



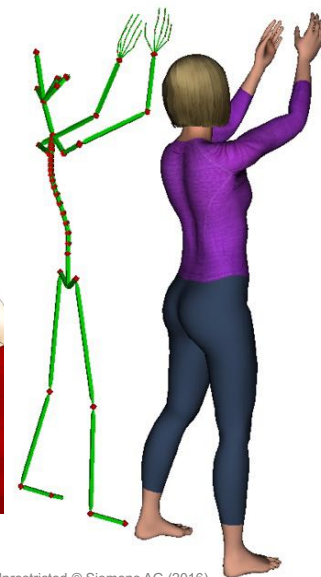
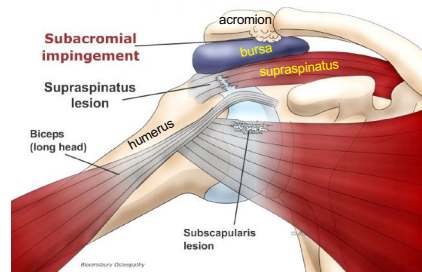
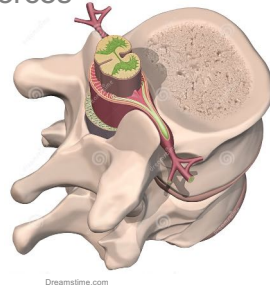
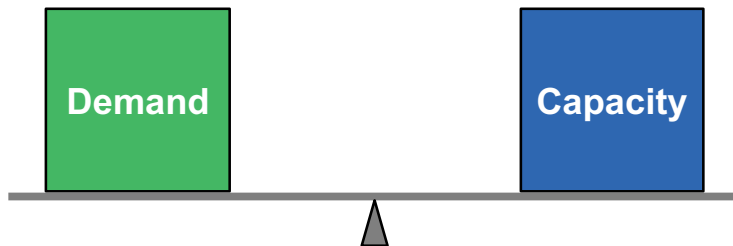
A Critical Analysis of Existing Methods for Biomechanical Risk Assessment

Jim Potvin, PhD
Potvin Biomechanics Inc.



Introduction

- Workplace injury risk
 - Demand / Capacity
- Ergonomic assessment tools
 - Demand
 - input loads & postures
 - manual materials handling, hand-intensive tasks, manual arm forces
 - calculate tissue demands
 - lumbar joint compression & shear forces
 - tendon forces
 - joint muscle strength demands
 - Capacity
 - biomechanics
 - passive tissue strength
 - muscle strength
 - physiology
 - cumulative passive tissue damage
 - muscle fatigue
 - psychophysics
 - perception of biomechanics & physiology feedback



- Ease of use vs validity??



Topics

- **Manual Materials Handling**

- Challenging the Validity of the Revised NIOSH Lifting Equation
 - Potvin (2014)
 - **The Liberty Mutual Manual Materials Handling Equations**
 - Potvin, Ciriello, Snook, Maynard & Brogmus (2021)

- **Upper Extremity Demands**

- Challenging the Validity of 3DSSPP for Estimating Manual Arm Strength
 - Hall, La Delfa, Lomas & Potvin (2021)
 - **The Arm Force Field**
 - La Delfa & Potvin (2017)
- **A Method to Assess Above-Shoulder Work**
 - Rempel & Potvin (in review)



Challenging the Validity of the Revised NIOSH Lifting Equation



NIOSH Guidelines

- Recommended Weight Limit
 - Epidemiology: increased risk of injury for some
 - Biomechanics: lumbar compression force of 3,400 N at L5/S1 joint
 - Physiology: 3.5 kcal/min metabolic cost
 - Psychophysics: 75% of females capable (Snook & Ciriello, 1991)

Revised NIOSH equation for the design and evaluation of manual lifting tasks

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ARUN GARG¶, and LAWRENCE J. FINE‡

