Biomechanical Modeling Analysis of Loads Configuration for Squat Exercise

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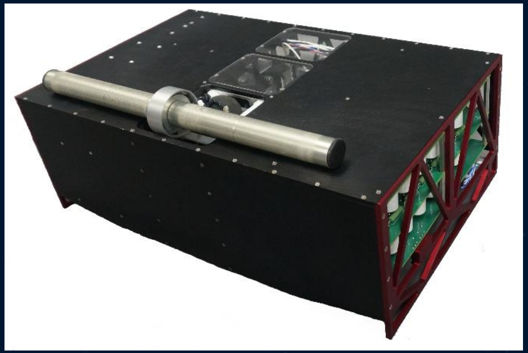
Introduction

- The ROCKY exercise device under development for the Multi-Purpose Crew Vehicle (MPCV) is a compact device with a single cable interface.
- The Digital Astronaut Project (DAP) is performing an analysis to estimate differences in kinematics and internal loads between exercises performed with the single cable configuration and Earth-based free weight exercises.
- Results of the analysis will aid in the determination of exercise device efficacy and aid in requirements definition.



Resistive Overload Combined with Kinetic Yo-Yo (ROCKY) Exercise Device (ZIN Technologies)

MPCV

Data Collection Methods

- Motion capture and ground reaction force data were collected as a subject performed squat exercises on the Hybrid Ultimate Lifting Kit (HULK) prototype exercise device with a single cable configuration and also while performing squats with free weights.
- All data was collected on one day in November, 2016 in the Exercise Countermeasures Lab at the Glenn Research Center.
- The test subject was male with a weight of 150 lbs. (68 kg) and a 68.5 inch (174 cm) stature.
- Squat exercise data was collected using three different load configurations including free weights, single cable T-bar and single cable Yo-Yo harness both interfacing with the HULK.
- Five repetitions at a load magnitude of 115 lbs. and a restricted stance of 13 inches deep by 21 inches wide were performed.

Load Configurations

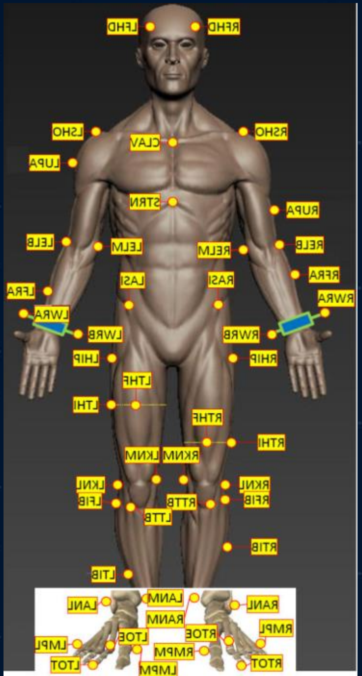
Free Weight

T-Bar

Harness

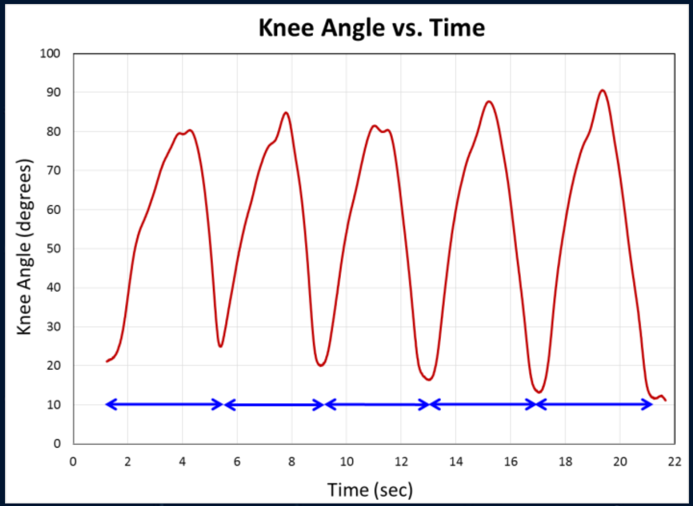
Data Collection and Analysis Methods

- Motion capture and force data.
  - Motion capture: BTS Smart-DX® (BTS Bioengineering, Brooklyn, NY) 12 camera system, 100 Hz sampling.
  - Ground Reaction Forces (GRF): BTS P-6000 force plates, 100 Hz sampling.
  - Device loads: HULK internal load cells at 200 Hz.
- Motion capture data was processed using the BTS Smart Tracker and Smart Analyzer software.
- Kinematics and internal loads were estimated using the OpenSim biomechanical modeling software from Stanford University.

