Psychophysical and Demographic Changes Require Rethinking Ergonomic Strategies

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Outline

- About the Authors
- Background and Introduction
- Physical, Psychophysical Demographic Changes
- Revising Ergonomics Research Strategies
  - Original Results
  - Hypothetical Results
    - *Main Results graph Tables 1 and 2*
- Discussion - Changes to Ergonomics Strategies
  - Ergonomic Action Level (EAL)
  - Prevention through Design (PtD)
    - Automation, Mechanization, Modularization, Prefabrication
- Bibliography – 32 referenced articles
- Question and Answer
About the Authors

Jim

- Undergraduate Studies – Math, Physics, Education; Graduate – Safety, Ergonomics
- ASSE Safety 2012 in Denver – Academic Forum presentation
- 1970 - present, SH&E Consultant for Insurance Companies
  - Liberty Mutual – Used Snook’s Tables, Customer Presentations w/Stover
  - Kemper Subsidiary - Used NIOSH LE – Oil/Gas and Construction Ops
  - Current Company
    - ANSI A10 Construction Standards Committee since 2000
      - Prevention through Design (PtD) Tech Report (completion 2016)

Sang

- Professor and Graduate Program Coordinator of OESH–Uni. of Wis, Whitewater
- Produced more than 110 Publications
- Frequent speaker at National and International Conferences
- Proponent of “Bridging the Gap between Academia and OESH Profession”
  - Practices “Research to Practice to Research (RtPtR)” model
SH & E Practitioner – Academic Researcher

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RtPtR
Research to Practice (RtP) Model
Background

- **WMSDs in Construction**
  - Work-related musculoskeletal disorders (WMSDs) and low back injuries are very common among construction workers (NIOSH).
  
  - The most commonly reported biomechanical risk factors with at least reasonable evidence for causing WMSDs include *excessive repetition, awkward postures, and heavy lifting*.

  - Many construction occupations/trades still require *substantial manual lifting and lowering of materials* which often results in overexertion.
    - *Overexertion* in manual lifting was among the most frequent exposure leading to injury or illness involving days away from work (Bureau of Labor Statistics [BLS]).

  - Workers who must often lift, stoop, kneel, twist, grip, stretch, reach overhead, or work in other awkward positions to do a job are at risk of developing a work-related musculoskeletal disorder (NIOSH).
Manual materials handling at construction

- How much a worker lifts is left to his or her discretion at the job site!!??
  - Often times weights of construction materials seemed to exceed a worker’s physical capacity and pain or injury to the worker will result (Choi, Borchardt, and Proksch, 2012; 2009).

- Need more data sources available to workers, managers, and health & safety professionals to aid in preventing work-related musculoskeletal disorders and injuries.

- More awareness of construction materials’ weight and task-related specific variables prior to manually lifting or lowering may be as important as how the materials are handled.
Physical Changes

Sports Examples from

- **William Perry** – 1st NFL player exceeding 300 lbs (1980s)
  - Today hundreds of NFL and College Football Players exceed 300 lbs
  - NFL reports average lineman weight increased: from about 200 lbs in 1935 to 275+ lbs in 1995

- **Lew Alcinder** – 7’ 2” and 265 lbs (1970s)
  - Today many NBA and college center match Statue and Weight

- **Weight** - General Population and Workers in US got HEAVIER since 1960s
  - Average Weight Increased
    - **Males** 168 lbs to 180 lbs; **Females** 142 lbs to 152 lbs
  - Body Mass Index (BMI) Increased (See report for BMI definition)
    - Average for Male & Female increased from **25** to **27.1**
    - Obese (BMI > 30) increased from 15% of adults to 27%
Demographic Changes

- **Age** - Workers in US got OLDER i.e. % of worker 65 years +
  - In 1990, 8.6%; By 2010, 13.8%; Projected for 2020, **19.2%**

- **Gender** – Male to Female Ratio of Workforce Narrowing
  - Workforce Participation Rate
    - Male Ratio Decreases and Female Ratio Increases
      - In 1960, Workforce Ratio – **Male 80% vs Female 40%**
    - By 2010, Workforce Participation Ratio –
      - **Male 60% vs Females of slightly less than 60%**
Psychophysical Changes

Since 1970s – 80s Snook’s Tables

- In 2001 Box Size Study, Ciriello “observed” shift in Maximum Acceptable Weight
  - Results:
    - Maximum Acceptable Weight (MAW) of Lifting/Lower Task Decreased from 1991 Liberty Mutual Research Guidelines
    - For Males - 69%; For Females - 67%

See Reference
- Ciriello (2001) Effect of box size, vertical distance & height of lowering tasks
- Ciriello et al (2011) Gender differences in psychophysically determined maximum acceptable weight and forces for industrial workers observed after twenty years.