‡ National Institute for Occupational Safety and Health,
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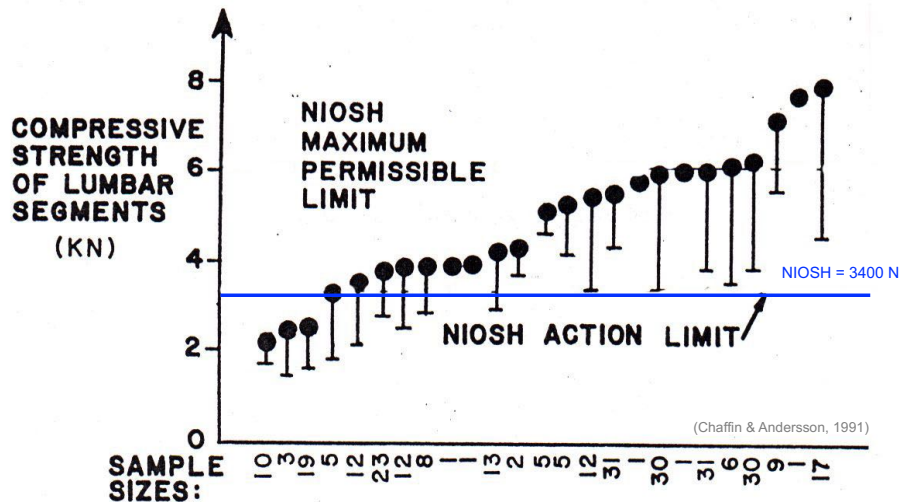
¶ Department of Industrial and Systems Engineering,
University of Wisconsin-Milwaukee, WI 53201, USA

ERGONOMICS, 1993, VOL. 36, NO. 7, 749-776



Criteria for Acceptable Loads

Biomechanics Criterion



Psychophysics Criterion

(Snook & Ciriello, 1991)

Table 3.

| Width† | Distances‡ | Percent‡ | Floor level to knuckle height One lift every | | | | | | | | |
|--------|------------|----------|---|----|----|----|----|----|-----|----|---|
| | | | 5 | 9 | 14 | 1 | 2 | 5 | 30 | 8 | |
| | | | s | | | | | | min | | h |
| 76 | | 90 | 5 | 6 | 7 | 7 | 8 | 8 | 9 | 12 | |
| | | 75 | 7 | 8 | 9 | 9 | 10 | 10 | 11 | 14 | |
| | | 50 | 8 | 10 | 10 | 11 | 12 | 12 | 13 | 17 | |
| | | 25 | 9 | 11 | 12 | 13 | 14 | 14 | 15 | 21 | |
| 75 | 51 | 10 | 11 | 13 | 14 | 14 | 15 | 16 | 17 | 23 | |
| | | 90 | 6 | 7 | 8 | 8 | 9 | 9 | 10 | 14 | |
| | | 75 | 7 | 9 | 9 | 10 | 11 | 11 | 13 | 17 | |
| | | 50 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 21 | |
| 25 | | 25 | 10 | 12 | 13 | 15 | 16 | 16 | 18 | 24 | |
| | | 10 | 11 | 14 | 15 | 17 | 18 | 18 | 20 | 27 | |
| | | 90 | 6 | 8 | 8 | 9 | 9 | 9 | 11 | 14 | |
| | | 75 | 8 | 10 | 11 | 11 | 12 | 12 | 13 | 18 | |
| | | 50 | 10 | 12 | 13 | 13 | 14 | 14 | 16 | 21 | |
| | | 25 | 11 | 14 | 15 | 15 | 16 | 17 | 19 | 25 | |
| | | 10 | 13 | 16 | 17 | 17 | 19 | 19 | 21 | 29 | |

Prediction of metabolic rates for manual materials handling jobs*

Garg et al (1978)

ARUN GARG, DON B. CHAFFIN** and GARY D. HERRIN**

Systems—Design Department, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin 53201; **The University of Michigan, Ann Arbor, Michigan, 48109

squat lift (kcal/lift)

$$\Delta E = 10^{-2} [0.514 BW (0.81-h_1) + (2.19L + 0.62 S \times 1.) (h_2 - h_1)] \text{ for } h_1 < h_2 \leq 0.81$$

Physiology Criterion

(Garg et al, 1978)

Revised NIOSH Lifting Equation

Recommended Weight of Lift (RWL) = 23 kg * H-mult * V-mult * D-mult * F-mult * A-mult * C-mult

H-multiplier - horizontal location of the load
 - middle of ankles to
 - middle of knuckles (cm)

$25 / H$

V-multiplier – vertical location of load

$1 - 0.003 | V - 75 |$

D-multiplier - vertical travel distance
 - origin to destination (cm)

