WEARABLES FOR PHYSICAL AND COGNITIVE PERFORMANCE MEASURES

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EVOLVING DEFINITION OF WEARABLES

- “an item that can be worn.”
- “an advanced electronic device that is incorporated into an accessory worn on the body or an item of clothing”
- “a category of electronic devices that can be worn as accessories, embedded in clothing, implanted in the user's body, or even tattooed on the skin.”
MEASURES OF INTEREST

• **Physical measures:**
  - Activity levels over time
  - Accelerometers
  - Inertial Measurement Units (IMUs)
  - Motion Capture:
    - Range of motion
    - Duty cycles
    - Posture
  - Contact forces
  - Metabolic rate (VO2 and VCO2)
  - Muscle oxygenation and SpO2
  - Nutritional status:
    - Glucose
    - Lactate
    - Hydration level

• **Psychophysiology measures:**
  - Heart Rate (HR)
  - Heart Rate Variability (HRV)
  - Respiration Rate (RR)
  - Respiratory Sinus Arrhythmia (RSA)
  - Galvanic Skin Response (GSR)
  - Skin Temperature

• **Cognitive measures:**
  - Eye Tracking
  - Electroencephalogram (EEG)
  - Functional near-infrared spectroscopy (fNIRS)
PHYSICAL AND COGNITIVE PERFORMANCE OF ASTRONAUTS

• Exercise Countermeasures
• To Support and Maintain Physical and Cognitive Health

Muscle and Bone

Neurobehavioral

EFFECTS OF SPACE ON THE HUMAN BODY

SENSORIMOTOR
Sensorimotor disturbances can impair a person's movement control.

CARDIOVASCULAR
Decreases in vascular function may reduce oxygen intake, which could lead to poor performance of physically demanding tasks.

SPINE
A body gets a little taller in space due to the expansion of the vertebrae. Could cause back pain on return to Earth.

MUSCLE
Lack of gravity causes muscle fibers to shrink, leaving a person weaker.

BONES
Prolonged exposure to space can cause loss of bone mass and bone minerals.

RADIATION
The body is at risk for radiation sickness and cancer.

SLEEP
Loss of sleep can lead to fatigue and psychological problems.

SOURCE: NASA
Janet Laworraine, USA TODAY
PHYSICAL AND COGNITIVE PERFORMANCE OF ASTRONAUTS

- Extra-Vehicular Activities (EVAs)
- Working in Spacesuits (limited mobility and limited visibility)
- Performing Complex, Detailed Procedures for about 6 hours

Physical Work

Food + Oxygen

- VO₂ consumed oxygen rate

- Carbon Dioxide
  - + ATP (heat), storage
  - VCO₂ produced carbon dioxide rate

Cognitive Work

<table>
<thead>
<tr>
<th>EV1</th>
<th>BMRRM WORKSITE SETUP (01.00)</th>
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</thead>
<tbody>
<tr>
<td>1. Translate to green Hook HR _______</td>
<td></td>
</tr>
<tr>
<td>2. Attach green hook</td>
<td></td>
</tr>
<tr>
<td>3. Translate to BGA worksite</td>
<td></td>
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<tr>
<td>4. Slow BMRRM Cover on HR _______ with MULTIBallstack Scoop</td>
<td></td>
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<tr>
<td>5. Attach large hook of RET from BMRRM Cover tether point to handrail</td>
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<tr>
<td>6. Translate to APFR _______</td>
<td></td>
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<tr>
<td>7. Retrieve APFR, stow on BRT</td>
<td></td>
</tr>
<tr>
<td>8. Translate to WIF</td>
<td></td>
</tr>
<tr>
<td>9. Install APFR in WIF _______</td>
<td></td>
</tr>
<tr>
<td>- Locking collar black-on-black</td>
<td></td>
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<tr>
<td>- Pull / twist test</td>
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<tr>
<td>10. Perform:</td>
<td></td>
</tr>
<tr>
<td>- Glove Inspection</td>
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<tr>
<td>- HAP check</td>
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<table>
<thead>
<tr>
<th>EV2</th>
<th>BMRRM WORKSITE SETUP (01.00)</th>
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<tbody>
<tr>
<td>1. Translate to APFR in WIF _______</td>
<td></td>
</tr>
<tr>
<td>2. Slow Crewlock Bag bundle on APFR</td>
<td></td>
</tr>
<tr>
<td>3. Retrieve APFR, stow on BRT</td>
<td></td>
</tr>
<tr>
<td>4. Translate to green Hook HR _______</td>
<td></td>
</tr>
<tr>
<td>5. Attach green hook</td>
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- WARNING
  1. Stabilize equipment in place prior to transferring equipment to RAFF