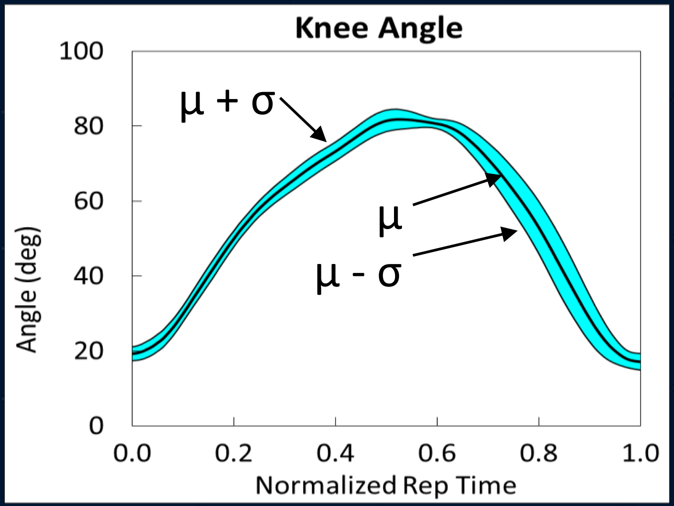


Procedures for Averaging Repetitions

- Normalized and averaged joint angle and joint moment results were calculated with OpenSim.
- The exercise repetitions were normalized and averaged by:
  - Determining the repetition start and stop times from a marker trajectory.
  - Resampling the outcomes onto a normalized time vector from 0.0 to 1.0.
  - Computing the ensemble average (μ) plotted as the thick black line.
  - Computing the standard deviation (σ) plotted as the blue band.



