What are the Major Ergonomics Issues in Transportation

- Back Stress
- Wrist Stress
- Shoulder Stress
- Balance
- Fatigue induced muscle weakness
- Vibration

The Usual Suspects...

- Force
- Posture
- Repetition
- Duration
Ergonomic Concerns in Transportation

Ergonomic Exposure Assessment Methods
- Shoulder Moment
- Back Compressive Force
- Other Biomechanical Stresses
- Whole Body Vibration

Ergonomics/Biomechanics Lab Research
- Preliminary Results
## Purpose of Ergonomics Research

- Reduce exposure to known and suspected risk factors related to injury
- Study work related injuries and disorders to determine causal/associate factors to reduce risk

<table>
<thead>
<tr>
<th>Event</th>
<th>Trauma Type</th>
<th>Typical Medical Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sudden External Force</td>
<td>Impact/Acute Trauma</td>
<td>Contusions, Lacerations, Fractures, Amputations, Joint Subluxations, Concussion, etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chaffin, 1987</td>
</tr>
<tr>
<td>Volitional Activity Internal Force</td>
<td>Overexertion Trauma</td>
<td>Tendinitis, Tenosynovitis, Myofascial Disorders, Nerve Entrapment Disorders, Cumulative Trauma Disorders, Low-Back Disorders, etc.</td>
</tr>
</tbody>
</table>
Commercial Truck Driving Concerns

- Commercial truck drivers are at increased risk for low back pain\[1\].
  - The truck driving population appears to particularly have increased problems with back pain\[1,2\], possibly related to combined exposures.

- An association between prolonged sitting, whole body vibration and occupational low back pain\[3\] has been reported, thus there may be an interaction between these exposures
  - Sitting may confound the relationship to some degree.

- Road conditions appear to result in the greatest magnitude of vibration exposures\[4\].
## Nonfatal Occupational Injuries and illnesses (Transportation)

<table>
<thead>
<tr>
<th>Industry</th>
<th>Total Recordable cases ($10^3$)</th>
<th>Cases with days away from work($10^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air transportation</td>
<td>35.2</td>
<td>19.4</td>
</tr>
<tr>
<td>Rail transportation</td>
<td>-</td>
<td>3.8</td>
</tr>
<tr>
<td>Water transportation</td>
<td>2.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Truck transportation</td>
<td>77.3</td>
<td>50.3</td>
</tr>
<tr>
<td>Transit transportation</td>
<td>16.6</td>
<td>9.9</td>
</tr>
<tr>
<td>Pipeline transportation</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Scenic and Sightseeing transportation</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Support activities for trans.</td>
<td>22.8</td>
<td>14.6</td>
</tr>
<tr>
<td>Couriers and messengers</td>
<td>37.8</td>
<td>25.4</td>
</tr>
<tr>
<td>Warehousing and storage</td>
<td>43.0</td>
<td>30.5</td>
</tr>
</tbody>
</table>

(BLS, 2008)
Biomechanical Stresses

Shoulder Moment
Back Compressive Force
Metabolic/Energy
Whole Body Vibration
Illustration of a Simplified Biomechanical Approach to Estimate Shoulder Moment

A Simplified Biomechanical Analysis Method (Utah Model)
SHOULDER MOMENT WORKSHEET

BW = BODY WEIGHT (lbs) 

D = HORIZONTAL DISTANCE FROM LOAD TO SHOULDER JOINT (in) 

L = LOAD WEIGHT (lbs) 

A = Forearm angle in degrees 

B = Upper arm angle in degrees 

\[ M_t = M_b + M_f \]

Where:

\[ M_b = 0.0115 \times D \times BW = 0.0115 \times \_ \times \_ = \_ \]

\[ M_f = 0.5 \times D \times L = 0.5 \times \_ \times \_ = \_ \]

\[ M_t = M_b + M_f = \_ \text{(in lbs)} \]

Note that:

\[ M_b = \text{Moment at the shoulder due to the weight of the arm;} \]

\[ M_f = \text{Moment at the shoulder due to the weight of the load in the hands;} \]

\[ M_t = \text{Total moment at the shoulder} = M_{\text{task}} \]

Substitute BW, D, L, into the above equation to estimate the total moment required at the shoulder (\( M_{\text{task}} \) expressed as in lb). Record the value from the tables based on angles A and B (\( M_{\text{cap}} \)). The table value is the maximum strength of an average male/female in that posture. The ratio of \( M_{\text{task}}/M_{\text{cap}} \) represents the required shoulder moment as percent of the maximum for the average male/female.

