COMPUTATIONAL BIOMECHANICAL MODELS OF SQUAT EXERCISE PERFORMED ON THE ADVANCED RESISTIVE EXERCISE DEVICE (ARED)


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BACKGROUND

NASA’s Digital Astronaut Project (DAP) Vision

The Digital Astronaut Project implements well-vetted computational models to predict and assess spaceflight health and performance risks, and enhance countermeasure development, by

- Partnering with subject matter experts to inform HRP knowledge gaps and countermeasure development decisions;
- Modeling and simulating the adverse physiologic responses to spaceflight on subjects exposed to vestibular and analog environments; and
- Ultimately providing timely input to mission architecture and operations decisions in areas where clinical data are lacking.

Methods: Bio-Mech., ARED & Integrated Modules

- Derived from motion capture (MoCap) and ground reaction force (GRF) data acquired on the ARED and training using modules exercise-experienced male subjects
- Constructed a forward dynamics module in LeibMOD (a plug-in to Adams™) using the performance of a 1-repetition maximum exercise
- Joint-only and joint/muscle configurations

ARED Device Module

- ARED is a resistance-training exercise device for the crew of the International Space Station (ISS)
- Rigid Body Dynamics module developed using Pro-E solid model files, engineering specifications, and engineering hardware verification data.
- Constructed in MS Adams™

Integration in LifeMOD

- Prior to model merge operation
- Present ARED exercise bar in serial model configuration
- Align reference frames of ARED and biomechanical modules
- Balancing of GRF’s (vs. measured GRF data) hierarchically determines proper co-alignment of the modules
- Visual inspection of model posture using Pro-E solid model and simulation analysis
- Model caliper marker weights are adjusted to obtain proper posture
- Physical contacts modeled as below

Joint and Muscle Training

- Adjustable parameters
  - Servo joints
  - Proportional gain
  - Derivative gain
  - Passive joints
  - Translational Stiffness/Damping
  - Rotational Stiffness/Damping
  - Muscles
  - Damping
  - Flex (P3, P4, and C16 model files)
  - FID joint
  - Insertion geometry

Other Steps

- Motion tracker agent
- Residual forces applied at pelvis in transverse directions to keep the model stable during the exercise
- Adjustable rotational and translational stiffness
- GRF data and joint angle errors iteratively verify the forward dynamics simulations
- With ARED
  - Without ARED – compare to existing biomechanical models
  - Adjust gain and stiffness damping until model is verified

Modeling of Contacts Between Biomechanical Module and ARED

- Contact plane
- Contact plane simulates节点 force plate measuring ground reaction forces
- Feets in contact with simulated force platform
- Grit contact with spinal marker on the upper bar
- Hands and upper back in contact with the bar

RESULTS: MUSCLE AND JOINT-ONLY MODULES

- Results of V&V of ASM-im in 1g per NASA-STD-7009
- Results Robustness
- Use History
- M&S Management
- People Qualifications
- Verification: Are the model results meaningful?
  - 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 for assessing the credibility of computational models in all V&V activities
- Validation: Are the model results correct?
  - Compare joint angles and displacements between the forward dynamics (driven by the trained module) and inverse dynamics (driven by MoCap data)
  - Vary the load setting on the ARED module and examine the resulting forces, muscle tensions and joint torques

DISCUSSION: ACCOMPLISHMENTS AND FINDINGS

- Accomplishments to date
  - Completed integrated modules for the 1g squat exercise in both joint-only (ASM-i) and muscle/joint (ASM-im) configurations.
  - Validated kinematics, joint forces/torques, muscle lengths and GRF
  - Validated model kinematics, dynamics and GRF’s versus literature on the squat exercise
  - Performed preliminary sensitivity analysis to quantify effects of perturbations to model parameters
  - NASA-STD-7009 credibility assessed for 1g, estimated for 0g

- Major Findings
  - Kinematic agreement is better during the ascent/descent phases than at the start/end of the movement
  - Joint forces are more accurately reproduced in the ASM-im model than the ASM-i
  - Relative muscle tensions among muscles mimic the activation patterns reported in the literature.
  - The 0g kinematics cannot be predicted by simply ignoring gravity and activating the VIs on the ARED.

FUTURE WORK

- Enhance ARED Squat Model
  - Obtain 0g motion capture data from ISS video to fully develop 0g ARED squat model
  - Quantify the effects of 0g and the VIs on exercise kinematics and dynamics
  - Analyze effects of posture, positioning and cadence on module outputs (kinematics, joint forces/torques and muscle tensions)
  - Overcome limitations in the 1g model such as small data set, artifacts and absence of upper body musculature

- Model Other Exercises on ARED
  - Single-leg Squat
  - Daeidit (pavlov model)
  - Heel Raise

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