Workers' Changing Psychophysical Characteristics Require Prevention through Design (PtD) and Safety, Health & Ergonomic (SH&E) Strategies at Construction Worksites

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Recent studies identified changes in the psychophysical characteristics of today's workers which suggest the set points of these evaluation tools may need to be revised (Ciriello et al., 2008, 2011). Safety, Health & Ergonomic (SH&E) researchers' and practitioners' primary focus has been on industries with the majority of workers such as manufacturing, retail and office support. Choi & Borchardt (2012) conducted a novel research to determine the Recommended Weight Limits (RWL) and Lifting Index (LI) of manual lifting tasks typically found on "construction worksites". The authors investigate the potential changes to RWL and LI in their previous study (Choi & Borchardt, 2012) including recommended good practices on manual handling materials, tools and equipment (MH-MTE) assuming the reported psychophysical characteristics of current workers is confirmed by additional research and the set points of these tools are revised. The authors hypothetically revised the Load Constant (LC) of NIOSH's Lifting Equation (LE) from 51lbs to 35 lbs based on recent psychophysical studies suggesting the set point should be "69% of guideline values" (Ciriello et al., 2008, 2011). We applied this hypothetical LE to determine the potential effect on the RWL and LI of the construction tasks evaluated in 2012. With the hypothetical LC of 35 lbs., approximately 2/3 of the trades in the study (i.e. ceiling installer, drywall installer, floor finisher, insulator, laborer, painter, plumber, and sod layer) were associated with highly stressful manual lifting tasks (LI > 3.0). A new strategy which the authors call "Ergonomic Action Level (EAL)" is needed so good practices anticipate the demographic makeup & psychophysical capacity of today's workers and are designed into today's worksites using Prevention through Design (PtD) techniques such as automation, mechanization, modularization and prefabrication.

Practitioner Summary: The authors believe Prevention through Design (PtD) is necessary to develop and implement effective SH&E strategies for today's construction workforce. Lowering the RWL of manual lifting tasks in construction increases the need for improved safety and ergonomic planning and designing.

Keywords: Psychophysical Characteristics, Changing Worker Demographics, Prevention through Design (PtD), Safety Health & Ergonomics (SH&E) Strategies, Construction

1. Physical, Psychological, Demographic Changes

The author recalls in 1980s, William Perry was the 1st National Football League (NFL) player whose weight exceeded 300 lbs. Today there are hundreds of NFL and College Football players whose weight exceeds 300 lbs. The NFL reports the average weight of NFL defensive lineman increased from 200+ lbs to 275+lbs from 1935 to 1995. The National Basketball Association (NBA) reports during the 1970s
seasons, Kareem Abdul-Jabbar aka Lew Alcindor was 7’ 2” and weighed 265 lbs. Today, many NBA and college centers match this stature and weight.

In the early 1960s, the average American male and female weighed 168 lbs and 142 lbs respectively. Today, the average male and female weight is 180 lbs and 152 lbs respectively (Cutler et al., 2003).

The primary measure of obesity is the Body Mass Index (BMI) i.e. weight in kilograms divided by height in meters squared (kg/m\(^2\)) or weight in pounds divided by height in inches squared and multiplied by a conversion factor of 703 ([lb/in\(^2\)] x 703). BMI is used as a screening tool to identify possible weight problems for adults. BMI between 25 – 30 is defined as Overweight and over 30 is Obese (Cutler et al., 2003). Medical evidence indicates rates of disease and death may increase when the BMI is above 25. A study published in the December 2014 issue of the Journal of the American College of Cardiology report people who are “severely obese” (BMI over 35) had twice the risk of developing heart failure than those of normal weight. Prevalence of adults in the US who are obese is still high, with about one-third of adults being obese in 2008 (Center for Disease Control).

