Fiscal Year:	FY 2022	**Task Last Updated:**	FY 07/27/2021
PI Name:	Weaver, Ashley Ph.D.		
Project Title:	Quantitative CT and MRI-based Modeling Assessment of Dynamic Vertebral Strength and Injury Risk Following Long-Duration Spaceflight		
Division Name:	Human Research		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	HUMAN RESEARCH--Space Human Factors Engineering		
Joint Agency Name:		**TechPort:**	No
Human Research Program Elements:	(1) **HFBP**:Human Factors & Behavioral Performance (IRP Rev H)		
Human Research Program Risks:	(1) **Dynamic Loads**:Risk of Injury from Dynamic Loads		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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Zip Code:	27101-4101	**Congressional District:**	12
Comments:			
Project Type:	FLIGHT,GROUND	**Solicitation / Funding Source:**	2015-16 HERO NNJ15ZSA001N-Crew Health (FLAGSHIP, NSBRI, OMNIBUS). Appendix A-Crew Health, Appendix B-NSBRI, Appendix C-Omnibus
Start Date:	10/01/2016	**End Date:**	08/31/2022
No. of Post Docs:	0	**No. of PhD Degrees:**	0
No. of PhD Candidates:	3	**No. of Master' Degrees:**	1
No. of Master's Candidates:	2	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	0	**Monitoring Center:**	NASA JSC
Contact Monitor:	Whitmire, Alexandra	**Contact Phone:**	
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Flight Program:	ISS		
Flight Assignment:	NOTE: End date changed to 8/31/2022 per L. Barnes-Moten/JSC (Ed., 8/2/21) NOTE: End date changed to 8/31/2021 per NSSC information/S. Huppman/HRP (Ed., 2/25/2020) NOTE: End date changed to 2/1/2020 per NSSC information (Ed., 7/8/19)		
Key Personnel Changes/Previous PI:	None		
COI Name (Institution):	Stitzel, Joel Ph.D. (Wake Forest University) Tooze, Janet Ph.D. (Wake Forest University)		
Grant/Contract No.:	NNX16AP89G		
Performance Goal No.:			
Performance Goal Text:			

Task Description:	Prolonged periods of near weightlessness can cause damage to astronauts' musculoskeletal system. This damage can increase the risk of skeletal tissue failure (e.g., fractures, tears) when experiencing forceful, dynamic loads. Fractures of the spine during dynamic conditions such as launch or landing could cause a mission to fail. This study will measure this degradation of astronauts' vertebrae and spinal muscles during missions aboard the International Space Station (ISS). We will then determine the extent of vertebral weakening of crewmembers during long-duration missions. Changes in pre- and post-flight vertebral geometry, volume, cortex thickness, and bone mineral density will be measured from existing lumbar quantitative computed tomography (qCT) scans, as well as from planned qCT scans of the cervical, thoracic, and lumbar spine from nine ISS crewmembers. Likewise, the pre- and post-flight spinal muscle volumes will be analyzed using both existing magnetic resonance imaging (MRI) scans and planned MRI scans from nine ISS crewmembers. The qCT and MRI scans will be analyzed to determine structural and material changes in the cervical, thoracic, and lumbar vertebrae and the spinal muscles that indicate damage which could weaken these tissues. Our unique engineering approach will measure the loss of vertebral strength during spaceflight conditions and predict the risk of failure during traumatic, dynamic loading conditions such as launch or landing. Vertebral strength and risk for vertebral fracture and injury will be quantified in dynamic simulations using a full human body model that is constructed using structural and material data gathered from the pre- and post-flight medical images for each astronaut. This study has significance in quantifying and addressing risks of long-duration spaceflight, including vertebral injury from dynamic loads, vertebral fracture, early onset vertebral osteoporosis due to spaceflight, and impaired performance due to reduced spinal muscle mass, strength, and endurance. NASA Human Research Program (HRP) Student Augmentation Award (August 2021 report): For the Artemis missions to the lunar surface, NASA is planning for astronauts to employ a transfer vehicle to travel from the Gateway to low lunar orbit, a descent vehicle to land on the surface of the Moon, and an ascent vehicle to return to the Gateway. Since the Moon's gravity is 6 times lower than Earth's gravity, astronauts may pilot a lunar transfer vehicle in the standing posture similar to the Apollo missions, rather than a conventional seated posture. However, injury risks associated with different postures of astronauts under lunar spaceflight related dynamic loading conditions are not completely understood. There is a need to quantify and understand astronaut body kinematics and injury risks in the standing posture during vehicle launch, abort, and landing scenarios encountered on space missions. This gap has been addressed under the current student award by carrying out computational assessment of different postures on astronaut response under lunar space-mission related dynamic loading conditions using full-body simulation with a finite element human body model. This study quantified injury risk associated with different postures for future lunar missions and will help in identifying critical regions for spacesuit and space-vehicle design to minimize astronaut injury risk for the future lunar missions.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Microgravity induces similar spinal changes to those seen in the aging population and people with limited mobility. Demonstrating how the vertebral column changes in response to microgravity can aid in refining the diagnostic and treatment protocols of physicians on Earth. Additionally, assessing vertebral column strength using finite element modeling can provide future techniques for assessing the efficacy of osteoporosis treatments, which would particularly benefit older adults.
