Supplementing Biomechanical Modeling with EMG Analysis

Beth Lewandowski, NASA Glenn Research Center (Presenter)
Kathleen Jagodnik, National Space Biomedical Research Institute and Baylor College of Medicine
Lawton Crentsil, George Washington University
Bradley Humphreys, ZIN Technologies, Inc
Justin Funk, ZIN Technologies, Inc
Christopher Gallo, NASA Glenn Research Center
William Thompson, NASA Glenn Research Center
John DeWitt, Wyle Science, Technology and Engineering
Gail Perusek, NASA Glenn Research Center
Problem Statement

• Given the small size of the Multi-Purpose Crew Vehicle (MPCV) exercise device, will it be able to provide sufficient physiological loading to maintain musculoskeletal performance?

• Advanced Exercise Concepts Project Risk:
  – (EM2ED-003) The single-strap design will not allow for exercises to be performed as specified in the functional requirements document (AEC-REQ-001)

• Advance Exercise Concepts Project Requirement:
  – [MPCV-AEC29] **Required Resistive Exercises**: the device shall allow the crew member to perform squat, deadlift and heel raise exercises with proper body positioning (according to JSC-29558, “Resistive Exercise Description Document”)

• OpenSim biomechanical modeling performed to inform risk mitigation
Biomechanical Models in OpenSim

- OpenSim is open source biomechanical simulation software (https://simtk.org/home/opensim)
  - For development of musculoskeletal models
  - For dynamic simulations of movement and kinematics
  - For estimating muscle and joint kinetics

- DAP uses a modified version of the Arnold (2010) lower body model (Gallo, 2016)

- Biomechanical modeling process
  - Experimental kinematic and kinetic data used as input
  - OpenSim biomechanical models used to estimate joint torques and muscle forces

EMG Supplementing Biomechanical Modeling

- EMG – Electromyography – A record of the electrical potential generated by activated muscle cells

- EMG data will be used to increase the credibility of the OpenSim models
  - Through validation of calculated muscle activity
  - By increasing the input data pedigree

- Data use within OpenSim:
  - As constraints in the calculation of muscle activity
  - As input data instead of calculated muscle activity
EMG System in the GRC Exercise Countermeasures Lab

- BTS Free EMG 300
- 16 wireless sensor system
- Smart Capture/Analyzer and EMG Analyzer software
- Muscles recorded:
  - Tibialis Anterior
  - Vastus Medialis
  - Rectus Femoris
  - Vastus Lateralis
  - Hip Adductor
  - Rectus Abdominis
  - External Obliques
  - Medial Gastrocnemius
  - Lateral Gastrocnemius
  - Semitendinosus
  - Biceps Femoris
  - Gluteus Maximus
  - Multifidus
  - Longissimus
  - Middle Trapezius
  - Upper Trapezius
EMG Data Collection Procedure

- Muscles active during each exercise were selected for recording and verified with a literature search.


- Signal strength was verified to determine correct sensor placement.
Maximum Voluntary Contraction

- EMG collected during ~5s Maximum Voluntary Contraction (MVC) for each muscle
- Muscle produces maximum force during isometric, 0 velocity contractions
- MVC used to normalize EMG signals from exercise trials

Test Variables

- **Exercises**
  - Squat (SQ)
  - Deadlift (DL)
  - Heel Raise (HR)
  - Single-leg squat (SLS)

- **Stance Variation (Controlled with foot markings)**
  - Shoulder width (SQ)
  - Restricted to 21” (SQ)
  - Hip width (DL)
  - Sumo (DL)
  - Toes pointed in (HR)
  - Toes pointed out (HR)
  - Free foot forward (SLS)
  - Free foot back (SLS)

- **Loading Configurations**
  - Free weight
  - Long bar
  - Yo-yo Harness (SQ, HR, SLS)
  - T-Bar (DL, HR)
  - Glenn Harness

- **External Load**
  - Body Weight
  - Low – 10-12 rep max load
  - Medium – 6-9 rep max load
  - Heavy – 3-5 rep max load

- **Cadence (Controlled with metronome)**
  - 4s (SQ, DL, SLS)
  - 2.5s (SQ, DL, SLS)
  - 2s (HR)
  - 1s (HR)

Exercises performed according to JSC 29558, Resistive Exercise Description Document and an experienced athletic coach monitored subject form
Variables Compared in this Presentation

• Compare EMG time course and amplitude between different test cases
  – Deadlift
    • Free weight
    • HULK one-point loading with T-bar
  – Squat
    • Free weight
    • HULK one-point loading with Yo-yo harness
EMG Data Processing Procedure

- DC component removal and bandpass filter (20 – 450 Hz)
- Rectify and envelop signal with RMS calculation, using a 250 ms window
- Normalize to MVC
- Break signal into repetitions
- Determine the time-normalized, average repetition, with a ± standard error band around the average
- Determine average, peak and integrated EMG for each repetition

Results - Squat

- Gluteus Maximus
- Vastus Lateralis
- Rectus Femoris
- Hip Adductors
- Longissimus
- Tibialis Anterior
- Medial Gastrocnemius
- Lateral Gastrocnemius

Free Weight
HULK and Yo-yo Harness
Summary Graphs - Squat

Mean Activation Squat

Peak Activation Squat

iEMG Squat
Results - Deadlift

Gluteus Maximus

Vastus Medialis

Rectus Femoris

Hip Adductors

Longissimus

Tibialis Anterior

Medial Gastrocnemius

Lateral Gastrocnemius

Free Weight

HULK and T-Bar
Summary Graphs - Deadlift

Mean Activation Deadlift

Peak Activation Deadlift

iEMG Deadlift

FRWT  TBAR

LONG  GLUTE  ADD  RF  VM  GAM  GAL  TA

FRWT  TBAR

LONG  GLUTE  ADD  RF  VM  GAM  GAL  TA

FRWT  TBAR

LONG  GLUTE  ADD  RF  VM  GAM  GAL  TA

FRWT  TBAR
Discussion

• Differences in muscle activation observed when exercise is performed with free weights vs. a single-strap exercise configuration

• Limitations with EMG analysis
  – Only one subject used
  – EMG data collected across days
  – MVC not achieved in all cases

• Differences should be explored further to determine their significance
  – Through the full biomechanical analysis currently underway
  – Through a review of the results by subject matter experts

• The full biomechanical analysis is informing the AEC project risk by providing a means of early evaluation
Thank you

Questions?