Knee angle vs. time for five cycles



Normalized average of five cycles

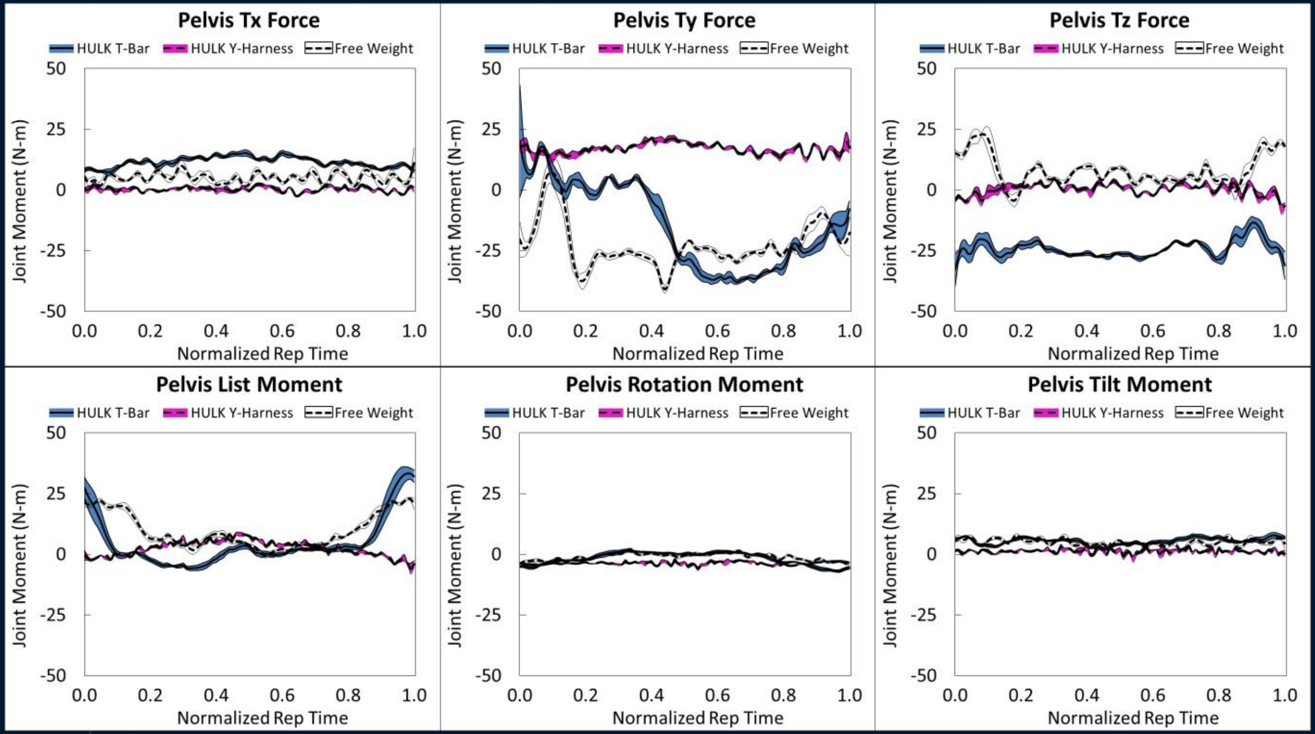
Statistical Analysis Methods

- A t-test analysis was performed to determine the significant differences between two sets of data.
- The t-test analysis was a sample by sample comparison between the paired waveforms of the 100 individual normalized samples.
- The t-test results in a p value revealing the probability that the differences observed were due to chance.
- A significant difference is defined when the p value remains less than 0.01 for 10 or more consecutive data samples (0.1 second).
- Tests were performed between the following configurations:
  - T-Bar vs. Y-Harness
  - Y-Harness vs. Free Weight
  - T-Bar vs. Free Weight

Results Verification

- All results are for the right side of the body. The results for the left side are comparable to the right.
- The residual forces and moments calculated from the data analysis were compared to the OpenSim guidelines.

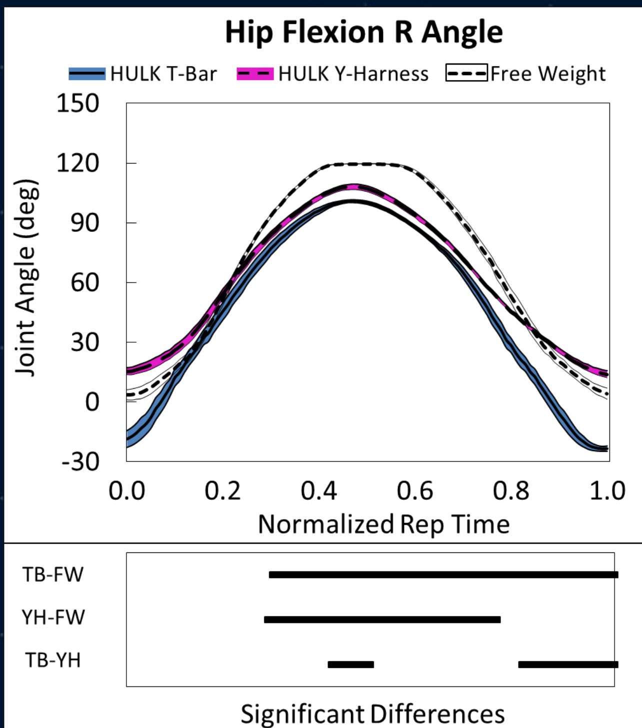
Load Configuration Comparison - 115 lb. load, Restricted Stance

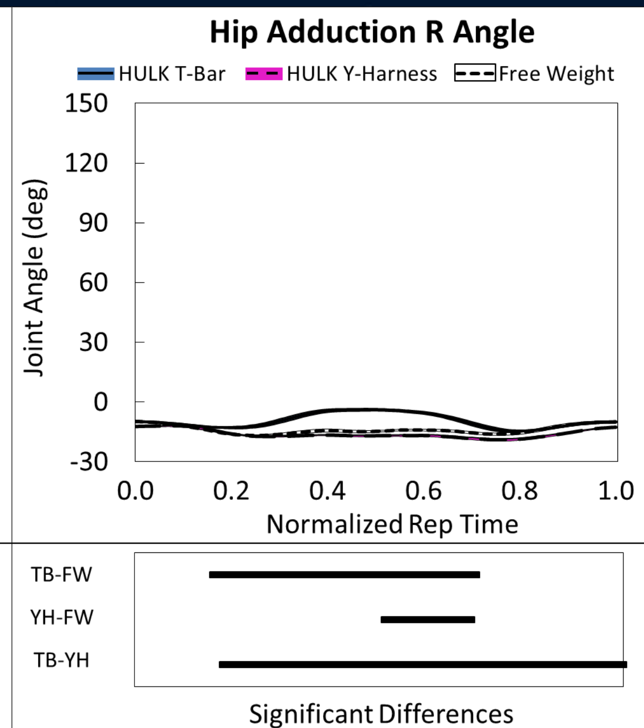


- Recommended residuals should be between +/- 25 N.
- FY and FZ are consistently between +/- 30 N for all trials.
- An investigation will be done to determine why the values are outside the range.

