How Do I Choose the Correct Ergonomics Assessment Tool(s)?

Jim Potvin, PhD
Introduction

• Why perform an ergonomics analysis?
  – Evaluate risk
    • qualitative
  – Employee placement (or screening)
    • task requirements
  – Return to work after an injury
    • worker readiness
  – Determine acceptable loads
    • quantitative
    • provides evidence for design (or redesign)
    • cost-benefit justification
Introduction

• **What is a ‘risk’ or a ‘hazard’?**
  – It is not ‘safe’ or ‘unsafe’
    • risk resides on a continuum
  – Thus, some risk always exists
  – Risk = Load / Capacity
    • load relative to individual’s capacity
    • load versus population capacity
      – muscle or tissue strength
      – endurance
      – both

• **Example**
  • shoulder moment demand = 42 Nm
  • individual’s strength is 35 Nm
    – Risk = Demand/Strength = 42 / 35 = 1.20
  • population strength is 45±9 Nm
    – Risk = Demand/Mean Strength = 42 / 45 = 0.93
Introduction

- What are the risk factors?

**Diagram:**
- Force
  - Non-neutral posture creates a moment that requires muscle force
  - Progressive decrease in tissue tolerance
  - Prevents muscle recovery
- Posture
- Repetition/Duration
- Vibration
Introduction

• What is ‘acceptable’ risk?
  – Threshold Limit Value (TLV)
    • the ‘line in the sand’
    • typically based on female workers
    • typically based on 25\textsuperscript{th} percentile
      – ie. 75\% capable
  – Where does the 75\% capable come from?
    • Snook (1978)
      – “a worker is three times more susceptible to low back injury if performing a manual handling task that is acceptable to less than 75\% of the working population”
        » only based on 191 subjects
  – If <75\% capable, will an injury certainly occur?
    • eg. car insurance
A Brief Statistical Interlude
The Normal Distribution

- Maximum bench press (lbs) of 55 individuals

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The Normal Distribution

Ranking Heights from Lowest to Highest

Mean = 166.93 cm
SD = 11.44 cm

In a Normal Distribution:
Half of the observations are higher than the mean of 166.93 cm, the other half are lower.

Max Bench Press (lbs)
**The Normal Distribution**

**75th percent capable**

75% of values higher than this

25% of values lower than this

Mean = 166.93 cm

SD = 11.44 cm

75% of the values = 75% of 55 = ~41
(or, all but 55 – 41 = 14 values)
are higher than 159 lbs.

This is 166.93 – 159 = 7.93 lbs below the mean.

= 7.93 / 11.44 = 0.69 SD
or ~ 2/3\text{rd} SD (z score = -0.67)

25\text{th} \%ile has z score = 0.67 = 166.93 – (11.44 \times 0.67) = 159.3 lbs
Ergonomics Tools

• Checklists
  – Washington State Caution and Hazard Zone Checklist
  – MSD Hazard Risk Assessment Checklist
  – QEC (Quick Exposure Checklist)
  – REBA (Rapid Entire Body Assessment)
  – ManTRA (Manual Tasks Risk Assessment)
**Ergonomics Tools**

- **Upper Extremities**
  - RULA (Rapid Upper Limb Assessment)
  - Strain Index
  - ACGIH Threshold Limit Value (TLV) for Hand Activity
Ergonomics Tools

- **Upper Extremities**
  - LUBA (Loading on the Upper Body Assessment)
  - OCRA (Occupational Repetitive Actions Index)
  - HandPak Software
  - ACGIH TLV for Upper Limb Localized Fatigue
    - Notice of Intended Change

\[
OCRA = \text{Frequency} + \text{Force} + \text{Posture} + \text{Additional factors} \times \text{Recovery multiplier} \times \text{Duration multiplier} = \text{Ocra Checklist}
\]

\[
MVC = -0.143 \times \ln(DC) + 0.066 \\
R^2 = 0.85
\]

ACGIH TLV - Upper Limb Localize Fatigue
Ergonomics Tools

• Manual Materials Handling
  – Psychophysical Tables
    • Liberty Mutual Tables
      – Snook & Ciriello (1991)
    • Ayoub et al (1989)

