PORTABLE LOAD MEASUREMENT DEVICE FOR USE DURING ARED EXERCISE ON ISS

1 Andrea Hanson, 2 Brian Peters, 2 Erin Caldwell, 2 Nate Newby, 2 Joe Sinka, 3 Galen Kreutzberg, 4 Lori Ploutz-Snyder.

1 NASA Johnson Space Center
2 Wyle Science Technology & Engineering Group
3 National Space Biomedical Research Institute Summer Student
4 Universities Space Research Association
The Advanced Resistive Exercise Device (ARED) was installed on ISS in 2009. ARED provides up to 600 lb resistive loads, and accommodates ~40 different exercises. Reliable and accurate exercise data has not been available since installation. Crewmembers fill out spreadsheets and manually record exercise data. Manual logs are not historically as accurate as direct measurement. XSENS ForceShoes™ are the first COTS portable load monitoring device (PLMD) to offer high accuracy (~2%), ground reaction force measurements. PLMDs are not as widely used on the ground, but are favorable technology option when considering future exploration needs.
Each Force Shoe is instrumented with:
- Two six degrees-of-freedom (6-DOF) tri-axial force (Fx,y: \(\pm 130 \text{ lb}_{\text{force}}\), Fz: \(\pm 260 \text{ lb}_{\text{force}}\)), and torque (Tx,y,z: \(\pm 177 \text{ lb-in}\) ) sensors.
- Two XSENS MTx sensors that measure tri-axial acceleration (\(\pm 180 \text{ m/s}^2\) ) and inertial parameters (\(\pm 1200 \text{ deg/s}\))
- Powered by 4 AA-batteries
- Communication via Bluetooth or serial USB cable
- Shoes weigh \(\sim 2.5 \text{ lb}\) each, and are \(\sim 1.5\) inches tall
The better the tools, the better the science

ARED design requirement states that load measurements must be accurate within ± 1%. Center of pressure should be measured within ± 0.5 cm.

- Errors of ±0.5cm and ±1.0cm in CoP calculation result in errors (7% and 14%, respectively) in joint torque calculations [McCaw & DeVita, J. Biomech, 1995] and is compounded during biomechanical analysis.

Bone responds positively to an accumulation of mechanical input (ground reaction forces).

- Overestimating GRF could reduce training benefits to crewmembers.
- Underestimating GRF could result in unnecessary discomfort and physical exertion.
WHY WE NEED ACCURATE MEASUREMENT

• Safety

<table>
<thead>
<tr>
<th>Rx (lbs)</th>
<th>±</th>
<th>1%</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>-</td>
<td>198</td>
<td>190</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>202</td>
<td>210</td>
<td>220</td>
</tr>
<tr>
<td>300</td>
<td>-</td>
<td>297</td>
<td>285</td>
<td>270</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>303</td>
<td>315</td>
<td>330</td>
</tr>
<tr>
<td>400</td>
<td>-</td>
<td>396</td>
<td>380</td>
<td>360</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>404</td>
<td>420</td>
<td>440</td>
</tr>
<tr>
<td>500</td>
<td>-</td>
<td>495</td>
<td>475</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>505</td>
<td>525</td>
<td>550</td>
</tr>
<tr>
<td>600</td>
<td>-</td>
<td>594</td>
<td>570</td>
<td>540</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>606</td>
<td>630</td>
<td>660</td>
</tr>
</tbody>
</table>

• ARED can deliver up to 600 lb exercise loads.
• Original ARED calibration curves believed to be erroneous up to ~10%.
• Can lead to inefficient prescriptions when Rx is underestimated for safety. *It is best to take out the guess work!*
• Researchers are forced to accept increased risk of erroneous/incomplete exercise log data which limits interpretation of results outcomes.
• Risk of promoting a poor countermeasure protocol or not promoting a promising one with large uncertainty in the data.
• May prolong research to reach statistical conclusions (higher cost, longer schedules).
• Uncertainty in the data limits the ability to close HRP Gaps and mitigate Risks.
• Cannot write effective requirements documents for next gen exercise hardware.
• Cannot send our crews off on long duration exploration missions with any confidence that we know how to best protect them.
• Lost opportunity to learn after enormous investment in the ISS, HRP funded science, CMS hardware updates.
• Research informs operations.
EXERCISE DATA SUPPORTS MANY GROUPS