Implications?
- If validated, “set points” of ergonomic assessment tools such as Load Constant (LC) of NIOSH’s Lifting Equation (LE) MAY need to be lowered i.e. Ideal 51lbs to 35 lbs
Methods

The Original Study in 2012*

Manual Lifting Task Observations

- Using the NIOSH’s 1991 Lifting Equation – A total of 292 measurements was taken at the origin and destination of lifting/lowering tasks in the construction workplace.


The 2015 Study

Hypothetically revised the **Load Constant (LC)** of NIOSH’s Lifting Equation (LE) from 51 lbs to **35 lbs** based on reported workers’ psychophysical changes which suggest the “set – point” of the LE may need to be lowered.**

The 2012 study*

- **Manual Lifting Task Observations**
  - The weight of common materials used by various construction trades was measured at job sites.
  - The NIOSH’s 1991 Lifting Equation components (task variables)
    - were either measured using a tape measure such as the distance between the origin and destination of the lift or
    - observed by the researcher such as the worker’s twisting motion and ability to grasp the materials.
  - Manual Lifting Observation Data Collection Sheet was prepared in an Excel spreadsheet
    - *After collection in the field, data was then entered into the non-printed excel format for further analysis*
The 2012 study*

Data Collection Variables

- Subject ID
- Trade / Occupation
- Gender
- Age (years)
- Construction Materials
- Weight (lbs)
- Horizontal Location (in) (Origin / Destination)
- Vertical Location (in) (Origin / Destination)
- Vertical Travel Distance (in)
- Asymmetry Angle (deg) (Origin / Destination)
- Frequency Rate (lifts / min)
- Duration (hrs)
- Object Coupling

Warm-up data collection session – see next…
Graphic Representations of Hand Location and Angle

Ref: NIOSH Publication No. 94-110 (Waters et al., 1994)
Using the NIOSH Lifting Equation

- **Step 1**: Measure and Record Task Variables
  - Origin and Destination

- **Step 2**: Determine Multipliers and RWL
  - Origin and Destination
  - Can only decrease the RWL from optimal 51 lbs

- **Step 3**: Compute Lifting Index
  - Single number representing relative risk of task
**1991 NIOSH Revised Lifting Equation**

\[ RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \]  
*(Waters et al., 1994)*

Where,

- **Load Constant (LC):** A constant term in the RWL equation defined as a fixed weight of 23 kg or 51 lb; generally considered the maximum load nearly all healthy workers should be able to lift under optimal conditions (i.e. all the reduction coefficients are unity).

- **Horizontal Multiplier (HM):** A reduction coefficient defined as 10/H, for H measured in inches, and 25/H, for H measured in centimeters.

- **Vertical Multiplier (VM):** A reduction coefficient defined as \((1-(.0075 [V-30]))\), for V measured in inches, and \((1-(.003 [V-75]))\), for V measured in centimeters.

- **Distance Multiplier (DM):** A reduction coefficient defined as \((.82 + (1.8/D))\), for D measured in inches, and \((.82 + (4.5/D))\), for D measured in centimeters.

- **Asymmetric Multiplier (AM):** A reduction coefficient defined as \((1-(.0032A))\), has a maximum value of 1.0 when the load is lifted directly in front of the body and decreases linearly as the Angle of Asymmetry (A) increases.

- **Frequency Multiplier (FM):** A reduction coefficient that depends upon the Frequency of Lifting (F), the Vertical Location (V) at the origin, and the Duration of Lifting.

- **Coupling Multiplier (CM):** A reduction coefficient based on the Coupling Classification and Vertical Location of the lift.
1991 NIOSH Lifting Equation cont.

**Recommended Weight Limit (R WL)**
- The load that most healthy adult workers could lift over a shift without increased risk of back injury

**Lifting Index (LI)**
- Relative estimate of physical stress associated with a lifting task
  - \( \text{LI} = \frac{\text{Actual Load Weight}}{\text{R WL}} \)
  - If, LI \( \leq 1 \), Acceptable
  - If, LI \( > 1 \), Unacceptable* ( >3 a sig. risk of injury+)

*LI>1, an increased risk for lifting-related low back pain for some fraction of the work force (Waters et al., 1993)
+LI>3, nearly all workers will be at an increased risk of work-related injury when performing highly stressful lifting tasks (NIOSH Publication No. 94-110)
Using the NIOSH Lifting Equation for Redesign

- Use *individual multipliers* to *identify specific contributors* to injury risk

- Use *Recommended Weight Limit (RWL)* to *design jobs*

- *Lifting Index (LI)* to *prioritize* ergonomic redesign and compare tasks
  - The larger the LI the greater the likelihood of injury
  - And the smaller the fraction of workers able to perform the job safely
## 2012 Results Using Load Constant (LC) 51 lbs

