Fiscal Year:	FY 2010	**Task Last Updated:**	FY 09/14/2010
PI Name:	Lang, Thomas F. Ph.D.		
Project Title:	An Integrated Musculoskeletal Countermeasure Battery for Long-Duration Lunar Missions		
Division Name:	Human Research		
Program/Discipline:	NSBRI		
Program/Discipline--Element/Subdiscipline:	NSBRI--Musculoskeletal Alterations Team		
Joint Agency Name:		**TechPort:**	Yes
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		
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Zip Code:	94143-0649	**Congressional District:**	8
Comments:			
Project Type:	Ground	**Solicitation / Funding Source:**	2007 NSBRI-RFA-07-01 Human Health in Space
Start Date:	09/01/2007	**End Date:**	04/30/2012
No. of Post Docs:	0	**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:	0	**Monitoring Center:**	NSBRI
Contact Monitor:		**Contact Phone:**	
Contact Email:			
Flight Program:			
Flight Assignment:	NOTE: Change in end date to 04/30/2012 (from 8/31/2011) per N. Gibbins/NSBRI (Ed., 9/19/2011)		
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Bloomberg, Jacob (NASA Johnson Space Center) Mulavara, Ajitkumar (USRA) Cavanagh, Peter (University of Washington) Grodsinsky, Carlos (ZIN Technologies, Inc.) Sibonga, Jean (USRA) Lee, Stuart (Wyle Integrated Sciences and Engineering Group) Spiering, Barry (California State University, Fullerton)		
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Task Description:

The degree to which the musculoskeletal system will maintain its integrity during prolonged sojourns in the reduced gravity of the lunar surface is presently unknown. It is, however, likely that without countermeasures there will be adaptive changes in muscle strength, bone mineral density, bone geometry, and sensorimotor status. When the combined effects of these changes are considered in the context of the construction and exploration tasks that will be performed at the lunar base or at other lunar sites, the risk of injury secondary to a fall is likely to be elevated. To address this fundamental problem, we have constructed a compact platform that integrates a time efficient integrated battery of countermeasures that can be conducted in the confines of the lunar habitat to minimize the risk of musculoskeletal injury. Ultimately, we expect that this battery of countermeasures will be validated using a 10° head-up bedrest simulation of a lunar mission, although it could also be tested in the standard 6 degree head down simulation. The specific objectives of the countermeasure battery are: to preserve muscle strength and cardiovascular fitness; to minimize decrements in postural stability, dynamic balance, and the ability to make corrective actions prior to a fall; to preserve functional performance on mission relevant tasks; and to minimize bone loss in the proximal femur. To accomplish these objectives, we have constructed a unique multi-functional countermeasure device which integrates cardiovascular, balance control, and resistance training functions. The stepper system provides cardiovascular exercise. When the stepper is locked down, the device may be utilized for lower body strengthening exercises such as squats, leg extensions and abductor/adductor exercises. To facilitate balance training, the stepper/resistive system is mounted on a Stuart Platform allowing 3D translations with a range of +- 10 cm and pitch/yaw/roll of +-10 degrees. In the second and third years of the study, based on a request from the Human Research Program, we have rescoped the project to carry out a training study in which we have evaluated the ability of CCD exercise to generate improvements in cardiovascular function and lower body resistive strength. 15 subjects underwent a 12 week training study which involved three weekly one hour sessions of cardiovascular and lower body resistive training. The cardiovascular training initially involved stepper exercise (5 subjects, 5% mean 12 week improvement in VO2max, non-significant change), but based on poor results we changed the aerobic protocol to bike exercise (10 subjects, 27% mean 12 week improvement in VO2max, p0.004), following a design simulation illustrating that a compact exercise bike could be folded into the footprint of the CCD. The 10 subjects exercised on the bike showed improvements ranging from 17%-38%. Leg press strength increased in all 15 subjects over 12 weeks (mean change 68%, range 47-85%, $p=0.0001$). Isokinetic strength measures showed variable response, with hip abduction, adduction and ankle plantarflexion strength increasing by 22%, 31% and 13% respectively (all $p<0.05$), but leg extension, leg flexion and hip flexion strength showed non-significant increases. Weight lifted by all subjects in each exercise increased significantly (all exercises $p=0.0001$) over the course of the study. Thus, from our training study data, we were able to conclude that CCD exercise was well tolerated, and could produce significant improvements in physical fitness, thus achieving the goal of the training study. Because one of the key goals of the project is to develop a novel exercise protocol in which squatting and hip ab/adduction exercise are employed to protect against hip bone loss, Dr. Cavanagh's group has adapted the Lifemodeler computational tool to simulate the effect of the muscle contractions produced by CCD squatting and ab/adduction exercise on the hip. This calculation incorporates the contractions of 47 muscles in the leg, and fully models all of the CCD exercise. To validate this model, Drs. Cavanagh and Hanson utilized the Orthoload Database, which contains results from studies of volunteers who received hip prostheses instrumented with strain sensors, allowing for calculation of hip loading forces associated with different exercises, including abduction and squatting. Simulating the exercise protocols used in the Orthoload Study, the Lifemodeler calculations produced hip loads that were in quantitative agreement with the measured Orthoload results, validating the use of Lifemodeler to estimate load forces on the hip associated with CCD exercises. These calculations showed that in 1g, CCD abduction exercise produced peak forces of four body weights on the hip, compared to 2.5 body weights for squatting exercise. On June 4, we presented the results of our training study and Lifemodeler work to the HHC Control Board. Based on the heavy load on the Bedrest Facility placed by the ongoing aRED studies, it was decided not to place the CCD into the bedrest study, but followup on our ab/adduction results were considered highly exciting and worthy of pursuit. Based on this evaluation, we plan for the final year of our grant, a detailed evaluation of the effects of ab/adduction exercise on hip bone strength and density as measured by quantitative computed tomography and finite element modeling. This study will compare standard aRED lower body exercise, combined aRED and ab/adduction and ab/adduction only, maintaining the same number of repetitions per group.