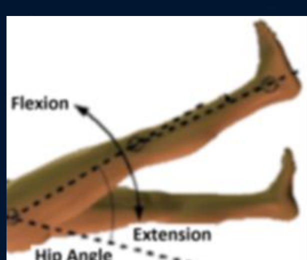
Squat Inverse Kinematics Results

Load Configuration Comparison - 115 lb. load, Restricted Stance



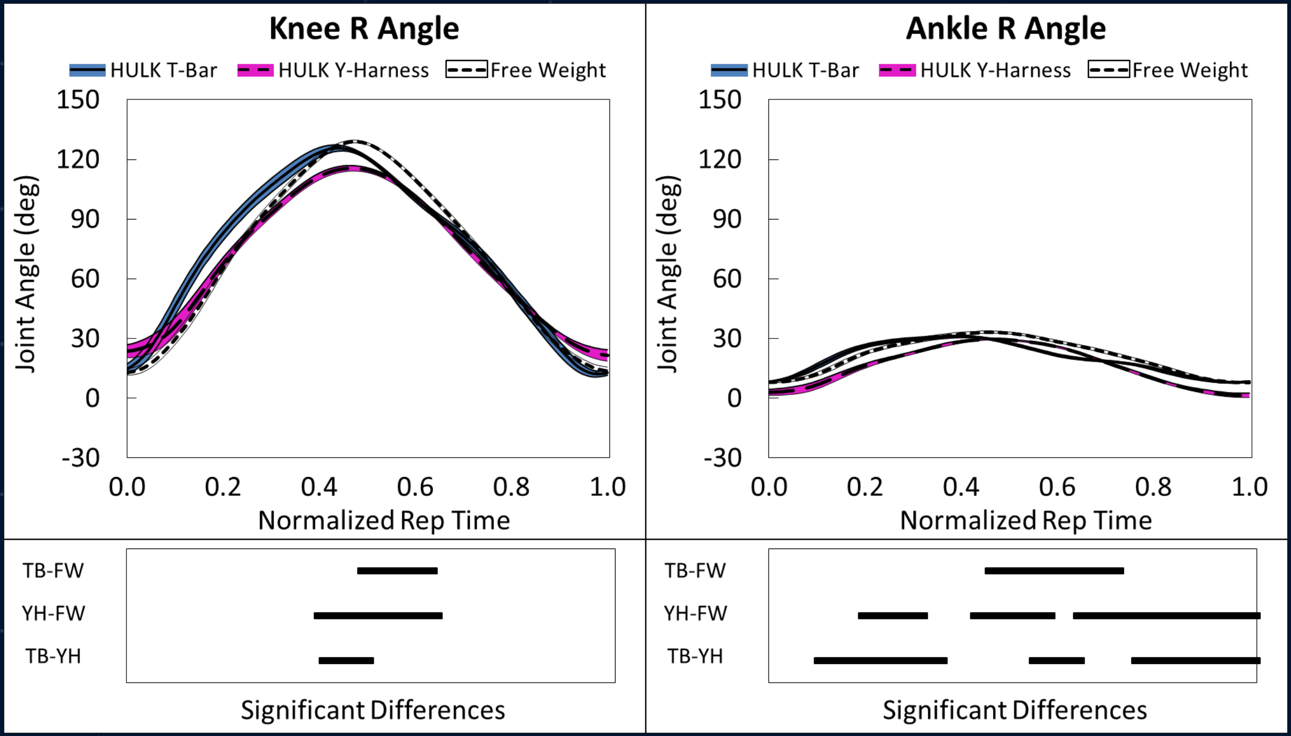


- Harness has the lowest hip adduction angle.
- T-bar results in a lower hip flexion angle than harness but over a wider range of motion.
- This is may be due to the different cable interface with the T-bar and harness and the test subject attempting to balance himself.

