Fiscal Year:	FY 2012	**Task Last Updated:**	FY 01/08/2013
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:			
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Contact Monitor:		**Contact Phone:**	
Contact Email:			
Flight Program:			
Flight Assignment:			
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 problem, we 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. For 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 rescoped the project to carry out a training study in which we have evaluated the ability of combined countermeasure device (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, $p=0.004$), 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 $p=0.0001$). Thus, 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 a project goal is to develop an exercise protocol in which squatting and hip ab/adduction exercise protect against hip bone loss, Dr. Cavanagh's group adapted the Lifemodeler computational tool to simulate the effect of the muscle contractions produced by CCD squatting and ab/adduction exercise. LifeModeler incorporates contractions of 47 muscles in the leg, and fully models all of the CCD exercise. To validate, Drs. Cavanagh and Hanson used 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. These calculations showed that 1g CCD abduction exercise produced peak forces of 4 body weights on the hip, compared to 2.5 body weights for squatting. On June 4, we presented our training study and Lifemodeler work to the Human Health Countermeasures (HHC) Control Board. Based on the heavy load on the Bedrest Facility, the CCD was not placed into the bedrest study, but followup on our ab/adduction results were considered highly exciting. Based on this, we carried out a study to evaluate the effects of ab/adduction exercise on hip bone strength and density measured by quantitative computed tomography and finite element modeling. We compared standard Advanced Resistive Exercise Device (aRED) lower body exercise, combined aRED, and ab/adduction and ab/adduction only, maintaining the same number of repetitions per group, in a 16 week study, with three exercise sessions per week. Eight subjects were assigned to each group. aRED exercise resulted in increased spine and femoral neck bone density, as well as increased hip strength by FEM in the stance loading condition. Ab/Add exercise showed increased cortical bone volume at the trochanter and a borderline insignificant increase of hip strength by FEM in the fall loading condition. The combined group showed no changes. Thus, while AbAdd exercise appears to have a modest osteogenic effect, any application of this approach for prevention of hip bone loss would require additional exercise. Given the modest osteogenic effect we observed, the value of Ab/Adductor exercise may rest more in preservation of functional mobility and fall protection rather than bone loss prevention.
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 combined countermeasure device (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.

Task Progress:	In the past year, we carried out a study to evaluate the effects of ab/adduction exercise on spine bone density and hip bone strength and density measured by quantitative computed tomography and finite element modeling. In 24 healthy subjects, we compared standard aRED lower body exercise, combined aRED, and ab/adduction and ab/adduction only, maintaining the same number of repetitions per group, in a 16 week study, with three exercise sessions per week. Eight subjects were assigned to each group. At the end of the study, two subjects had dropped out, leaving us with 8 subjects in the Ab/Add group, and 7 subjects each in the aRED and combined groups. The three groups showed differential responses of spine and hip bone density and hip bone strength to 16 weeks of training. The group of subjects doing aRED-like exercise consisting of squats and deadlifts showed robust increases in vertebral trabecular bone density (9% $p<0.05$), as well as smaller but statistically significant increases in femoral neck integral bone density, femoral neck cortical bone density, and femoral neck cortical volume. No changes were observed in the trochanteric region of the hip. No changes were observed in trabecular bone at any subregion of the hip. Using non-linear finite element modeling based on the quantitative computed tomography (QCT) images, we estimated changes of hip whole bone strength under simulated conditions of single-legged stance and a posterolateral fall. We observed that in the aRED-like group, there was a 9% increase in stance strength ($p<0.05$) but not in fall strength. The group of subjects carrying out abduction and adduction exercise showed no changes in any of the vertebral bone parameters. Abduction and adduction exercise resulted in changes in cortical bone parameters at the trochanter, with a 4.4% increase ($p<0.01$) in cortical bone volume, and a marginally insignificant 2.1% increase in the trochanteric compressive strength index, which integrates bone density and size to provide a measure of the resistance of the trochanter to compressive loading forces. Finite element computed strength in simulated fall loading resulted in a borderline insignificant trend ($p=0.15$) towards an increase (5.5%). The group doing combined exercise (half aRED-like and half abduction and adduction) showed no changes in any of the bone parameters. Thus, our study showed that standard aRED exercises consisting of squats, deadlifts, and heel raises have an osteogenic effect on the spine and to a lesser extent on the hip, focused on the femoral neck. While abductor and adductor exercise appears to have a modest osteogenic effect (cortical bone formation) on the trochanter of the hip, the failure of the combined group to show any changes indicates that any adbuctor/adductor exercise needs to be carried out in addition to the standard exercise protocol. The modest effects hint that the proper focus of the exercise could be functional mobility and strength rather than bone protection.
Bibliography Type:	Description: (Last Updated: 03/20/2017)
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