\[ \frac{M_{\text{task}}}{M_{\text{cap}}} = \_ \quad \text{(from above)} \]

\[ M_{\text{cap}} = \_ \quad \text{(from table based on angles A, B)} \]

\[ \frac{M_{\text{task}}}{M_{\text{cap}}} = \_ \times 100.0 = \text{percent maximum} \]

Ratios below .5 (task required shoulder moment is less than half the maximum for the average male/female) will not present a hazard for most workers unless the frequency is quite high, and ratios above 1.0 (task required shoulder moment exceeds the maximum for the average male/female) will present a hazard for many members of the workforce.
## Shoulder Moment Capability (in lb)

<table>
<thead>
<tr>
<th>Forearm angle (A)</th>
<th>45</th>
<th>90</th>
<th>135</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upperarm angle (B)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>632</td>
<td>691</td>
<td>751</td>
<td>810</td>
</tr>
<tr>
<td>45</td>
<td>598</td>
<td>658</td>
<td>717</td>
<td>777</td>
</tr>
<tr>
<td>90</td>
<td>565</td>
<td>624</td>
<td>684</td>
<td>743</td>
</tr>
<tr>
<td>135</td>
<td>531</td>
<td>591</td>
<td>650</td>
<td>710</td>
</tr>
<tr>
<td>180</td>
<td>498</td>
<td>557</td>
<td>617</td>
<td>676</td>
</tr>
</tbody>
</table>

50% Male

<table>
<thead>
<tr>
<th>Shoulder Moment Capability (in lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>45</td>
</tr>
<tr>
<td>90</td>
</tr>
<tr>
<td>135</td>
</tr>
<tr>
<td>180</td>
</tr>
</tbody>
</table>

50% Female
Risk Evaluation – Back Compressive Force

NIOSH guidelines:

**Low Risk**
BCF < 3400 N

**Moderate Risk**
3400 N < BCF < 6400 N

**High Risk**
BCF > 6400 N

### Spinal Segment Compression Tolerances (kN)

<table>
<thead>
<tr>
<th>Age (Years)</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>4.4</td>
<td>6.0</td>
</tr>
<tr>
<td>30</td>
<td>3.8</td>
<td>5.0</td>
</tr>
<tr>
<td>40</td>
<td>3.2</td>
<td>4.1</td>
</tr>
<tr>
<td>50</td>
<td>2.5</td>
<td>3.2</td>
</tr>
<tr>
<td>60</td>
<td>1.8</td>
<td>2.3</td>
</tr>
</tbody>
</table>

NIOSH Limits of 3.4 kN for both genders and all ages

Jäger et al. 2001
LBCF = 0.0167 \times (BW)(H) \times \sin\theta + 0.145(L \times HB) + 0.8[(BW/2) + L] + 23

WHERE:

BW = body weight (kg)
H = worker height (cm)
\theta = torso angle with vertical
L = load weight (kg)
HB = horiz. dist. From hands to L5/S1 (cm)
0.8 = \cos 40^\circ \ (L5/S1 \ inclination)

*R^2=0.96 \ compared \ to \ 3DSSPP
Slope = 0.99

Merryweather et al., 2009
3D Static Strength Prediction Program
Dynamic Lifting Model

\[ \vec{F} = m \vec{a} \]

\[ \vec{F}_{ubw} = m_{ubw} (\vec{a}_g + \vec{a}_{dub}) \]

\[ \vec{F}_M = \sum_{d_{es}} \vec{M} \]

\[ \vec{F}_{ua} = m_{ua} (\vec{a}_g + \vec{a}_{dua}) \]

\[ \vec{F}_{la} = m_{la} (\vec{a}_g + \vec{a}_{dla}) \]

\[ \vec{F}_L = m_L (\vec{a}_g + \vec{a}_{dL}) \]

Merryweather et al., Journal of SH&E Research Winter 2008
Static vs. Dynamic Response?

Force Neglected when using static models

![Graph showing the comparison between dynamic and static back stress over time](image)
Load Displacement Velocity Constant (LDVC)

$$UBCF_d = UBCF_s \times LDVC$$

- Better able to predict actual peak BCF while lifting
- There is some indication that Peak BCF is a reasonable predictor for risk of back injury, but cumulative loading is also important

Merryweather et al, 2008
Cumulative Load Estimation

Stoop Lift and Lower

Dynamic Load Component

Cumulative Static Load

Time (sec)

Newtons

Resultant GRF

Resultant (Ground Reaction Force)

0.000 0.400 0.800 1.200 1.600 2.000 2.400 2.800 3.200

0.000 1.000 2.000 3.000 4.000 5.000 6.000 7.000 8.000

Newton's
Low-Back and Shoulder Summary

• Keep torso upright (as much as possible)
• Keep the load/force close
• Push/Pull at mid-torso height
• Avoid Twisting
• Avoid Jerking
• Get Help when needed
Nearly the only widely used model that considers physical capability, fatigue, and repetition to estimate a Risk Score.