- Fulfill medical requirements.
- CMS Engineering troubleshoots hardware life cycles and anomalies.
- ISS structures group analyze impact to station structure.
- Enhance existing hardware, and inform future device requirements and design.
- Research: SPRINT, VO2 Max, Treadmill Kinematics, ARED Kinematics.
## GROUND & PARABOLIC FLIGHT TESTS

### Controlled ground evaluation

<table>
<thead>
<tr>
<th>Test Stand Load</th>
<th>Flight</th>
<th>Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean (±SD)</td>
<td>spread</td>
</tr>
<tr>
<td>Average % of Target (Fz, ±SD)</td>
<td>91.8% (±1.5)</td>
<td>90.4 – 94.4%</td>
</tr>
<tr>
<td>Average % of Target (Fx,y,z, ±SD)</td>
<td>105.0% (±1.8)</td>
<td>102.4 – 107.8%</td>
</tr>
<tr>
<td></td>
<td>N=6</td>
<td>N=51</td>
</tr>
</tbody>
</table>

### Parabolic Flight

<table>
<thead>
<tr>
<th>Bungee Load</th>
<th>Flight Day 2</th>
<th>Flight Day 4*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean (±SD)</td>
<td>spread</td>
</tr>
<tr>
<td>Average % of Target (Fz, ±SD)</td>
<td>99.3% (±2.8)</td>
<td>94.6 – 101.7%</td>
</tr>
<tr>
<td>Average % of Target (Fx,y,z, ±SD)</td>
<td>103.7% (±1.9)</td>
<td>101.8 – 106.6%</td>
</tr>
<tr>
<td></td>
<td>N=5</td>
<td>N=3</td>
</tr>
</tbody>
</table>

### HILT

<table>
<thead>
<tr>
<th>HILT Eval</th>
<th>HILT Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean (±SD)</td>
</tr>
<tr>
<td>Average % of Target (Fx,y,z, ±SD)</td>
<td>101.2% (±0.8)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HILT Eval</th>
<th>Function Checkout</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean (±SD)</td>
</tr>
<tr>
<td>Average % of Target (Wireless)</td>
<td>100.3% (±0.8)</td>
</tr>
<tr>
<td>Average % of Target (Wired)</td>
<td>100.6% (±1)</td>
</tr>
</tbody>
</table>
ISS FORCE SHOE ENGINEERING EVALUATION

• Hardware arrived to ISS on 39S (May 2014).
  • Wireless receiver will arrive on Orb2 (~July 3\textsuperscript{rd}).
• First data expected by June/July 2014.

• Aims of hardware demonstration:
  • 1: Use the ForceShoes\textsuperscript{TM} as a means to measure static loads on ARED.
  • 2: Collect dynamic data during ARED exercise to aid in the ongoing evaluation of the XSENS ForceShoe\textsuperscript{TM} to support HRP sponsored research.

Static load data will be collected on the T2 under stationary (non-motorized) conditions, to compare the ForceShoe\textsuperscript{TM} load measure to that recorded by the T2 load sensors.

• Inform transition of use for research, and modifications required to next generation PLMD for use as a daily operational tool.
FORCE SHOES HARDWARE

- Launched to ISS May 29th!
METHODS & ANALYSIS

• Each static load measure will be made in triplicate.
  • Up to 6 load levels with treadmill bungees.
  • Up to 20 load increments on ARED.
    • High and low bar static load measures.
  • Squat, deadlift, bicep curls.

• Data will be analyzed for:
  • Repeatability and Accuracy.
  • Tri-axial force components.

• Evaluate range/robustness of Bluetooth communication.
ESTIMATION OF LOAD DISTRIBUTION
RESEARCH TAKES SPACE!

