PORTABLE LOAD MEASUREMENT DEVICE FOR USE DURING ARED EXERCISE ON ISS

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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: ±130 lb\textsubscript{force}, Fz: ±260 lb\textsubscript{force}), and torque (Tx,y,z: ±177 lb\textsubscript{in}) sensors.
- Two XSENS MTx sensors that measure tri-axial acceleration (± 180 m/s\textsuperscript{2}) and inertial parameters (± 1200 deg/s).
- Powered by 4 AA-batteries
- Communication via Bluetooth or serial USB cable
- Shoes weigh ~2.5 lb each, and are ~1.5 inches tall
BENEFITS TO RESEARCH

• 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>
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<tbody>
<tr>
<td>200</td>
<td>-</td>
<td>198</td>
<td>190</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>+</td>
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<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>
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</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.
### Controlled ground evaluation

<table>
<thead>
<tr>
<th>Test Stand Load</th>
<th>Flight</th>
<th>Ground</th>
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</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>N=6</td>
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<td>N=51</td>
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### 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>
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<tr>
<td>N=5</td>
<td></td>
<td>N=3</td>
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### HILT

<table>
<thead>
<tr>
<th>HILT Eval</th>
<th>HILT Evaluation</th>
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</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 3rd).
- First data expected by June/July 2014.
- Aims of hardware demonstration:
  - 1: Use the ForceShoes™ 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™ to support HRP sponsored research.

Static load data will be collected on the T2 under stationary (non-motorized) conditions, to compare the ForceShoe™ 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

ISS Front Squat on ARED - Motion Corrected to Keep Feet Stationary

Hip Angle

Knee Angle

Ankle Angle

ISS ARED Front Squat Estimated Normal and Shear Forces

Time [s]
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!

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Flight Projects Team
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Anthony Rys, NASA JSC
Steve Huppman, Wyle
## ARED EXERCISES

<table>
<thead>
<tr>
<th>Traditional Bar Exercises:</th>
<th>Traditional Cable Exercises:</th>
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<tbody>
<tr>
<td>Heel Raises</td>
<td>Biceps curls</td>
</tr>
<tr>
<td>Front Squat</td>
<td>Bent over row</td>
</tr>
<tr>
<td>Single leg squat</td>
<td>Triceps extension</td>
</tr>
<tr>
<td>Squat</td>
<td>Upright row</td>
</tr>
<tr>
<td>Sumo squat</td>
<td>Single arm row</td>
</tr>
<tr>
<td>Bench press</td>
<td>Side bend</td>
</tr>
<tr>
<td>Shoulder press</td>
<td>Crunches/Situps</td>
</tr>
<tr>
<td>Shrugs</td>
<td>Cable deadlift</td>
</tr>
<tr>
<td>Deadlift</td>
<td>Cable RDL</td>
</tr>
<tr>
<td>Romanian deadlift</td>
<td>Cable sumo deadlift</td>
</tr>
<tr>
<td>Sumo deadlift</td>
<td>Cable triceps extension</td>
</tr>
<tr>
<td>Biceps curl</td>
<td>Hip adduction</td>
</tr>
<tr>
<td>Bent over row</td>
<td>Hip abduction</td>
</tr>
<tr>
<td>Tricep extension</td>
<td>Hip extension</td>
</tr>
<tr>
<td>Upright row</td>
<td>Hip flexion</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Lateral shoulder raise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear shoulder raise</td>
<td></td>
</tr>
<tr>
<td>Triceps kickback</td>
<td></td>
</tr>
<tr>
<td>Wrist curl</td>
<td></td>
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</table>
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 OR at least 25 minutes of vigorous aerobic activity per week OR a combination of the two

AND

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

© 2013
Learn more at heart.org/ActivityRecommendations.

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?

<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>
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<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>
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<tr>
<td>T2</td>
<td>30 min</td>
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<td>30 min</td>
<td>30 min</td>
<td></td>
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</tr>
<tr>
<td>CEVIS</td>
<td></td>
<td>30 min</td>
<td></td>
<td></td>
<td>30 min</td>
<td></td>
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</tr>
</tbody>
</table>

- **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**