<table>
<thead>
<tr>
<th>Observation</th>
<th>HM</th>
<th>VM</th>
<th>DM</th>
<th>AM</th>
<th>FM</th>
<th>CM</th>
<th>RWL (lbs)</th>
<th>Load Wt (lbs)</th>
<th>LI</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n=292)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>0.56</td>
<td>0.89</td>
<td>0.89</td>
<td>1.00</td>
<td>0.85</td>
<td>0.95</td>
<td>15.96</td>
<td>30.00</td>
<td>1.54</td>
</tr>
<tr>
<td>Std Dev</td>
<td>0.29</td>
<td>0.07</td>
<td>0.05</td>
<td>0.20</td>
<td>0.14</td>
<td>0.03</td>
<td>7.13</td>
<td>26.57</td>
<td>2.44</td>
</tr>
<tr>
<td>Min</td>
<td>0.19</td>
<td>0.63</td>
<td>0.82</td>
<td>0.42</td>
<td>0.35</td>
<td>0.90</td>
<td>2.84</td>
<td>1.00</td>
<td>0.04</td>
</tr>
<tr>
<td>Max</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.94</td>
<td>1.00</td>
<td>33.36</td>
<td>192.00</td>
<td>12.76</td>
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</tbody>
</table>

### 2014 Results using LC of 51lbs

<table>
<thead>
<tr>
<th>LC</th>
<th>HM</th>
<th>VM</th>
<th>DM</th>
<th>AM</th>
<th>FM</th>
<th>CM</th>
<th>RWL (lbs)</th>
<th>Load Wt (lbs)</th>
<th>LI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>51.00</td>
<td>0.69</td>
<td>0.87</td>
<td>0.91</td>
<td>0.84</td>
<td>0.78</td>
<td>16.33</td>
<td>30.70</td>
<td>2.35</td>
</tr>
</tbody>
</table>
## 2015 Hypothetical Results Using Load Constant (LC) 35 lbs

### Observation (n=292)

<table>
<thead>
<tr>
<th>Observation</th>
<th>HM</th>
<th>VM</th>
<th>DM</th>
<th>AM</th>
<th>FM</th>
<th>CM</th>
<th>RWL (lbs)</th>
<th>Load Wt (lbs)</th>
<th>LI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>0.56</td>
<td>0.89</td>
<td>0.89</td>
<td>1.00</td>
<td>0.85</td>
<td>0.95</td>
<td>10.95</td>
<td>30.00</td>
<td>2.25</td>
</tr>
<tr>
<td>Std Dev</td>
<td>0.29</td>
<td>0.07</td>
<td>0.05</td>
<td>0.20</td>
<td>0.14</td>
<td>0.03</td>
<td>4.90</td>
<td>26.57</td>
<td>3.56</td>
</tr>
<tr>
<td>Min</td>
<td>0.19</td>
<td>0.63</td>
<td>0.82</td>
<td>0.42</td>
<td>0.35</td>
<td>0.90</td>
<td>1.95</td>
<td>1.00</td>
<td>0.06</td>
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<tr>
<td>Max</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.94</td>
<td>1.00</td>
<td>22.89</td>
<td>192.00</td>
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</tbody>
</table>

### Average

<table>
<thead>
<tr>
<th>LC</th>
<th>HM</th>
<th>VM</th>
<th>DM</th>
<th>AM</th>
<th>FM</th>
<th>CM</th>
<th>RWL (lbs)</th>
<th>Load Wt (lbs)</th>
<th>LI</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.00</td>
<td>0.69</td>
<td>0.87</td>
<td>0.91</td>
<td>0.84</td>
<td>0.78</td>
<td>0.96</td>
<td>11.21</td>
<td>30.70</td>
<td>3.42</td>
</tr>
</tbody>
</table>
Lifting Index Results
Comparison by Trade & Occupation

[Bar chart showing lifting index results for various trades and occupations, with comparisons for LC=35lbs and LC=51lbs.]
Conclusions

Acceptable i.e. Lifting Index less than 1.0

- Electricians – both for 35 lbs and 51 lbs

Unacceptable - Lifting Index greater than 1.0 but less than 3.0

LI>1, an increased risk for lifting-related low back pain for some fraction of the work force (Waters et al., 1993

- 8 Trades for 51 LC and 4 Trades for 35 LC

Significant Risk of Injury - Lifting Index greater than 3.0

LI>3, nearly all workers will be at an increased risk of work-related injury when performing highly stressful lifting tasks (NIOSH Publication No. 94-110)

- 8 Trades for 51 LC and 8 Trades for 35 LC
Conclusions Summary

1. Worker characteristics are changing faster than researchers can provide scientific conclusions and develop practical “good practices”.

2. Additional research is needed to study the changing physical, psychological and demographic changes of today’s workforce.