$0.82 + (4.5 / D)$

F-multiplier - frequency of lifting
 - lifts / minute on average

from look-up table

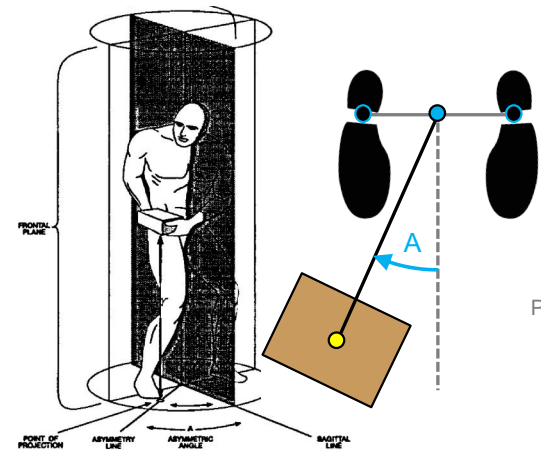
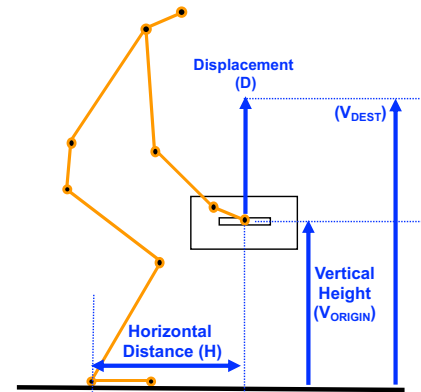
A-multiplier - asymmetry angle
 - rotation of shoulders wrt ankles (deg)

$1 - (0.0032 * A)$
 (at A > 135 deg, A-mult = 0)

C-multiplier - coupling quality

| | | |
|-------------------|------|------|
| Good (handles) | 1.00 | 1.00 |
| Fair | 0.95 | 1.00 |
| Poor (no handles) | 0.90 | 0.90 |

| | |
|--------|--------|
| V < 75 | V ≥ 75 |
| 1.00 | 1.00 |
| 0.95 | 1.00 |
| 0.90 | 0.90 |



Potvin (2021)

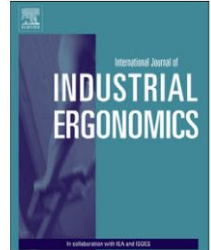




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Comparing the revised NIOSH lifting equation to the psychophysical, biomechanical and physiological criteria used in its development

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Composite Acceptable Load (CAL): Potvin (2014)

- Start with Snook Table values
 - 27 locations x 8 frequencies = 216 conditions
- Replace values based on:
 - Biomechanics Criterion
 - determine hand load resulting in 3,400 N compression force
 - Potvin (1997)
 - Physiology Criterion
 - use Garg Equations to determine loads resulting in
 - 3.1 kcal/min ($V \leq 75$ cm)
 - 2.2 kcal/min ($V > 75$ cm)
- Composite Acceptable Load (CAL)
 - most conservative (lowest) of:
 - Psychophysics Criterion
 - Biomechanics Criterion
 - Physiology Criterion

| Discipline | Design criterion | Cut-off value | | |
|---------------|--------------------------------|---------------------|-------|-------|
| Biomechanical | Maximum disc compression force | 3.4 kN (770 lbs) | | |
| | | Duration of lifting | | |
| | Lift location (V) cm (in.) | < 1 h | 1-2 h | 2-8 h |
| | $V \leq 75$ (30) | 4.7 | 3.7 | 3.1 |
| | $V > 75$ (30) | 3.3 | 2.7 | 2.2 |