In 1971 both male and females adults in the US had an average BMI of 25 which increased to 27.1 by 1994. But the % of adults whose BMI exceeded 30 increased from 15% in 1971 to 28% by 1994. From 1970 to 1994, a significant % of the general population of adults in the US was heavier, more obese with an increase risk of serious health problems (Cutler et al., 2003). In 2007, the Duke University Health and Safety Surveillance System found obese workers (BMI >/= 40) had twice the number of Workers’ Compensation claims as recommended-weight workers (BMI < 25) i.e. 11.65 vs 5.80 claims per 100 Full Time Employees respectively (Ostbye et al., 2007). The estimated number of workdays lost to obesity related illness or injury is 40 million days per year at a cost of 1% of US Gross National Product (GNP) i.e. $147 billion (Bennington, 2010). The increase of obesity in the US is expected to continue. Two thirds of Americans are overweight and are less physically active than their parents’ and grandparents’ generations (Stein, 2007).

The average age of US workers is increasing primarily because the huge number of “baby boomers” who entered the labor pool starting in the mid-1960s are choosing to work (full or part-time) beyond the tradition retirement age of 65. In 1990, 8.6% of workers 65 years old or older participated in the labor force. Twenty years later in 2010, labor force participation of workers 65+ increased to 13.8% and is projected to continue increasing to 19.2% of the labor force by 2020 (Toossi, 2012). Wright & Mital (1999) found age had no significant influence on older peoples’ (age 55 – 74) psychophysical (acceptable) material handling strengths (capabilities) to lift loads. While several biological changes naturally occur with age such as reduction in muscle mass and oxygen uptake resulting in less physical capacity, older workers leverage their knowledge, skills and motivation so the quantity and quality of work equals or exceeds younger workers (Fox et al., 2015). Consequently, workers over 50 performing manual tasks are less likely to be injured by overexertion but reduction in visual/hearing acuity and balance makes them more prone to slip/falls. Once injured, older workers heal slower with higher lost work days (Schwatka et al., 2012).

The labor force participation rate of US workers of Hispanic and Asian origin shows a steady increase i.e. 8.4% and 3.7% respectively in 1990; 14.2% and 4.7% in 2010; projected to be 17.5% and 5.7% in
The safety and ergonomics implications of workers’ ethnicity are beginning to be studied. For example, roofers of Hispanic origins have a higher fatal fall rate than non-Hispanic origins (Dong et al., 2013).

Another significant change which has occurred in the past 50 years is the labor force participation rate by gender. In 1960, slightly more than 80% of males and slightly less than 40% were females were in the labor force. By 2010, the work force participation rate narrowed to slightly more than 60% of males and slightly less than 60% of females (Toossi, 2012). Recent research which attempted to redo the “Snook’s Tables of the 1970s” shows male worker capacity to perform manual tasks such as lifting/lowering, pushing/pulling and carrying has decreased significantly but female capacity to perform these manual tasks without overexertion remained about the same (Ciriello et al., 2008). The physical capacity of both genders to perform these manual tasks without overexertion has converged with only slight differences (Ciriello et al., 2011).

2. Changes to Ergonomics Research Strategies

Researchers studying workers’ capacity to perform manual tasks may assume workers’ characteristics have remained unchanged. The authors believe worker characteristics are changing faster than researchers can provide scientific conclusions and develop “good practices” for industry.

The physical, psychological and demographic changes of the US workforce since the 1960s are complex and are expected to continue to change for the foreseeable future. Because of the complexity of worker characteristics, research requires long periods of time. For example, Snook’s Table and the University of Michigan’s Biomechanical models were developed in the 1970s and 80s, NIOSH’s Lifting Equation was revised in 1994 and further refined by the Variable Lifting Equation (Waters et al., 2009). One of the limitations of applying the LE to “outdoor” construction lifting tasks in the temperature range 66 – 79 degrees F and humidity range of 35 – 50% (Waters et al., 1994). Many construction tasks are performed above or below these ranges so the risk of injury from overexertion in these ranges needs to be studied in the future.