SPACE DEMANDS INNOVATION!
TO THE MOON, MARS & BEYOND!

International Space Station

Habitable Volume: 15,000 Ft³

Orion Capsule

Habitable Volume: 316 Ft³
PORTABLE LOAD MONITORING DEVICES

XSENS
ForceShoe™

Nike+
Hyperworkout Shoe

Aurora Flight Systems:
Enhanced Dynamic Load Sensors –
Phase II SBIR

JSC Robotics Team:
X1/X2 Force Shoe
ADVANCED EXERCISE CONCEPTS

Design requirements: small footprint, low power usage, resistance and aerobic capabilities in one device... highly effective.
ISS IS A TEST-BED FOR FUTURE EXERCISE HARDWARE DESIGN

THANKS!

Contact Info:
andrea.m.hanson@nasa.gov
Acknowledgments

Exercise Physiology, & Countermeasures Lab
Brian Peters, Wyle
Lori Ploutz-Snyder, USRA
Erin Caldwell, Wyle
Nate Newby, Wyle
Joe Sinka, Wyle
Galen Kreutzberg, NSBRI Summer Student
Linda Loerch, NASA
Noel Skinner, Wyle

Funding
NASA Human Research Program
Barbara Corbin, NASA HRP
David Baumann, NASA HRP

Flight Projects Team
Stephanie Flint, NASA JSC
Anthony Rys, NASA JSC
Steve Huppman, Wyle

ISS Medical Projects
Alonso Fuentes, Lockheed Martin
David Sehrt, Lockheed Martin

Crewmembers
Inc. 40, 41, 42
ARED EXERCISES

### Traditional Bar Exercises:
- Heel Raises
- Front Squat
- Single leg squat
- Squat
- Sumo squat
- Bench press
- Shoulder press
- Shrugs
- Deadlift
- Romanian deadlift
- Sumo deadlift
- Biceps curl
- Bent over row
- Tricep extension
- Upright row
- Hip adduction
- Hip abduction
- Hip extension
- Hip flexion
- Lateral shoulder raise
- Rear shoulder raise
- Triceps kickback
- Wrist curl

### Traditional Cable Exercises:
- Biceps curls
- Bent over row
- Triceps extension
- Upright row
- Single arm row
- Side bend
- Crunches/Situps
- Cable deadlift
- Cable RDL
- Cable sumo deadlift
- Cable triceps extension
- Hip adduction
- Hip abduction
- Hip extension
- Hip flexion
RECOMMENDATIONS ON PHYSICAL ACTIVITY LEVELS FROM THE AHA AND ACSM

The American Heart Association Recommendations for Physical Activity in Adults

At least 30 minutes of moderate-intensity aerobic activity per week is equivalent to 150 minutes. OR

At least 25 minutes of vigorous aerobic activity per week is equivalent to 75 minutes. OR

A combination of the two.

AND

Muscle-strengthening activity 2 days per week for additional health benefits.

Add years to your life one step at a time.

Physical inactivity is the leading cause of death in the United States. Just 150 minutes of exercise a week reduces your risk of death by treating and preventing heart disease, high blood pressure, diabetes, stroke and more.

HOW DO ACSM/AHA RECOMMENDATIONS COMPARE TO ISS EXERCISE?

- **Recommended:**
  - 2 days of strength training
  - 150 min of moderate aerobic exercise per week
  - ~10,000 steps per day
- **Actual:**
  - 6 days muscle strengthening
  - ~180 minutes aerobic activity
  - 5-6K steps per day, 4 days a week are acquired
- **Intensity is absolutely key to success in order to reduce exercise time**

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARED</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>30 min</td>
<td>30 min</td>
<td>30 min</td>
<td>30 min</td>
<td>30 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEVIS</td>
<td></td>
<td>30 min</td>
<td></td>
<td></td>
<td></td>
<td>30 min</td>
<td></td>
</tr>
</tbody>
</table>