  – Metabolic equations
    • Garg et al (1978)
    • Dempsey et al (2008)

  \[ \text{Maintenance of body postures}^* : \]
  Sitting \( \dot{E} = 0.023 \text{ BW} \)

  \text{Standing, bent position} \( \dot{E} = 0.028 \text{ BW} \)

  \text{Net metabolic cost of tasks:}
  \text{stoop lift (Kcal/lift)}
  \[ \Delta E = 10^{-7} [0.325 \text{ BW} (0.81-h_1) + (1.41L + 0.76 S \times L) (h_2 - h_1)] \text{ for } h_1 < h_2 \leq 0.81 \]

  \text{squat lift (kcal/lift)}
  \[ \Delta E = 10^{-5} [0.514 \text{ BW} (0.81-h_1) + (2.19L + 0.62 S \times L) (h_2 - h_1)] \text{ for } h_1 < h_2 \leq 0.81 \]

Liberty Mutual Tables
Ergonomics Tools

• Manual Materials Handling
  – Biomechanics software
    • 3DSSPP
    • Santos
    • Delimia
    • RAMSIS
    • HumanCAD 3
    • Jack

Jack

Santos

3DSSPP
Ergonomics Tools

• Manual Materials Handling
  – Integrated methods
    • NIOSH Equations
    • ACGIH TLV for Lifting

| Vertical Zone                              | Horizontal Zone
<table>
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<tr>
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<tbody>
<tr>
<td>Close: &lt; 30 cm</td>
<td>Intermediate: 30 to 60 cm</td>
</tr>
<tr>
<td>Reach limit C or 30 cm above shoulder to 8 cm below shoulder height</td>
<td>16 kg</td>
</tr>
<tr>
<td>Knuckle height to below shoulder</td>
<td>32 kg</td>
</tr>
<tr>
<td>Middle shin to knuckle height E</td>
<td>18 kg</td>
</tr>
<tr>
<td>Floor to middle shin height</td>
<td>14 kg</td>
</tr>
</tbody>
</table>

\[ \text{RWL} = 23 \text{ kg} \times H \cdot \text{fac} \times V \cdot \text{fac} \times D \cdot \text{fac} \times F \cdot \text{fac} \times A \cdot \text{fac} \times C \cdot \text{fac} \]

- H - 25/H
- V - 1 - 0.003 | V - 75 |
- D - 0.82 + (4.5/D)
- A - 1 - (0.0032 * Angle)
- C - Coupling
  - Good 1.00
  - Fair 0.95
  - Poor 0.90

ACGIH TLV for Lifting

- angular displacement of load from sagittal plane
  - 0.71 @ 90 degrees

NIOSH Lifting Equation
Ergonomics Tools

- Manual Materials Handling
  - Integrated methods
    - BakPak software
    - Composite Acceptable Load
      - Potvin (2014)
    - Mital et al. (1993)
How Do I Choose the Correct Ergo Assessment Tool?

- **Example: Lifting**
  - **Criteria**
    - Epidemiology
      - injury statistics
  
  - Biomechanics
    - lumbar compression force
    - joint strength demands
      - simple tools (2DSSPP, WatBak)
      - more complex (3DSSPP)
      - advanced (Jack, Santos, Delmia)

- **Psychophysics**
  - how are these studies done?
    - Snook & Ciriello (1991)

- **Physiology & Metabolic Cost**
  - cardiovascular demand
    - calories burned
How Do I Choose the Correct Ergo Assessment Tool?

• **Example: Lifting**
  - **Criteria**
    - **Epidemiology**
      - **Strengths:** can be gathered from all jobs, comprehensive
      - **Limitations:** not specific to a task or task elements, may not reflect tissue injuries

• **Biomechanics**
  - **Strengths:** compression can be calculated with confidence, has capacity limits
  - **Limitations:** limited data on effects of repetition

• **Psychophysics**
  - **Strengths:** based on an integration of senses, subjects were trained
  - **Limitations:** tends to overestimate acceptable loads at high and low frequencies

• **Physiology & Metabolic Cost**
  - **Strengths:** can be used for a combination of tasks, can be measured accurately now (eg. Fitbit)
  - **Limitations:** overestimate capacity at low frequencies.
How Do I Choose the Correct Ergo Assessment Tool?