3. If recent studies by Cireillo et al (2008 & 2011) are validates, then today’s workers may be at higher risk of overexertion from manual handling of materials, tools and equipment.
Discussion
Changes to Ergonomics Strategies

A Conceptual “Ergonomic Action Level (EAL)”

• Analogous Concept to Action Level for Toxic/Hazardous Substances or Noise Exposures
• The Authors believe when a manual task has a Lifting Index of 0.7 or greater, the contractor should begin to Take Action.

The Action should follow:

• Hierarchy of controls
  • Elimination, Modification, Administrative Controls
  • Prevention through Design (PtD)
  • Architects, Designers, Engineers, Constructors

• Mechanization, Automation, Modularization, Prefabrication
Mechanization Increases Productivity

Backhoe vs. Bigger Shovel

- Worker with a backhoe
  - More Productive
  - Less Exposure to Overexertion
Mechanization Increases Productivity

**Powered Buggy vs. 2 Wheel Wheelbarrow**

- **Powered Buggy**
  - 18 cu. ft capacity i.e. 2/3 cubic yd
  - Faster than worker can push wheelbarrow
  - More productive, less potential for overexertion

- **Wheel barrow requires multiple trip, manually pushed by worker**
  - 6.5 cu. ft capacity i.e. about ¼ cubic yd.
Mechanization Increases Productivity

**Bulk Sand Bags vs. 2 Wheel Wheelbarrow**
- Bulk Sand Bags moved by mechanically on worksite
  - 3000 lb capacity
  - More productive, less potential for overexertion
- Wheel barrow requires multiple trip, manually pushed by worker
Mechanization Increases Productivity, Reduces Overexertion

Sod Laying
Rolls vs. Pieces

- Sod Rolls (40” x 90’) = 300 sq. ft/roll
  - 1,800 lbs per roll
- Sod Pieces (18” x 6’) = 9 sq. ft/piece
- \( B(\text{Sod}) = 6 - 7 \text{ lbs per sq. ft, therefore Sod Pieces weigh 54 – 63 lbs} \)
Mechanization Increases Productivity, Reduces Overexertion

Concrete Forming

Aluminum Form in Racks vs. Insulated Concrete Forms (ICF)

- Aluminum Concrete Form
  - Lighter and easier to handle vs 4’x8’ wooden forms
  - Rack storage enables mechanical placing in foundation & loading/unloading on trucks
- Insulated Concrete Forms – Styrofoam forms very light & easy to handling
Mechanization
Improves Productivity, Reduces Overexertion

Mechanized Shingle Removal

• Reduces Tear Off Crew Size
• Vacuumed Debris into Hopper Reduces Cleanup
  • More Productive
  • Less Exposure to Overexertion
Mechanization Equalizes Gender Participation
Automation  Improves Productivity, Reduces Overexertion

Automated vs. Manual Brick Laying

- Reduces Crew Size
- Reduces Manual Handling Paving Bricks
- Increases Productivity
- Less Exposure to Overexertion
Automation Improves Productivity, Reduces Overexertion

Microwave Asphalt Pavement Repair

- University of Minnesota – heats asphalt to 300 degree F in 7 minutes
- Reduces Crew Size
- Increases Productivity
- Reduces Manual Handling, Overexertion, Other Exposures
- Author did prototype review early design in the 1980s
Modularization
Improves Productivity, Reduces Overexertion & Other Exposures such as Falls

Exterior “Brick” Cladding vs Real Brick

- Reduces Manual Handling Task
- Reduces Other Exposure
- Improves Productivity
Modularization

New Idea?

- American Systems – Built Homes - early modular construction about 1917
  - Crafted from precut lumber and prefabricated components
- Marshall Erdmann PreFab Homes – mass producing homes in 1950s
  - Frank Lloyd Wright improved design of prefab homes
Prefabrication

Prefabrication
Improves Productivity, Reduces Overexertion & Other Exposures such as Falls

Factory or Jobsite Prefabrication

• Improve Productivity
• Reduces Manual Handling Task
• Reduces Other Exposure such as fall from ladders
Prefabrication
Improves Productivity, Reduces Overexertion & Other Exposures

Chinese builder puts up 57-story skyscraper in 19 days

Factory Built Building Components
Key References

Prevention through Design (PtD)


DHHD (NIOSH) Publication #2013-135 at: http://www.cdc.gov/niosh/docs/2013-135/ PtD – Reinforce Concrete Design


The authors are contributors to ANSI/ASSE TR-A10-2-2014 Technical Report – Prevention through Design for Construction and Demolition Safety and Health which is scheduled for completion in 2016.
Key References cont.


This handbook and DVD video attempts to help address the potential Cumulative Trauma exposures from Off the Job ergonomic risk factors that construction workers encounter At Home.

The presenter co-authored the script for this video in 1998 for Coastal Video (now DuPont Sustainable Solutions)

Questions