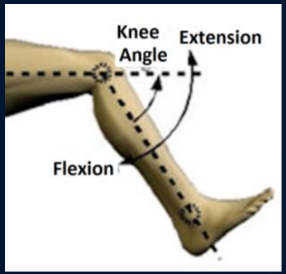


Squat Inverse Kinematics Results

Load Configuration Comparison - 115 lb. load, Restricted Stance

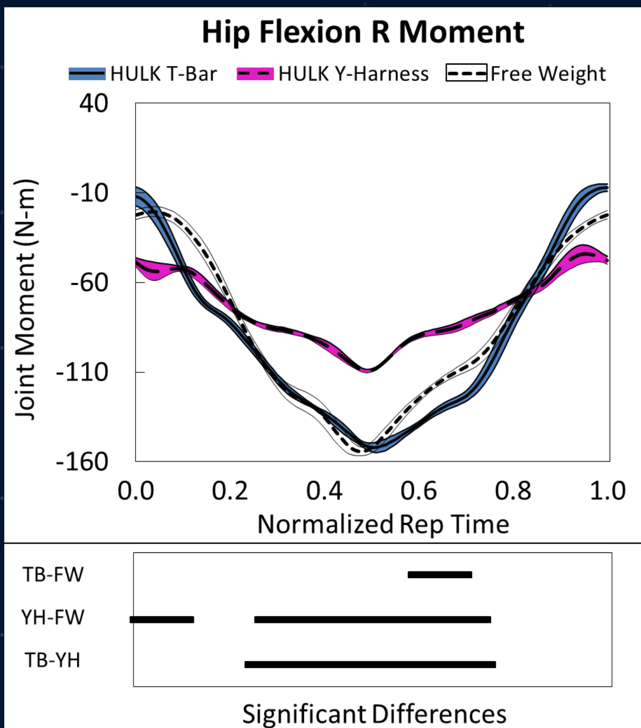


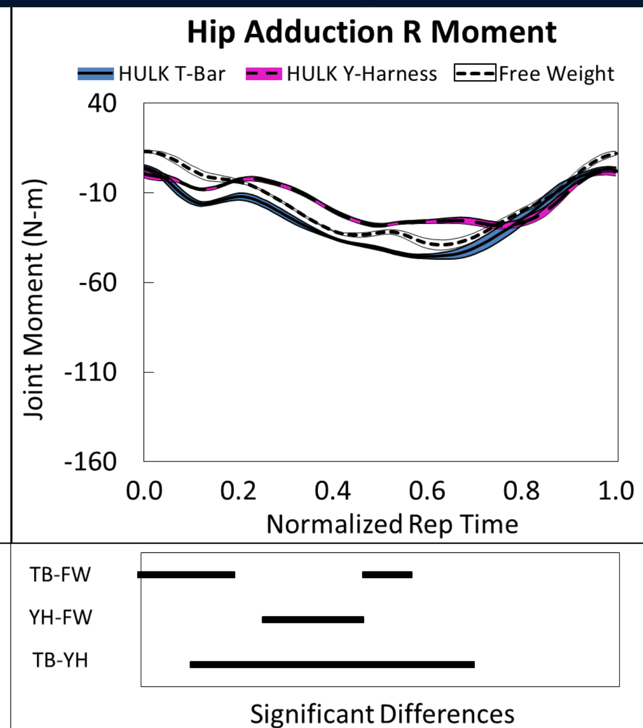
- Harness has lower knee and ankle angles because the test subject was not squatting as deep while using the harness.



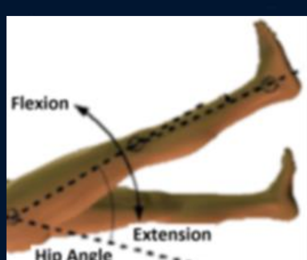
Squat Inverse Dynamics Results

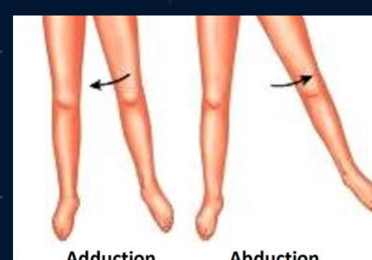
Load Configuration Comparison - 115 lb. load, Restricted Stance