- Designed to “prevent or reduce the occurrence of lifting related low-back pain in workers”

(Waters et al., 1993)
# Recommended Weight Limit (RWL)

\[ RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \]

<table>
<thead>
<tr>
<th>Load Constant</th>
<th>Metric</th>
<th>U.S. Customary</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC</td>
<td>23 kg</td>
<td>51 lb</td>
</tr>
<tr>
<td>HM</td>
<td>(25/H)</td>
<td>(10/H)</td>
</tr>
<tr>
<td>VM</td>
<td>1-(.003 V-75)</td>
<td>1-(.0075 V-30)</td>
</tr>
<tr>
<td>DM</td>
<td>.82 + (4.5/D)</td>
<td>.82 + (1.8/D)</td>
</tr>
<tr>
<td>AM</td>
<td>1-(.0032A)</td>
<td>1-(.0032A)</td>
</tr>
<tr>
<td>FM</td>
<td>From Table 5</td>
<td>From Table 5</td>
</tr>
<tr>
<td>CM</td>
<td>From Table 7</td>
<td>From Table 7</td>
</tr>
</tbody>
</table>
Lifting Index

\[
LI = \frac{\text{Load Weight}}{\text{Recommended Weight Limit}} = \frac{L}{RWL}
\]

• The LI can be used to categorize and prioritize a job risk

• NIOSH indicates that lifting tasks with a LI>1.0 pose an increased risk for lifting-related low back pain for some fraction of the workforce (Waters et al., 1993).
Analysis Tips Based on RNLE

1. If HM is low perform both a back compressive force and shoulder moment analysis.

2. IF VM is low and the vertical location is High (>30”) perform a shoulder moment analysis.

3. IF VM is low and vertical location is low (<30”) perform a back compressive force analysis.

4. If FM is low perform a metabolic analysis.
The new “Liberty Mutual Manual Materials Handling Tables” provide both the male and female population percentages capable of performing manual material handling tasks without over exertion:
- Lifting/Lowering
- Pushing/Pulling
- Carrying

Require collecting minimal data for performing estimates.
Purpose of Liberty Mutual Tables

- Provide the user with an objective risk assessment ... to build a solution by:
  1. Helping recognize risk factors associated with MMH
  2. Helping make good business decisions on implementing cost effective ergonomics solutions that offer the highest degree of control.

- Manual Materials Handling Guidelines, Liberty Mutual Insurance
Whole Body Vibration

Taken from: *Measuring Vibration*, Brüel and Kjaer (1)
Whole-body vibration (WBV): mechanical energy oscillations that are transferred to the body as a whole

- In contrast to specific body regions (e.g., segmental vibration)
- Transmission usually through supporting system (e.g., seat or platform)
WBV Exposure

- **Effects of Acute Exposure**
  - Increased Heart Rate
  - Hyperventilation
  - Headache
  - **Loss of Balance**
  - Motion Sickness (< 1 Hz)
  - **Muscle Fatigue**
  - Discomfort
  - Decreased Cognitive Function
  - Effects on Speech
  - **Blurred Vision**
  - Turbulent Blood Flow due to arterial stenosis

- **Effects of Chronic Exposure**
  - Suppression of reflexes
  - Gastrointestinal bleeding (12 Hz, 1.5g, 130 hours ??)
  - Suppression of Gastric Function
  - Loss of hearing
  - Increased Risk of Low Back Pain
  - Spine: Bone / Cartilage degeneration
    - Lumbar (4-8 Hz)
    - Thoracic (5-10 Hz)
    - Cervical (20-30 Hz)
Tissue Structure-Function

- Structure
  - Architecture
  - Anatomy

- Function
  - Tissue Stress-Strain Force-Elongation

- Extracellular Events
  - Cell Synthesis
  - Material Properties
    - Collagen Types and amounts
    - Crosslinking
    - PG types and amounts
Exposure to whole-body vibration (WBV) shows strong epidemiologic evidence as a risk factor for lumbar spine disorders (NIOSH 1997)

Vehicles and industrial machinery may vibrate at fundamental frequency similar to the body’s natural resonance frequency
What can we do to reduce exposure to WBV?

