tibial amputations. We believe there are many other applications as well. |
| **Task Progress:** | 1) COMPLETE DATA COLLECTION IN eZLS FACILITY: The largest human study to date has been completed in the Exercise Countermeasures Laboratory utilizing the eZLS facility at NASA Glenn Research Center. The activity monitoring system was tested at 1g, 3/8g, and 1/6g gravity loads in the eZLS during a variety of locomotor activities and functional tasks, including walking, running, loping, hopping, ladder climb, platform jump down, rock carry, obstacle course, static hopping, and squat exercise.<br>2) DEPLOY SOFTWARE UPDATES & INCREASE DATA THROUGHPUT: A comprehensive analysis of the wireless communication protocol and software configuration was conducted. It was determined that the sample frequency of the lower body sensor could be reduced from 1024Hz to 512Hz to assist in data throughput without significantly compromising science end points. The data structure was updated to an aggregation rate of 16, which also enhanced data throughput. These software updates have resulted in more reliable communication and more consistent data logging.<br><br>3) CONTINUED DATA ANALYSIS: Data analysis has been an on-going effort over the last year. Analysis of the data continues to suggest that the partial gravity environments of the moon or Mars will not alone be osteoprotective. Exercise will remain a necessary countermeasure in these environments. On-going work in this study will utilize the enhanced Daily Load Stimulus theory to help answer this question. It is certain that running in reduced gravity will still benefit from use of a subject load device to keep additional loading on the long-axis of the body and increase impact during locomotor exercises. Enhancements have been made to our activity recognition neural network programs. This will allow real-time reporting of a subject's daily activity and progress toward individual daily load stimulus target goals. Data sharing agreements have been made with members of NASA Glenn's Integrated Medical Model (IMM) team who is exploring input of the jump down data into their bone fracture risk model, and with Joern Rittweger of the German Aerospace Association to explore the energy losses experienced during static, stiff-legged hopping in 1g, 3/8g, and 1/6g environments. We will follow their progress in analysis of these data over the next year.<br><br>4) FLIGHT READINESS: Initial feasibility tests of the system aboard a parabolic flight have been performed courtesy of a colleague conducting a separate experiment. The system performed well during the flight. Plans to conduct a designated study aboard a dedicated parabolic research flight are being explored. Validation of the sensors in parabolic flight would advance our goals toward flight readiness. The sensors have successfully been interfaced with the Smartphone platform which can be used as a portable data logging system. Currently one sensor communicates with the phone at a time, and the feasibility of connecting two Bluetooth devices to one phone is being explored. |
| **Bibliography Type:** | Description: (Last Updated: 03/08/2018) |
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| **Articles in Peer-reviewed Journals** | Hanson AM, Gilkey KM, Perusek GP, Thorndike DA, Kutnick GA, Grodsinsky CM, Rice AJ, Cavanagh PR. "Miniaturized sensors to monitor simulated lunar locomotion." Aviat Space Environ Med. 2011 Feb;82(2):128-32. PubMed PMID: 21329028 , Feb-2011 |
| **Awards** | Hanson A. "AsMA Fellows Scholarship, May 2011." May-2011 |
| **Awards** | Hanson A. "NSBRI Postdoctoral Fellow, November 2010." Nov-2010 |
| **Awards** | Monitoring Bone Health Project Team. "NASA Group Achievement Award, June 2011." Jun-2011 |
| **Dissertations and Theses** | Genc KO. "The Effects of Altered Gravity Environments on the Mechanobiology of Bone: From Bedrest to Spaceflight." Dissertation, Case Western University, June 2011. , Jun-2011 |