Recent preliminary studies that “repeated” the psychophysical studies of the 1970 – 80s i.e. Snook Tables (Snook et al., 1970, 1978) and published by Liberty Mutual Research Institute for Safety (Snook & Ciriello, 1991) show a significant shift in Maximum Acceptable Weight (MAW) for male workers performing lifting/lowering and carrying tasks (69%) and lesser shift i.e. 82% of Maximum Average Force (MAF) in the pushing/pulling tasks (Ciriello et al., 2008). A similar shift was “observed” in 2001 when studying lowering tasks of varying box sizes (Ciriello, 2001) if confirmed by future research, these suggest the Load Constant (LC) of 51 lbs for NIOSH LE and its European derivatives should be reduced to 35 lbs.

Lowering this LC to 35 lbs would have implications beyond the US since the majority of manual lifting tasks in construction worldwide would exceed this hypothetical 35 lbs. For example, a study in 2013 in Nigeria (Adeyemi et al., 2013) shows 76% of construction lifting tasks had a lifting index (LI) greater than 1.0 using the current 51 lbs LC of NIOSH’s LE so using the lower LC would mean even fewer lifting tasks could be performed without the risk of overexertion. This study also concluded redesigning work methods is necessary and construction managers need proactive measures to incorporate ergonomics into their job methods to achieve Single Task LI of 1.0 or less. In a two year study in nine construction trades, more than half (i.e. 73%) of workers reported the most important reason for using ergonomic measures was lightening the load (Boschman et al., 2015).

Tables 1 and 2 below show the change in the average Recommended Weight Limit (RWL) and average Lifting Index (LI) from the authors’ 2012 study when hypothetical Load Constant (LC) of 35lbs is used instead of the current LC of 51lbs. The average RWL decreased from 16.33 lbs. to 11.21 lb. and the average LI increased significantly from 2.35 to 3.42. From the NIOSH perspective, it is likely 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).

### Table 1. 2014 Results using LC of 35lbs

<table>
<thead>
<tr>
<th>Observation (n=292)</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>
</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>22.89</td>
<td>192.00</td>
<td>18.60</td>
</tr>
</tbody>
</table>

### Table 2. 2012 Results using LC of 51lbs

<table>
<thead>
<tr>
<th>Observation (n=292)</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>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>
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<tr>
<td>Min</td>
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<td>0.63</td>
<td>0.82</td>
<td>0.42</td>
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<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>
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<td>1.00</td>
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<td>0.94</td>
<td>1.00</td>
<td>33.36</td>
<td>192.00</td>
<td>12.76</td>
</tr>
</tbody>
</table>

### Graph

- **LC=35lbs**
- **LC=51lbs**

The graph illustrates the lifting index (LI) for various trade/occupations, comparing the results for LC=35lbs and LC=51lbs.的职业。
Figure 1. Lifting Index Results Comparison by Trade/Occupation

Figure 1 shows the changes in the median Lifting Index (LI) by Trade/Occupation from the authors' 2012 study when hypothetical Load Constant (LC) of 35lbs is used instead of the current LC of 51lbs. With LC of 51 lbs., there were only one third (5 out of 14 trades) recorded LI>3.0. However, with the hypothetical LC of 35 lbs., it turned out that approximately 2/3 of trades (i.e., ceiling installer, drywall installer, floor finisher, insulator, laborer, painter, plumber, and sod layer) associated with highly stressful lifting tasks (LI>3.0). According to NIOSH, nearly all workers will be at an increased risk of a work-related injury when performing highly stressful lifting tasks (i.e., lifting tasks that would exceed a LI of 3.0) (Waters et al., 1994).

3. Implications for “Good Practices”

Because worker characteristics changed during past decades of research, assessment tools and good practices may not be applicable for current workers. The authors propose a new ergonomic strategy, an Ergonomic Action Level (EAL), similar to the Action Level used in the industrial hygiene area. The concept of EAL is that good practices should anticipate changes in worker characteristics and be designed into tasks below the level known or suspected to cause injury to workers. For example, the Informational Appendix D of ANSI/ASSE A10 -2007 (2013) Reduction of Musculoskeletal Problems in Construction asks contractors to consider "What heavy materials or equipment are being handled on site – anything over 20 pounds?" and "Do workers have to lift more than 20 pounds often?" These "informational only" questions which are not part of the approved standard, suggest contractors should "take action" i.e. identify and consider changes when materials and equipment weighing more than 20 pounds are lifted often. This suggested "action point" is considerably below the 51 lbs of Load Constant (LC) of NIOSH’s current LE.