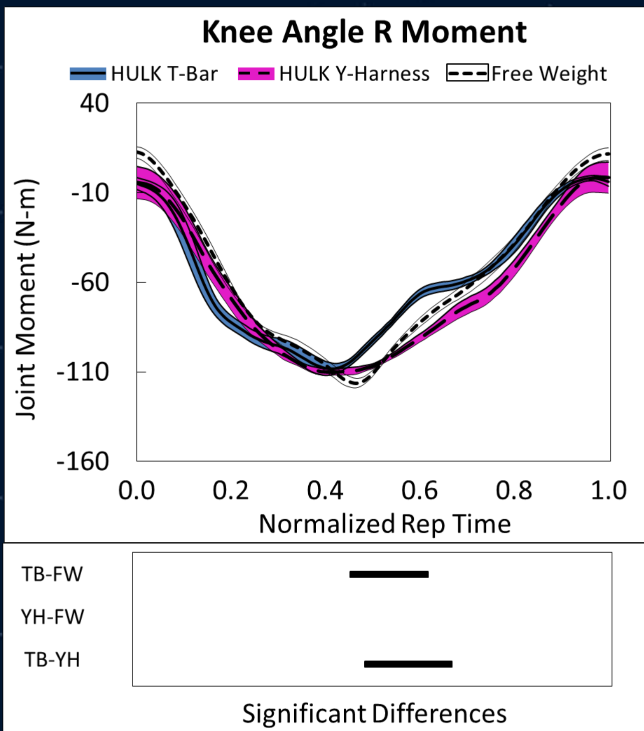
- Harness has a lower hip flexion moment vs. T-bar and free weight.

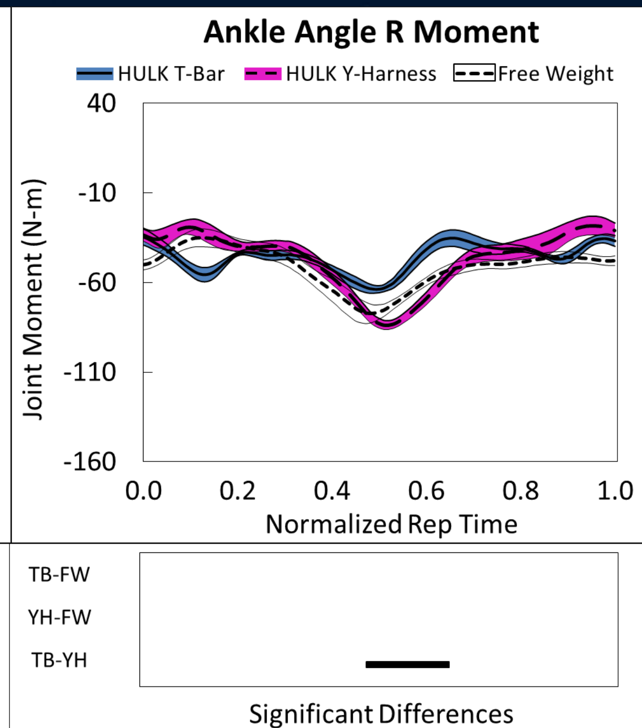




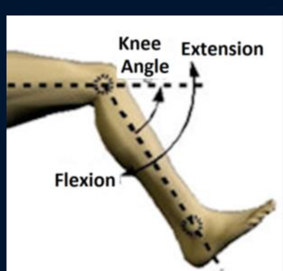
Squat Inverse Dynamics Results

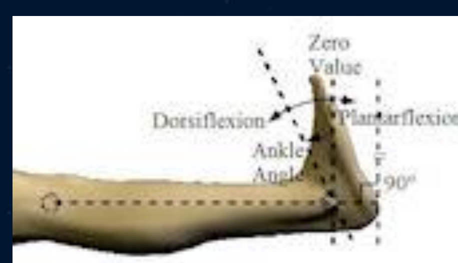
Load Configuration Comparison - 115 lb. load, Restricted Stance





