BIOMECHANICAL MODELING OF THE DEADLIFT EXERCISE TO IMPROVE THE EFFICACY OF RESISTIVE EXERCISE MICROGRAVITY COUNTERMEASURES

K.M. Jagodnik 1,2, W.K. Thompson 1, C.A. Gallo 1, J.K. DeWitt 3, J.H. Funk 1, N.W. Funk 4, G.P. Perusek 1, C.C. Sheehan 1, B.E. Lewandowski 1

1 NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, OH 44135; 2 Raymore College of Medicine, 1 Baylor Plaza, Houston, TX 77030
3 KBR Wyle, 2400 NASA Parkway, Houston, TX 77058; 4 ZIN Technologies, 6745 Engle Road, Airport Executive Park, Cleveland, OH 44130

INTRODUCTION & MOTIVATION
- Extended spaceflight typically results in the loss of muscular strength and bone density due to exposure to microgravity.
- Resistive exercise countermeasures have been developed to maintain musculoskeletal health during spaceflight.
- The Advanced Resistive Exercise Device (ARED) is the “gold standard” of available devices; however, its footprint and volume are too large for use in space capsules employed in exploration missions.
- The Hybrid Ultimate Lifting Kit (HULK) device, with its smaller footprint, is a prototype exercise device for exploration missions.
- This work models the deadlift exercise being performed on the HULK device using biomechanical simulation, with the long-term goal to improve and optimize astronauts’ exercise prescriptions, to maximize the benefit of exercise while minimizing time and effort invested.

PROJECT VISION

NASA’s Digital Astronaut Project Vision

The Digital Astronaut Project (DAP) implements vetted computational models to predict and assess spaceflight health and performance risks and to enhance countermeasure development by

- Partnering with subject matter experts to inform Human Research Program (HRP) knowledge gaps and countermeasure development decisions
- Modeling and simulating the adverse physiologic responses to exposure to reduced gravity and analog environments
- Ultimately providing timely input to mission architecture and operations decisions in areas where clinical data are lacking

RISKS & GAPS

Human Research Program Risks/Gaps Addressed

Risks:
- The Risk of Impaired Performance Due To Reduced Muscle Mass, Strength and Endurance
- The Risk of Bone Fracture
- The Risk of Early Onset Osteoporosis Due To Spaceflight

Gaps:
- What exercise protocols are necessary to maintain skeletal health, and can exercise hardware be designed to provide these?
- What is the minimum exercise regimen needed to maintain fitness levels for tasks?
- What is the minimum set of exercise hardware needed to maintain those fitness levels?

MOTION CAPTURE

- BTS Bioengineering Smart-D 12-camera motion capture system used
- Recorded data are digitized to translate physical data into biomechanical model in OpenSim

EXERCISE HARDWARE

Hybrid Ultimate Lifting Kit (HULK) 3

- Compressed air and piston assembly provides direct resistance
- Servo motor provides an eccentric overload
- Load cells in cables for load history
- Offers a wide variety of resistance exercises

MODELING METHODS

OpenSim Biomechanical Deadlift Model

- Human Data: 1 human subject performed 18 deadlift trials; load, load configuration, cadence and stance width were varied across trials
- Deadlift model consists of a modified version of the Full Body Model 1 in OpenSim
- Deadlift model is scaled to the test subjects
- Model is based on subject’s anthropometrics and motion capture data while in static pose and exercising
- HULK resistance load applied to model as a force at the bar ends
- Ground reaction force from force plates applied to model at the feet

EMG

- BTS Free EMG System: 16 wireless sensors placed according to http://seriam.org & Thought Technology Ltd. surface EMG placement guide
- DC component removal, rectify and envelop signal with RMS calculation
- Signals normalized to MVC

ACKNOWLEDGMENTS

This work is supported by the National Space Biomedical Research Institute through NCC 9-58. This work is funded by the NASA Human Research Program, managed by the NASA Johnson Space Center. Specifically, this work is part of the Digital Astronaut Project (DAP), which directly supports the Human Health and Countermeasures (H&C) Element. The DAP project is managed out of NASA/Glenn Research Center (GRC) by Dr. Nelly Gilkey as Deputy Project Manager. Beth Lewandowski, Ph.D., is the DAP Project Scientist, and John DeWitt, Ph.D., is the Deputy Project Scientist.

REFERENCES

3. High Eccentric Resistive Overload Device, Concept of Operations, ZIN Technologies, Cleveland, OH.

HULK DEADLIFT EXERCISE RESULTS

Inverse Kinematics Results: Joint Angles for Different Loading Configurations

Inverse Dynamics Results: Moments for Different Loading Configurations

DISCUSSION

- Inverse Kinematics & Inverse Dynamics analyses reveal similarities and differences between experimental loading configuration conditions to inform exercise prescriptions.
- This EMG data can be used to qualitatively compare muscle activity for different exercise parameters; these results can yield non-obvious conclusions about how exercise design affects the activity of specific muscles.
- The 16 recorded muscles are each affected differently by varying loading conditions; employ this knowledge to reason in designing exercise prescriptions to achieve effective activity for a wide range of muscles.

CHALLENGES & LIMITATIONS

- Improve consistency of EMG data over different data collection sessions by standardizing maximum voluntary contraction (MVC) recording
- Include more human subjects for a more representative and general data set
- Collect additional trials to achieve more confidence in results

FUTURE WORK

- Compare versions of deadlift model that include and exclude arms to determine the influence & utility of this model component
- Develop musculoskeletal model to better reflect human physiology
- Improve EMG data collection methods & analysis to yield quantitative results
- Further develop deadlift model to include shoulder stability

VERIFICATION & VALIDATION

- Ensure that root mean square (RMS) marker positions are within OpenSim guidelines
- Joint errors are within 2 degrees of experimental values
- Employ NASA-STD-7009 standards to assess credibility
- Compare deadlift modeling results with ground-based 1g deadlift exercise studies published in the literature

ACKNOWLEDGMENTS

This work is supported by the National Space Biomedical Research Institute through NCC 9-58. This work is funded by the NASA Human Research Program, managed by the NASA Johnson Space Center. Specifically, this work is part of the Digital Astronaut Project (DAP), which directly supports the Human Health and Countermeasures (H&C) Element. The DAP project is managed out of NASA/Glenn Research Center (GRC) by Dr. Nelly Gilkey as Deputy Project Manager. Beth Lewandowski, Ph.D., is the DAP Project Scientist, and John DeWitt, Ph.D., is the Deputy Project Scientist.

www.nasa.gov