The authors believe if a “proactive” Ergonomic Action Level (EAL) is used as a design guideline, upstream planning will be needed because the weight of common construction materials and equipment will most likely exceed these new guidelines. Architects, engineers, constructors, manufacturers and Safety & Ergonomic Practitioners will need to rethink the construction process to include increased automation, mechanization, modularization and prefabrication.

Hierarchy of Controls per ANSI/AIHA Z10-2005 directs the best and most effective control is eliminate/“design out” work site exposures followed by substitution, engineering controls, administrative controls, and as the last resort –personal protective equipment (PPE).

Here are some examples to consider. It is obvious that a backhoe operator can move more dirt safely than a laborer with a shovel. Landscape contractors have mechanized the sod laying task by using bulk rolls that are cut and placed mechanically. The author recalls as a laborer in the 1960s handling 4’ x 8’ wooden concrete foundation forms that weighed over 100 lbs, but today’s aluminum forms are lighter and hoisted into place by truck mounted hoists. The development of Insulated Concrete Blocks (ICB) for foundations and above ground walls further reduces manual tasks and construction time. Nano particles are beginning to be used to strengthen concrete as a replacement for rebar eliminating the manual handling and tying at worksites. The removal of asphalt shingles from residential roofs has recently been mechanized - see http://www.arrelsystems.com . The author envisions the strenuous manual task of roofing with asphalt shingles might be changed by using a large, prefabricated section hoisted in place by crane or the development of a track mounted, automated “shingling device”. Installing embedded concrete inserts into ceiling forms would eliminate the need for prolonged overhead drilling that would be needed to place all-thread rods for a ceiling system (Albers &Estill. 2007). Requiring employees to use a mechanical lift or hoist to raise themselves closer to their work would prevent them from having to raise their arms above their shoulders (Choi et al., 2007). Mechanical placement of kerbs in the UK could replace manual handling (Bust et al., 2005). Using a mechanical device to hold a heavy tool in place while the employee is using the tool would reduce the physical burden for the worker (Bust et al., 2005).
The authors have discussed how the weight of common construction materials could be determined more easily at work sites using a concept called the B Factor of Construction Materials (Choi et al., 2009) (Borchardt & Choi, 2012 & 2013). The author is currently working on a “B Factor” App which would enable safety and ergonomic practitioners to determine weight of common construction material on worksites so workers’ capacity can be better matched with task demands. An engineering control approach could be used to modify the size, weight and design of packaging of construction materials at the manufacturing facility.

4. Discussion

The increase in the average LI to 3.42 (>3.0) for construction tasks in the authors’ 2012 study means most experts agree nearly all current workers performing these highly stressful lifting tasks will be at increased risk of work related injury. The decrease in the average RWL to 11.21lbs means few lifting tasks can be performed manually at worksites by current workers without significant weight reduction of materials, tools, equipment or significant changes in work methods such as automation, mechanization, creating modular components. However, reducing the weight of construction materials, tools and equipment to RWL may not be feasible in many cases because of the increased packaging and handling costs.

The authors believe Prevention through Design (PtD) is necessary to develop and implement effective SH&E strategies for today’s construction workforce. Lowering the RWL of manual lifting tasks in construction increases the need for improved safety and ergonomic planning and designing phases.

If the suggested set point for today’s males workers is validated and reduced to the suggested 69% of Liberty Mutual’s original MAW or NIOSH LC, then “nearly all workers will be at increased risk of injury” when manually handling materials, tools and equipment at worksites. This increases the importance of Prevention through Design (PtD) and implementing other SH & E strategies at worksites.

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References