- **Example: Lifting**
  - Integrating Criteria
    - NIOSH Lifting Equation
      - Epidemiology: increased risk of injury for some
      - Biomechanics: compression of 3400 N at L5/S1
      - Psychophysics: 75% of women and 99% of men
      - Physiology: 3.5 kcal/min

How Do I Choose the Correct Ergo Assessment Tool?

- **Example: Lifting**
  - Integrating Criteria

How Do I Choose the Correct Ergo Assessment Tool?

- **Example: Lifting**
  - Integrating Criteria

  Mital et al (1993)

## Lifting and Lowering

75% Capable (=25th percentile)

*(Adapted from Mital, Nicholson & Ayoub, 1993; by Potvin, 2008)*

<table>
<thead>
<tr>
<th>Vertical Range (cm)</th>
<th>H (cm)</th>
<th>Frequency (per minute)</th>
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<tr>
<td></td>
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<td>0.002</td>
</tr>
<tr>
<td>132</td>
<td>58</td>
<td>20 / 11</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>23 / 12</td>
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<tr>
<td>Floor</td>
<td>63</td>
<td>21 / 11</td>
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<tr>
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<td>50</td>
<td>24 / 12</td>
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<tr>
<td></td>
<td>42</td>
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<tr>
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<td>27 / 16</td>
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<td>42</td>
<td>27 / 19</td>
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</table>

Values shown as Male/Female. For example: 20 / 11 means that the Male limit is 20 and the Female limit is 11

- **Bolded** values corrected based on the biomechanical criterion
- **Underlined** values corrected based on physiological data in the literature
How Do I Choose the Correct Ergo Assessment Tool?

- **Example: Lifting**
  - Integrating Criteria
    - Potvin (2014)
Integration by the NIOSH Lifting Equation

- Potvin (2014)
  - Comparing the revised NIOSH lifting equation to the psychophysical, biomechanical and physiological criteria used in its development
    - International Journal of Industrial Ergonomics, 44: 246-252

Table 4
Average Acceptable Lifting Indices and RWL percent capable values pooled within frequency \((n = 27)\), range \((n = 9)\), box width \((n = 9)\) and \(D\) \((n = 9)\). Individual ALI values were calculated by dividing the CAL from Table 1 by the corresponding RWL from Table 3. RWL percent capable are presented only in the frequency range where the psychophysical MAWL defined the CAL in almost all conditions.

<table>
<thead>
<tr>
<th></th>
<th>Acceptable lifting indices</th>
<th>Percent capable of RWL</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Frequency (Lifts/min)</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>0.002 0.033 0.2 0.5 1 4.3 6.7</td>
<td>Mean</td>
</tr>
<tr>
<td>Frequency</td>
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<tr>
<td>Range</td>
<td>S–R</td>
<td>1.39 1.26 1.37 1.43 1.45 2.17 2.52</td>
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<tr>
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<td>K–S</td>
<td>1.32 1.10 1.20 1.25 1.29 1.84 2.14</td>
</tr>
<tr>
<td></td>
<td>F–K</td>
<td>1.52 1.48 1.62 1.68 1.71 2.79 3.14</td>
</tr>
<tr>
<td>Width</td>
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<td>1.49 1.40 1.57 1.64 1.64 2.58 3.04</td>
</tr>
<tr>
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<td>1.36 1.20 1.27 1.32 1.36 2.01 2.37</td>
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<td>1.30 1.17 1.26 1.32 1.34 1.93 2.15</td>
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<td>1.41 1.30 1.43 1.50 1.51 2.26 2.57</td>
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<td>25</td>
<td>1.34 1.23 1.33 1.38 1.43 2.19 3.50</td>
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Recommendations

• Become familiar with all of the available tools

• Use tools that estimate physical quantities
  – lumbar spine compression
  – joint strength demands
  – metabolic cost

• Find good criteria to compare those quantities to
  – eg. 3400 N compression, 25th percentile strength, 3.5 kcal/min

• Understand the limitations of each tool
  – Be critical of the tools
  – What are the boundaries
    • applicable frequency range
    • constraints
      – eg. symmetrical?, two-handed lifting?, good coupling? 8 hours?

• Choose the tool(s) that have the least severe limitations for your task
  – note: they all have limitations for every task
Thank you

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www.PotvinBiomechanics.com