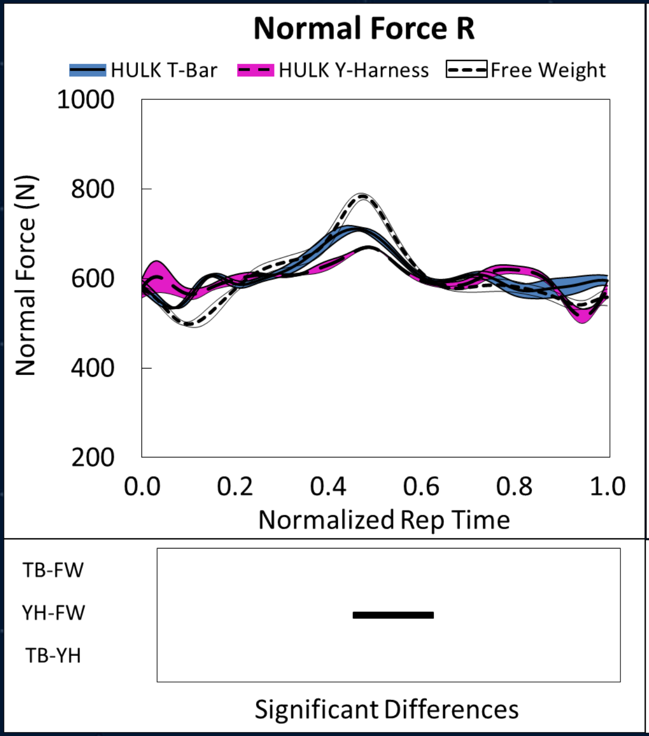
- Both knee and ankle moment show little difference between the exercises.

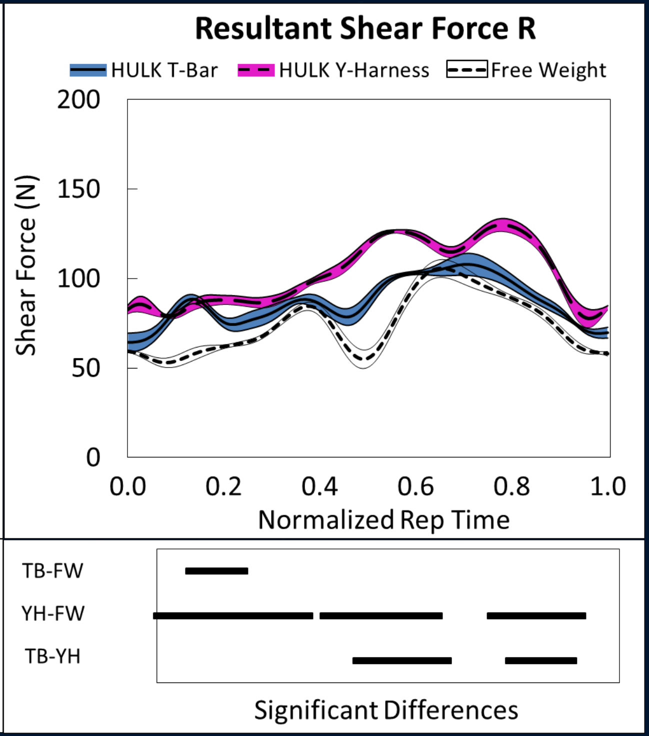




Force Plate Ground Reaction Forces

Load Configuration Comparison - 115 lb. load, Restricted Stance





- Harness has a higher shear force due to the test subject pushing back on the force plates to maintain balance while the cable pulls him forward.

Summary and Future Work

- This presentation provides partial results from the analysis performed to explore the differences between exercising with free weights and with a single cable exercise device.
- Differences were estimated for one subject at a single 115 lb. load.
- Use of a harness can allow astronauts to load the body with greater resistance in a safer manner. The test subject occasionally struggled holding the T-bar with a 115 lb. load.
- The OpenSim model used for this analysis has not been fully vetted using DAP project verification and validation methods.
- Future analyses will be performed at other load levels and with additional test subjects to determine consistency of the results.

Summary and Future Work

- Additional future work includes:
  - Obtaining expert opinions on the impact of the differences.
  - Providing the results as input to bone and muscle adaptation models for estimating chronic impact.
  - Supporting training studies performed with the compact exercise devices by providing internal loading estimates for exercises performed during those studies.
  - Aiding harness design requirements and operational exercise protocol development.
  - Investigate possible hardware or other issues responsible for the high residual values.