- Adequately maintain vehicles, particularly suspension components, including tires.
- Keep suspension seat in good repair.
- Check whether a suspension seat is fitted suitable to the vibration characteristics of the machine.
- If a suspension seat is fitted, ensure it is correctly adjusted to the operator’s weight according to the manufacturer’s instructions.
- Ensure operators understand the importance of proper adjustments for seated posture.
Research at the University of Utah

Field and Laboratory Studies Related to Transportation

Ergonomics and Safety Program

http://www.mech.utah.edu/ergo
Response of Lumbar Spinal Physiology to Chronic Occupational Whole Body Vibration

Research performed by Bryan Howard, PhD - graduate work at the University of Utah (2007)
Study Population

- **Experimental Group**
  - Over 300 male haul truck operators from KUCC were solicited for participation
  - 14 individuals volunteered

- **Control Group**
  - 30+ office workers from various office buildings at KUCC were solicited for participation
  - 14 individuals were selected to best match the haul truck volunteer population based on several confounding variables
## Whole Body Vibration & Lumbar Physiology Results

<table>
<thead>
<tr>
<th>Axis</th>
<th>Measure</th>
<th>Haul Truck</th>
<th></th>
<th>Expose</th>
<th>Office</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>95% CI of the Mean</td>
<td></td>
<td>Mean</td>
<td>95% CI of the Mean</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
</tr>
<tr>
<td>X</td>
<td>Max Power</td>
<td>190.90</td>
<td>81.66</td>
<td>300.16</td>
<td>0.59</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
<td>1.54</td>
<td>1.23</td>
<td>1.85</td>
<td>0.90</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>Power at 5 Hz</td>
<td>1.35</td>
<td>0.44</td>
<td>2.26</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Y</td>
<td>Max Power</td>
<td>150.72</td>
<td>56.41</td>
<td>245.04</td>
<td>0.65</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
<td>0.75</td>
<td>0.58</td>
<td>0.91</td>
<td>0.91</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>Power at 5 Hz</td>
<td>0.64</td>
<td>0.15</td>
<td>1.13</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Z</td>
<td>Max Power</td>
<td>635.53</td>
<td>182.71</td>
<td>1088.37</td>
<td>0.09</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
<td>1.66</td>
<td>1.28</td>
<td>2.04</td>
<td>3.89</td>
<td>2.73</td>
</tr>
<tr>
<td></td>
<td>Power at 5 Hz</td>
<td>6.68</td>
<td>0.75</td>
<td>12.61</td>
<td>0.01</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Conclusions Regarding WBV Measurement

- Haul Truck Exposures
  - Demonstrated magnitudes that placed the exposures near the lower/moderate health caution boundary
  - Dominate frequencies were associated more with motion sickness than health risks

- Office Exposures
  - Demonstrated magnitudes that placed the exposures well below the lower/moderate health caution boundary
Goal: to quantitatively describe the physical factors that may lead to fall injuries associated with mounting and dismounting commercial trucks
### Questionnaire Data

<table>
<thead>
<tr>
<th>Current Back Pain</th>
<th># Falls Mounting (lifetime)</th>
<th># Falls Dismounting (lifetime)</th>
<th>Fell and Caught self Mounting</th>
<th>Fell and Caught self Dismounting</th>
<th>Lost Work Because of Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.5%</td>
<td>2.2</td>
<td>3.2</td>
<td>62.5%</td>
<td>66.7%</td>
<td>30.7%</td>
</tr>
</tbody>
</table>

- Mean years driving truck = 7 yrs. 2 mo.
- N=19

- Study at UMICH (2007-2010): Previously slipped or fallen: 8% ingress, 21% egress
- Of those who slipped or fell: 47% injured
- Features associated with slip/fall:
  - Steps: 57%
  - Handholds: 7%
  - Ground: 20%

  - Merryweather & Thiese, Pilot Data

  - Reed et al, 2009
Important Factors to Consider

Factors
- Step Dimensions
- Proper Foot Placement On Steps
- First Step Height
- Driver Fatigue
- Environmental Conditions
- Proper Technique (3 point contact)
- Handle Design
- Worker Anthropometry

Applicable Standards
- SAE J185: Steps and Handholds on Offroad and Construction Equipment (equiv. to ISO 2867-1980)
- US Federal Motor Carrier Safety Administration Standard Part 399 Subpart L
- US Military Standard 1472f
Biomechanical Modeling