Rationale for HRP Directed Research:

Research Impact/Earth Benefits:

Outside of the space medicine community, there is a growing appreciation of the importance of an integrated musculoskeletal approach towards prevention of age-related skeletal fractures. Hip fractures, which represent the most serious manifestation of osteoporosis, rarely occur without falls, and the exercise strategies developed here could potentially be adapted to an older demographic, with the same compact exercise and balance countermeasures geared towards reduction of falls and bone loss in the growing population of elderly.

We believe that the compact characteristics of the CCD which are optimal for the spaceflight environment will also fulfill the needs for an in-house exercise device or for a nursing home. It is well known that impaired balance is associated with aging and with an increased risk of falling. Balance training exercise in the elderly has been shown to reduce risk of falls. In particular, resistive exercise has been shown to increase muscle strength in the elderly, and increases in muscle strength and balance are associated with improvements in performance and mobility, which are important determinants of quality of life in the elderly. Finally, by focusing on resistive exercise in the abductor and adductor muscle groups, this device is expected both to improve lateral balance and reduce the rate of age-related bone loss by stressing those muscle groups that attach at the hip and thus provide significant mechanical loads on the proximal femur.

In the past year, we demonstrated the efficacy of CCD exercise for improvement of muscle strength and aerobic fitness, and implemented and validated a computer simulation to estimate the loads on the hip exerted by lower body muscles during CCD exercise.

15 subjects completed our 12 week training study, which involved pre- and post training evaluation of VO2max, leg press strength, and isokinetic measures of knee extension and flexion strength, hip ab/adduction strength, hip flexion strength and ankle plantarflexion strength. 5 subjects underwent a 12 week training study which involved three weekly one hour sessions of cardiovascular and lower body resistive training. The cardiovascular training initially involved stepper exercise (5 subjects, 5% mean 12 week improvement in VO2max, non-significant change), but based on poor results we changed the aerobic protocol to bike exercise (10 subjects, 26% mean 12 week improvement in VO2max, $p<0.05$), following a 3D design simulation illustrating that a compact exercise bike could be folded into the footprint of

Task Progress:	the CCD. The 910 subjects exercised on the bike showed improvements ranging from 17%-38% (95 CI). Leg press strength increased in all 15 subjects over 12 weeks (mean change 68%, range 47-85% 95CI, $p=0.0001$). Isokinetic strength measures showed variable response, with hip abduction, adduction and ankle plantarflexion strength increasing by 22%, 31% and 13% respectively (all $p<0.05$), but leg extension, leg flexion and hip flexion strength showing non-significant increases. Weight lifted by all subjects in each exercise increased significantly over the course of the study. Thus, from our training study data, we were able to conclude that CCD exercise was well tolerated, and could produce dramatic improvements in physical fitness, thus achieving the goal of the training study. LifeModeler Calculations: Dr. Cavanagh's group has adapted the Lifemodeler computational tool to estimate the peak hip loads exerted by the muscle contractions produced by CCD squatting and ab/adduction exercise. This calculation incorporates the contractions of 47 muscles in the leg, and fully models all of the CCD exercises. To validate this model, Drs. Cavanagh and Hanson utilized the Orthoload Database, which contains results from studies of volunteers who received hip prostheses instrumented with strain sensors, allowing for calculation of hip loading forces associated with different exercises, including abduction and squatting. Simulating the exercise protocols used in the Orthoload Study, the Lifemodeler calculations produced hip loads that were in quantitative agreement with the measured Orthoload results, validating the use of Lifemodeler to estimate load forces on the hip associated with CCD exercises. These calculations showed that in 1g, CCD abduction exercise produced forces of four body weights on the hip, compared to 2.5 body weights for squatting exercise.
Bibliography Type:	Description: (Last Updated: 03/20/2017)
Articles in Peer-reviewed Journals	Streeper T, Cavanagh PR, Hanson AM, Carpenter D, Saeed I, Kornak J, Frassetto L, Grodsinsky C, Funk J, Lee SM, Spiering BA, Bloomberg J, Mulavara AP, Sibonga J, Lang T. "Development of an integrated countermeasure device for use in long-duration space flight." Acta Astronautica. Submitted, 2010. , Jul-2010