COMPUTATIONAL MODELING USING OPENSIM TO SIMULATE A SQUAT EXERCISE MOTION

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National Aeronautics and Space Administration

MOTION CAPTURE

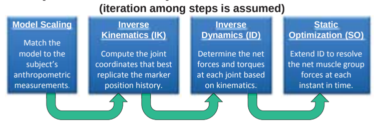

Motion Capture and Force Plates


OpenSim Model Squat Kinematics


OpenSim Model Squat Kinetics

OPENSIM MODEL WORK FLOW

OpenSim Descriptive Model Work Flow
(iteration among steps is assumed)



PROJECT VISION

NASA's Digital Astronaut Project Vision

The Digital Astronaut Project (DAP) implements well-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 AND GAPS

Human Research Program Risks/Gaps Addressed

Risk of Muscle Atrophy: Impaired performance due to reduced muscle mass, strength and endurance

- **Gap M7:** Can the current in-flight performance be maintained with reduced exercise volume?
- **Gap M8:** What is the minimum exercise regimen needed to maintain fitness levels for tasks?
- **Gap M9:** What is the minimum set of exercise hardware needed to maintain those fitness levels?

Risk of Loss of Bone Mineral Density: Early onset of osteoporosis and bone fracture

- **Gap Osteo 7:** Identify options for mitigating early onset osteoporosis before, during and after spaceflight. *(formerly Gap B15)*
- **Gap Osteo 6:** How do skeletal changes due to spaceflight modify the terrestrial risk of osteoporotic fractures? *(formerly Gap B1)*

SIGNIFICANCE

Significance

- Future exploration spacecraft will require a compact exercise device due to mass and volume constraints
- Different exercise configurations are being evaluated to determine effective countermeasures given mass, volume and power constraints
- Biomechanical models simulating the exercise motion will account for the variables associated with exercising

OBJECTIVES

Objectives

- Determine specific and anatomically localized outcomes: joint torques and forces, muscle forces for a known set of kinematics and loading
- Compare the effect exercising with a bar load applied to a single point at the back of the neck vs. a harness load distributed about four points on the back has on the muscle and joint loads

EXERCISE HARDWARE

Hybrid Ultimate Lifting Kit (HULK)[3]
(ZIN Technologies)

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


HULK Squat Exercise

Harness Simulated Load

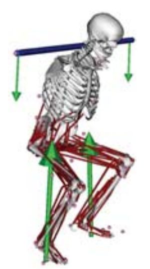
- Harness load is distributed over four points on the back
- Same load used as for bar
- 30% load at the shoulders
- 70% load at the lower back
- Motion capture data not taken using harness
- Same kinematics as bar load were used


Harness

MODELING METHODS

OpenSim Biomechanical Model

- Base model was scaled to the test subject
- 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
- Deep and parallel squats performed by subject

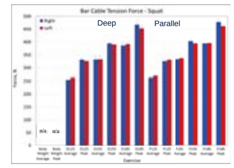

OpenSim Model of Squat Exercise with HULK Bar Load


Modified Loading Scheme to Simulate Harness Load

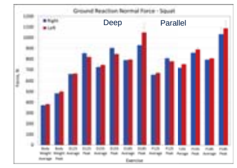
HULK SQUAT EXERCISE BAR AND HARNESS LOAD RESULTS

MEASURED DATA

HULK Squat Kinematics

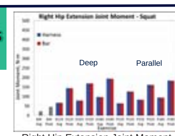


HULK Bar Cable Loads

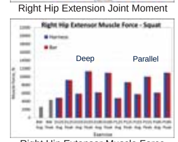


Ground Reaction Forces

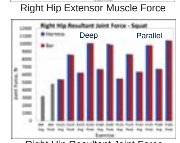
MODEL RESULTS HIP



Right Hip Extension Joint Moment

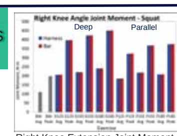


Right Hip Extensor Muscle Force

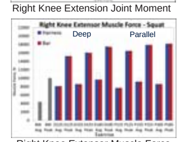


Right Hip Resultant Joint Force

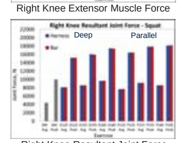
MODEL RESULTS KNEE



Right Knee Extension Joint Moment

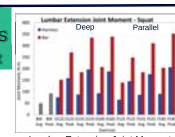


Right Knee Extensor Muscle Force

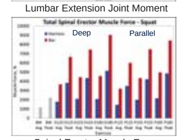


Right Knee Resultant Joint Force

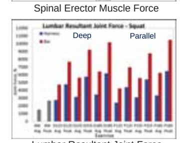
MODEL RESULTS LUMBAR



Lumbar Extension Joint Moment



Spinal Erector Muscle Force



Lumbar Resultant Joint Force

RESULTS DISCUSSION

Results Discussion

- The muscle and joint loads on the lower body are nearly the same for the bar and the harness because the bar kinematics were used for the harness analysis
- The load on the back lumbar area decreases with the harness because the load is distributed over multiple points on the back rather than the one bar contact point
- Deep squats do not necessarily load the knee more than parallel squats

VERIFICATION AND VALIDATION

Verification and Validation

- Ensure root mean square (RMS) marker positions are within OpenSim[1] guidelines
- Joint errors are within 2 degrees
- Compare calculated forces, muscle tensions and joint torques with reported measurements in the literature made under similar loading conditions
- Conform to NASA-STD-7009 standards to assess credibility[2]

ACCOMPLISHMENTS

Accomplishments to Date

- Motion capture data collected using the HULK exercise device with test subject performing multiple exercises
- The data was analyzed extensively using OpenSim
- The analysis resulted in vastly improved knowledge of OpenSim and how the program operates

CHALLENGES AND LIMITATIONS

Current Challenges and Limitations

- OpenSim models are relatively untested for the resistance exercise intensity being performed and the range of motion of the joints (knee) during a squat
- Outcomes are highly sensitivity to muscle model parameters
- DAP models are non-traditional applications of OpenSim

FUTURE WORK – MODELING

OpenSim Model

- Verify the muscle path and attach points are modeled correctly especially at the knee where the force is high during a squat
- Verify muscles are following the wrap surfaces in the model correctly during motion
- Verify the muscle parameters are correct for the demands required during a squat

DATA COLLECTION & ANALYSIS

Data Collection and Analysis

- Perform motion capture testing on a test subject using a harness with the HULK exercise device
- Collect foot ground reaction forces and the tensile cable force exerted through the harness
- Perform an OpenSim analysis on the data and compare to the bar analysis

ACKNOWLEDGEMENTS

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 (HHC) Element. The DAP project is managed out of NASA/Glenn Research Center (GRC) by DeVon W. Griffin, Ph.D., and Lealem Mulugeta of USRA Houston serves as the DAP Project Scientist.

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