- Determine foot forces using 6 degree of freedom force platforms
- Estimate ankle moment requirements
- Investigate lower limb shock loading
- Determine optimum hand and foot locations
- Propose administrative and engineering controls to reduce fall hazards

\[ RCOF = \frac{F_x}{F_z} \]
RCOF-Ingress/Egress

**Ingress RCOF**

**Egress RCOF**

- Sample
- mu
- 2nd Step
- Ground
3D Biomechanical Modeling
University of Michigan - 3DSSPP
Agricultural Tractor Operator Study

- Goal: evaluate factors associated with falls among agriculture workers, specifically while mounting and dismounting tractors
  - 3D motion analysis describing kinematics and spatial constraints

Table 1 Survey Results Part A

<table>
<thead>
<tr>
<th>Question</th>
<th>Avg. of Respondents</th>
<th>Min. of Respondents</th>
<th>Max. of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>31</td>
<td>20</td>
<td>49</td>
</tr>
<tr>
<td>Weight</td>
<td>189</td>
<td>165</td>
<td>215</td>
</tr>
<tr>
<td>Height (inches)</td>
<td>70.1</td>
<td>67</td>
<td>74</td>
</tr>
<tr>
<td>Average Years of Experience Operating a Tractor</td>
<td>19.1</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>The Average time per use of a Tractor in Hours</td>
<td>6.6</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>The Average Time Between Breaks During Operation in Hours</td>
<td>4</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Survey Item</td>
<td>% Experienced</td>
<td>% Did Not Experience</td>
<td>% Experienced Other</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>----------------</td>
<td>----------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Experienced Pain or Discomfort During Operation</td>
<td>85.7</td>
<td>14.3</td>
<td>0</td>
</tr>
<tr>
<td>Experienced an Increase in Discomfort during the Harvest Season</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reported Having Lasting Effects as a Result of Using Tractors More Than 5 Days</td>
<td>57.4</td>
<td>42.6</td>
<td>0</td>
</tr>
<tr>
<td>Reported that the Pain Affected Them Occasionally</td>
<td>57.1</td>
<td>0</td>
<td>42.9</td>
</tr>
<tr>
<td>Seen a Health Care Provider for Pain</td>
<td>14.3</td>
<td>85.7</td>
<td>0</td>
</tr>
<tr>
<td>Reported that the Pain was Painful but Did Not Affect Work</td>
<td>57.1</td>
<td>0</td>
<td>42.9</td>
</tr>
<tr>
<td>Reported Experiencing Numbness Seldom</td>
<td>28.6</td>
<td>71.4</td>
<td>0</td>
</tr>
<tr>
<td>Reported Experiencing a Weakening in the Knees Occasionally</td>
<td>28.6</td>
<td>57.1</td>
<td>14.3</td>
</tr>
<tr>
<td>Reported Occasionally Pressing the Wrong Lever When Attempting to Perform an Operation Occasionally</td>
<td>71.4</td>
<td>0</td>
<td>28.6</td>
</tr>
<tr>
<td>Reported Occasionally Pressing the Wrong Lever Accidentally</td>
<td>42.9</td>
<td>0</td>
<td>57.1</td>
</tr>
</tbody>
</table>
Different Ingress/Egress Systems
Irregular Surface Gait Biomechanics-Railroad Ballast

- Evaluate lower-limb stresses while walking on railroad yard ballast
- Railroad worker walking conditions
  - Uneven surfaces
  - Loose aggregate
- Need for better understanding of risk for OA
  - Walking on railroad ballast
  - Walking on sloped surfaces
• Track Length – 24 ft (7.3 m)
• Track Width – 30 in (76 cm)
• Ballast Depth – 6-7 in (15-20 cm)
• Condition - slightly compacted to reduce shifting during data collection.

• Mainline Ballast Large ballast (~1.5” rock)
• Yard Ballast (~0.75” rock)
• Level and Sloped (7°)

Force Plate Isolation Fixture
Example of Results
Knee Moment and Joint Load

\[ M_{\text{adduction}} = \text{Medial Compartment Compression Force} \]

Andriacchi, 1994
Knee ABD/ADD Moments

ABD/ADD Moment Left Knee

![Graph showing ABD/ADD Moment for the left knee.](image)

ABD/ADD Moment Right Knee

![Graph showing ABD/ADD Moment for the right knee.](image)

\( p < 0.0001 \)
References