- CAUTION
  TT Cannon connector: On detailed connectors, do not rotate collar or manipulate cable/connector using collar or connector tool (i.e., handle cable by cable)

- Translate to PYS5, retrieve 1 large (size 3²) Cannon Connector Cap from P5 (J153, J154, J159, or J160) or J5 (J43, J44, J45, or J46)

- Translate to ______ BGA worksite

- Install APFR in WIF _______ |
| - Locking collar black-on-black |
| - Pull / twist test |

- Temp stow Crewlock Bag #1 on HR _______ |

- Temp stow Cannon Connector cap in Crewlock Bag #1 (or to exterior for EV1 access)
H-3PO PROJECTS

Human Physiology, Performance, Protection, and Operations (H-3PO)

Technical Areas:
- Spacesuits and Exploration Operations
- Exercise Physiology and Performance
- Occupant Protection

1-g Monitoring
- Increasing Pre-flight baseline data collection

Physical and Cognitive EVA Simulations (PACES)
- APACHE - Hybrid Reality Environment

EVA Operations Software (EOS)
- Suite of tools for EVA decision support

Exploration Atmosphere – chamber study
- Higher Oxygen / Lower pressure environment
- Flammability Concerns
USING COMMERICAL OFF-THE-SHELF (COTS) WEARABLES

• 1-g Monitoring
  • Increasing Pre-flight baseline data collection

• Sleep duration and quality
  • Heart rate while sleeping

• Activity levels
  • Heart Rate while exercising

• Nutrition (manually logged)

Oura smart ring
Polar M600 smart watch
Garmin Vivoactive3 smart watch

Polar H10 Heart Rate sensor chest strap
CHALLENGES WITH COTS WEARABLES

• Limited choice in the resolution / sampling rates of devices’ sensors
• Individual preferences vary
• Limited “real estate” on the person
• Wire management and robustness
• Fit for a range of body shapes and sizes
• Spaceflight constraints:
  • Data syncing and transmission
  • Flammability and Radiation concerns
  • Lack of a gravitational vector (e.g. “steps” data is not meaningful in micro-G)
CHALLENGES WITH COTS WEARABLES

• Raw data is often not accessible, or requires multiple applications or custom code development
• Seldom provide access to full and complete data
  • Lack of standardization in sensor design
  • Lack of control over the format of data output
• Proprietary algorithms
• Software license fees
• API programming overhead
DATA INTEGRATION

• Integrating / combining data from multiple sources
• Post-processing to time sync and bin appropriately
• Loss of resolution when combining at the “lowest common denominator” resolution

Workarounds:
• Time syncing devices before data collection
• Event Markers for laboratory testing
PHYSICAL AND COGNITIVE EVA SIMULATIONS (PACES)

- Wearables Data Collection:
  - OxyCon – breath-by-breath analysis
  - HTC Vive Movement Trackers
  - Equivital - Activity, HR, RR
  - Bittium Faros 360 – Electrocardiogram (ECG) with 3-lead and 1-lead configs
  - Polar H10 Heart Rate sensor chest strap
PHYSICAL AND COGNITIVE EVA SIMULATIONS (PACES)

- Scenarios in development:
  - **Overhead Activity:**
    - Airlock / Egress Operations
    - Loading and Unloading Equipment
    - Airlock / Ingress Operations
    - EVA Close / Clean up
  - **Translation Activity:**
    - Ambulation on foot
    - Transporting Equipment
    - Transportation by driving
  - **Station Activity:**
    - Documentation / Inspection
    - Experimental Package Deployment
    - Handheld Instrumentation
    - Maintenance / Repair / R&R
    - Construction / Deploy

Diagram:
- Physical Workload
  - Low
  - High
- Cognitive Workload
  - Low
  - High
PHYSICAL AND COGNITIVE WORKLOAD

Physical Performance Measures

Psychophysiological Measures

Cognitive Performance Measures

• Heart Rate Variability (HRV)
• Respiration Rate (RR)
• Respiratory Sinus Arrhythmia (RSA)
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• Skin Temperature
ALGORITHM DEVELOPMENT

Physical workload

Cognitive workload

• **Psychophysiology measures:**
  • Heart Rate (HR)
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**Example:** Changes in heart rate and temperature occur when performing physical work and similar changes also occur when under psychological stress.

Algorithms for integrating and analyzing multiple data sources are required to differentiate between physical and cognitive changes.
CONCLUSIONS & FUTURE WORK

• Access to full and complete data is necessary
• Individual preferences vary, so we need standardization between various devices
• Operational environment of spaceflight puts constraints on:
  • Data syncing and transmission
  • Flammability and Radiation concerns
  • Lack of a gravitational vector (“steps” data is not meaningful in weightlessness)
• Algorithms are needed to infer physical workload and cognitive workload changes from various psychophysiological measures