Task Progress:	The objectives of this project for the prior reporting year and the resulting progress on each objective is summarized below. Objective 1. Publish retrospective analyses of the pre- and post-flight spinal muscle changes. Retrospective quantitative computed tomography (qCT) scans from 16 crewmembers were analyzed to characterize back muscle geometry, volume, and fat infiltration changes in crewmembers of long-duration spaceflight. Results of this study have been published in a paper titled "Trunk Skeletal Muscle Changes on CT with Long-Duration Spaceflight" in the Annals of Biomedical Engineering journal. Retrospective magnetic resonance imaging (MRI) scans of the lower back of six crewmembers were used to analyze size and fat infiltration changes in the muscles that support the spine. Correlations between muscle change and onboard exercise were also analyzed. Results of this study have been submitted for publication. Objective 2. Acquire, process, and begin analyzing the prospective pre- and post-flight data to quantify spinal muscle and bone changes. Prospective qCT and MRI data collection has been completed for all nine of the enrolled subjects. Bone and muscle morphology and quality measures are underway and will continue for all the subjects. Objective 3. Develop methodology to develop astronaut-specific finite-element vertebrae models from prospective CT scan data and analyze changes in spinal injury risk from pre- to post-flight. Different morphing methodologies to develop subject-specific finite element vertebrae models from the prospective CT data have been compared and optimum morphing methods for all the vertebrae have been identified. Pre- and post-flight subject-specific finite element vertebrae models are being developed using these methods. Vertebral compression test simulations are being conducted to assess effects of space-induced changes on vertebral compression strength using these subject-specific vertebrae models. Objective 4. Develop and validate a new modular deformable spine simplified finite-element human body model to study the effects of musculoskeletal changes on astronaut spinal injury risk. To study the effects of musculoskeletal changes on astronaut spinal injury risk, a modular deformable spine finite element human body model is being developed by incorporating a deformable spine in the existing simplified human body model. This newly developed model has been validated against PMHS (post mortem human surrogates) and volunteer test data from the literature to assess its biofidelity. Objective 5. Assess effects of different postures on astronaut body kinematics and injury risk for future lunar missions. (HRP student augmentation award 2020). This year, the standing and seated postures of astronauts for future lunar missions have been simulated using full-body finite element human body models. From these simulations, kinematics and injury metrics for different body regions have been extracted and compared between the different postures and also against the injury assessment reference values from the literature.

Bibliography Type:	Description: (Last Updated: 08/02/2022)
Abstracts for Journals and Proceedings	Lalwala M, Devane K, Gayzik FS, Weaver AA. "Finite Element Analysis of the Effects of Active Muscles on Head Injury Evaluation in Spaceflight Landings." Presented at the Biomedical Engineering Society Annual Meeting, Virtual, October 2020. Abstracts. Biomedical Engineering Society Annual Meeting, Virtual, October 2020. , Oct-2020
Abstracts for Journals and Proceedings	Lalwala M, Koya B, Gayzik FS, Weaver AA. "Integration and Validation of a Deformable Spine into a Simplified Human Body Model." Presented at the NHTSA International Workshop on Human Subjects for Biomechanical Research, Virtual, October 2020. Proceedings of the Forty-Eighth NHTSA Workshop on Human Subjects for Biomechanical Research, October 2020. , Oct-2020
Abstracts for Journals and Proceedings	Lalwala M, Koya B, Gayzik FS, Stitzel JD, Weaver AA. "Computational Assessment of Body Kinematics and Injury Risks for Astronauts in a Standing Posture during Lunar Launch/Landing." Presented at the 2021 NASA Human Research Program Investigators' Workshop, Virtual, February 1-4, 2021. Abstracts. 2021 NASA Human Research Program Investigators' Workshop, Virtual, February 1-4, 2021. , Feb-2021
Abstracts for Journals and Proceedings	Dash S, Greene KA, Tooze J, Weaver AA. "Changes In Lumbar And Thoracic Spine Muscles In Long Duration ISS Missions." Presented at the 2021 NASA Human Research Program Investigators' Workshop, Virtual, February 1-4, 2021. Abstracts. 2021 NASA Human Research Program Investigators' Workshop, Virtual, February 1-4, 2021. , Feb-2021
Abstracts for Journals and Proceedings	Greene KA, Withers SS, Lenchik L, Tooze JA, Weaver AA. "Abdominal Skeletal Muscle Changes in Long-Duration Space Crew." Presented at the 2021 NASA Human Research Program Investigators' Workshop, Virtual, February 1-4, 2021. Abstracts. 2021 NASA Human Research Program Investigators' Workshop, Virtual, February 1-4, 2021. , Feb-2021
Abstracts for Journals and Proceedings	Lalwala M, Koya B, Gayzik FS, Stitzel JD, Weaver AA. "Computational Assessment of a Standing versus a Seated Posture on Body Kinematics and Injury Risks for Astronauts during Lunar Launch and Landing." Presented at the Global Human Body Models Consortium (GHBMC) User's Workshop, Virtual, April 2021. Abstracts. Global Human Body Models Consortium (GHBMC) User's Workshop, Virtual, April 2021. , Apr-2021
Abstracts for Journals and Proceedings	Lalwala M, Koya B, Newby N, Somers J, Gayzik FS, Stitzel JD, Weaver AA. "Computational Modeling of Astronaut Kinematics and Injury Risks in a Standing Posture during Lunar Launch and Landing." Presented at the Ohio State University Injury Biomechanics Symposium, Virtual, May 2021. Abstracts. Ohio State University Injury Biomechanics Symposium, Virtual, May 2021. , May-2021
Articles in Peer-reviewed Journals	Greene KA, Withers SS, Lenchik L, Tooze JA, Weaver AA. "Trunk skeletal muscle changes on CT with long-duration spaceflight." Ann Biomed Eng. 2021 Apr;49(4):1257-66. https:// ; PMID: 33604800; PMCID: PMC8207531 , Apr-2021
Dissertations and Theses	Dash S. "Quantifying the Musculoskeletal Changes due to Long-Duration Spaceflight using Medical Imaging." Master's Thesis. Virginia Tech – Wake Forest University School of Biomedical Engineering and Sciences, Winston-Salem, NC, May 2021. , May-2021