EMG-Based Ergonomic Analysis of the Levitate Airframe at John Deere and Toyota Canada

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Shoulder Injuries in the Workplace

- Longest recovery time of any body part: 23 median days missed (Bureau of Labor Statistics, 2016)

- Common causes: Bursitis, tendinitis, tendon tears, impingement, instability, and arthritis (AAOS, 2010)

- Avoid sustained overhead postures
Threshold Limit Values (ACGIH, 2016)

Duty Cycle 10% = MVC 39.5%

Duty Cycle 50% = MVC 16.5%

MVC = -0.143 * ln(DC) + 0.066
Shoulder Injury Prevention

• Worksite modifications: Lower object, raise worker, reduce load, robotic & passive assistive devices

• Levitate Airframe exoskeleton designed to support arm weight during overhead shoulder postures

• Early Airframe testing using welding and painting simulators at Vermeer (Butler, 2016)
Purpose and Hypothesis

- **Purpose:** Assess Levitate Airframe exoskeleton during on-site job tasks

- **Hypothesis:** Deltoid muscle activity would be reduced with Airframe

- **Exploratory:** What job tasks appear to benefit more/less from Airframe use
Participants

• John Deere: 6 experienced participants, 2 work sites
  Toyota: 11 experienced participants

• John Deere: 6 job tasks (assembly, painting, parts hanging, welding)
  Toyota: 10 job tasks (overhead assembly)

• John Deere: 10 min of data per task, tasks measured 3 times
  Toyota: 12 min of data per task, 9 tasks had 10 cycles, 1 had 3 cycles
Experimental Protocol

**Consecutive Test**
- Task With/Without Exoskeleton
- Task Without/With Exoskeleton
- MVICs

**Fatigue Test #1 (John Deere)**
- Task Exoskeleton
- MVICs
- Workday With
- Task Exoskeleton
- MVICs

**Fatigue Test #2 (John Deere)**
- Task Without
- MVICs
- Workday Without
- Task Without
- MVICs

MVICs – maximum voluntary isometric contractions
Electromyography (EMG) Setup

- Delsys Trigno wireless EMG system
- Sensors placed bilaterally on deltoid, biceps, trapezius, and erector spinae
- Sampling frequency 1926 Hz
- MVICs: shoulder abduction, elbow flexion, trunk extension
- Signals inspected for non-physiological artifacts
EMG Processing and Analysis

• Bandpass Butterworth filter from 20-450 Hz*, rectified, low-pass filter at 10 Hz for linear envelope

• MVICs: maximum 1 second EMG amplitudes

• Job tasks: dominant arm, back averaged, maximum 10% and 50% (Toyota) 1 second EMG amplitudes, normalize by MVICs

• Paired t-tests: p < 0.05 (John Deere), p < 0.03 (Toyota)
John Deere – Maximum 10% EMG

- Deltoid: ↓ 8.1% MVIC, p = 0.08
  - Without: Red, Exoskeleton: Yellow

- Biceps: ↓ 4.8% MVIC, p = 0.05

- Trapezius

- Spinae

TLV

EMG Amplitude (%MVIC)

Deltoid | Biceps | Trapezius | Spinae
--- | --- | --- | ---
Without | Exoskeleton
John Deere – Fatigue at End of Shift

- Deltoid: ↑ 9.3 %MVIC, p = 0.06
- Biceps: ↑ 4.8 %MVIC, p = 0.09

TLV
John Deere – Deltoid Reduction by Task

Maximum 10% EMG
Toya – Maximum 10% EMG

![Graph showing EMG amplitude (%MVIC) for different muscle groups (Deltoid, Biceps, Trapezius, Spinae) comparing 'Without' and 'Airframe' conditions.](image)

- **Deltoid**:
  - Without: 30 %MVIC
  - Airframe: 25 %MVIC
  - TLV: 24.5 %MVIC
  - Significance: p = 0.02

- **Biceps**:
  - Without: 30 %MVIC
  - Airframe: 18 %MVIC
  - TLV: 18.5 %MVIC
  - Significance: p = 0.01

- **Trapezius**:
  - Without: 30 %MVIC
  - Airframe: 26 %MVIC
  - TLV: 25 %MVIC
  - Significance: p = 0.01

- **Spinae**:
  - Without: 30 %MVIC
  - Airframe: 23 %MVIC
  - TLV: 23.5 %MVIC
  - Significance: p = 0.01
Toyota – Maximum 50% EMG

<table>
<thead>
<tr>
<th>Muscle</th>
<th>EMG Amplitude (%MVIC)</th>
<th>Without</th>
<th>Airframe</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoid</td>
<td>15</td>
<td>10</td>
<td>↓ 4.4 %MVIC</td>
<td>0.001</td>
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<tr>
<td>Biceps</td>
<td>10</td>
<td>9.1</td>
<td>↓ 0.9 %MVIC</td>
<td>0.001</td>
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<tr>
<td>Trapezius</td>
<td>15</td>
<td>17.2</td>
<td>↓ 2.2 %MVIC</td>
<td>0.03</td>
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<tr>
<td>Spinae</td>
<td>15</td>
<td>16.1</td>
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<td></td>
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</tbody>
</table>

TLV
Toyota – Deltoid Reduction by Task

EMG Reduction (%MVIC)

<table>
<thead>
<tr>
<th>Job</th>
<th>EMG Reduction</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<tr>
<td>2</td>
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<td>7</td>
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<tr>
<td>9</td>
<td>1.0</td>
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<tr>
<td>10</td>
<td>0.5</td>
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</tbody>
</table>

Maximum 50% EMG
Discussion – Deltoid Amplitudes

- Exoskeleton reduced 10% maximum deltoid EMG for both John Deere and Toyota studies
- Exoskeleton reduced 50% maximum deltoid EMG for Toyota study
- Exoskeleton reduced deltoid EMG for 5 of 6 job tasks at John Deere
- Exoskeleton reduced deltoid EMG for 9 of 10 job tasks at Toyota
Discussion – Plausible Explanations

• Deltoid: Exoskeleton supports primary functions of shoulder flexion and abduction

• Biceps: Exoskeleton stabilizes shoulder to indirectly support elbow flexion

• Trapezius: Supports shoulder abduction, shoulder straps may increase activity, neck support may be beneficial

• Erector spinae: Exoskeleton support of deltoid reduces anterior lean, frame promotes more upright posture
Discussion – Strengths, Limitations

- On-site data strengths: Experienced workers, ‘real world’ job tasks, end of shift fatigue

- On-site data limitations: Limited video/force data, less control, time consuming

- Assessment strength: EMG scaled to participant capability

- Assessment limitation: Long-term exoskeleton effects unknown
Discussion – Recommendations

• Exoskeleton most likely to benefit repetitive overhead movements that challenge deltoid

• Maximum 10% and 50% EMG amplitudes may be useful for assessing low vs. high repetition jobs

• Important to consider EMG amplitudes relative to TLVs

• Assess specific job tasks for potential benefits of assistive devices
Questions?

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References