Supplementing Biomechanical Modeling with EMG Analysis

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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)

**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

**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)

**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

- Piitulainen et al., Multi-channel electromyography during maximal isometric and dynamic contractions, J Electromyogr Kinesiol, 23, 302-310, 2013.
Results - Squat

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

![Graphs showing muscle activation](image)

**Legend:**
- Green: Free Weight
- Blue: HULK and Yo-yo Harness
Results - Deadlift

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

Free Weight
HULK and T-Bar
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?