Composite Acceptable Load (CAL): Potvin (2014)

| Range | V | D | Width | H | Frequency (Lifts/min) | | | | | | | |
|-----------------------|-------|----|-------|------|-----------------------|-------|------|------|----|-----|-----|-----|
| | | | | | 0.002 | 0.033 | 0.2 | 0.5 | 1 | 4.3 | 6.7 | 12 |
| S-R | 128.0 | 76 | 75 | 57.5 | 10 | 8 | 8 | 8 | 7 | 5.4 | 2.8 | 0.6 |
| Shoulder to Arm Reach | 140.5 | 51 | 75 | 57.5 | 11 | 9 | 9 | 9 | 8 | 7.8 | 4.1 | 1.1 |
| | 153.5 | 25 | 75 | 57.5 | 12 | 10 | 9 | 9 | 9 | 8 | 7 | 2.9 |
| Arm Reach | 128.0 | 76 | 49 | 44.5 | 11 | 9 | 8 | 8 | 8 | 5.4 | 2.8 | 0.6 |
| | 140.5 | 51 | 49 | 44.5 | 12 | 10 | 9 | 9 | 9 | 7.8 | 4.1 | 1.1 |
| Arm Reach | 153.5 | 25 | 49 | 44.5 | 13 | 11 | 10 | 10 | 9 | 8 | 7 | 2.9 |
| | 128.0 | 76 | 34 | 37.0 | 13 | 11 | 10 | 10 | 9 | 5.4 | 2.8 | 0.6 |
| Arm Reach | 140.5 | 51 | 34 | 37.0 | 14 | 12 | 11 | 11 | 11 | 7.8 | 4.1 | 1.1 |
| | 153.5 | 25 | 34 | 37.0 | 16 | 14 | 12 | 12 | 12 | 9 | 8 | 2.9 |
| K-S | 66.0 | 76 | 75 | 57.5 | 12.3 | 12 | 11 | 11 | 10 | 8 | 4.6 | 1.3 |
| Knuckle to Shoulder | 78.5 | 51 | 75 | 57.5 | 12.8 | 12.8 | 12 | 12 | 11 | 9 | 5.2 | 2.2 |
| | 91.5 | 25 | 75 | 57.5 | 14.0 | 14 | 13 | 13 | 12 | 9 | 8 | 5.8 |
| Knuckle to Shoulder | 66.0 | 76 | 49 | 44.5 | 14 | 12 | 11 | 11 | 10 | 8 | 4.6 | 1.3 |
| | 78.5 | 51 | 49 | 44.5 | 15 | 13 | 12 | 12 | 11 | 9 | 5.2 | 2.2 |
| Knuckle to Shoulder | 91.5 | 25 | 49 | 44.5 | 17 | 14 | 13 | 13 | 12 | 9 | 8 | 5.8 |
| | 66.0 | 76 | 34 | 37.0 | 15 | 13 | 12 | 12 | 11 | 8.8 | 4.6 | 1.3 |
| Knuckle to Shoulder | 78.5 | 51 | 34 | 37.0 | 17 | 14 | 13 | 13 | 12 | 9.0 | 5.2 | 2.2 |
| | 91.5 | 25 | 34 | 37.0 | 18 | 16 | 14 | 14 | 13 | 11 | 10 | 5.8 |
| F-K | 0.0 | 76 | 75 | 62.5 | 10.9 | 10.9 | 10 | 10 | 9 | 9 | 2.5 | 0.0 |
| Floor to Knuckle | 12.5 | 51 | 75 | 62.5 | 11.0 | 11.0 | 11 | 11 | 10 | 9 | 7.5 | 0.0 |
| | 25.5 | 25 | 75 | 57.5 | 11.0 | 11.0 | 11.0 | 11.0 | 11 | 11 | 10 | 0.0 |
| Floor to Knuckle | 0.0 | 76 | 49 | 49.5 | 13.6 | 12 | 10 | 10 | 10 | 9 | 2.5 | 0.0 |
| | 12.5 | 51 | 49 | 49.5 | 13.7 | 13.7 | 12 | 12 | 11 | 9 | 7.5 | 0.0 |
| Floor to Knuckle | 25.5 | 25 | 49 | 44.5 | 13.8 | 13.8 | 13 | 12 | 12 | 11 | 10 | 0.0 |
| | 0.0 | 76 | 34 | 42.0 | 15.7 | 14 | 13 | 13 | 12 | 11 | 2.5 | 0.0 |
| Floor to Knuckle | 12.5 | 51 | 34 | 42.0 | 15.8 | 15.8 | 15 | 15 | 14 | 12 | 7.5 | 0.0 |
| | 25.5 | 25 | 34 | 37.0 | 16.0 | 16.0 | 15 | 15 | 14 | 13 | 12 | 0.0 |

H = 20 + Width / 2
H = 25 + Width / 2

Compression = 3400 N

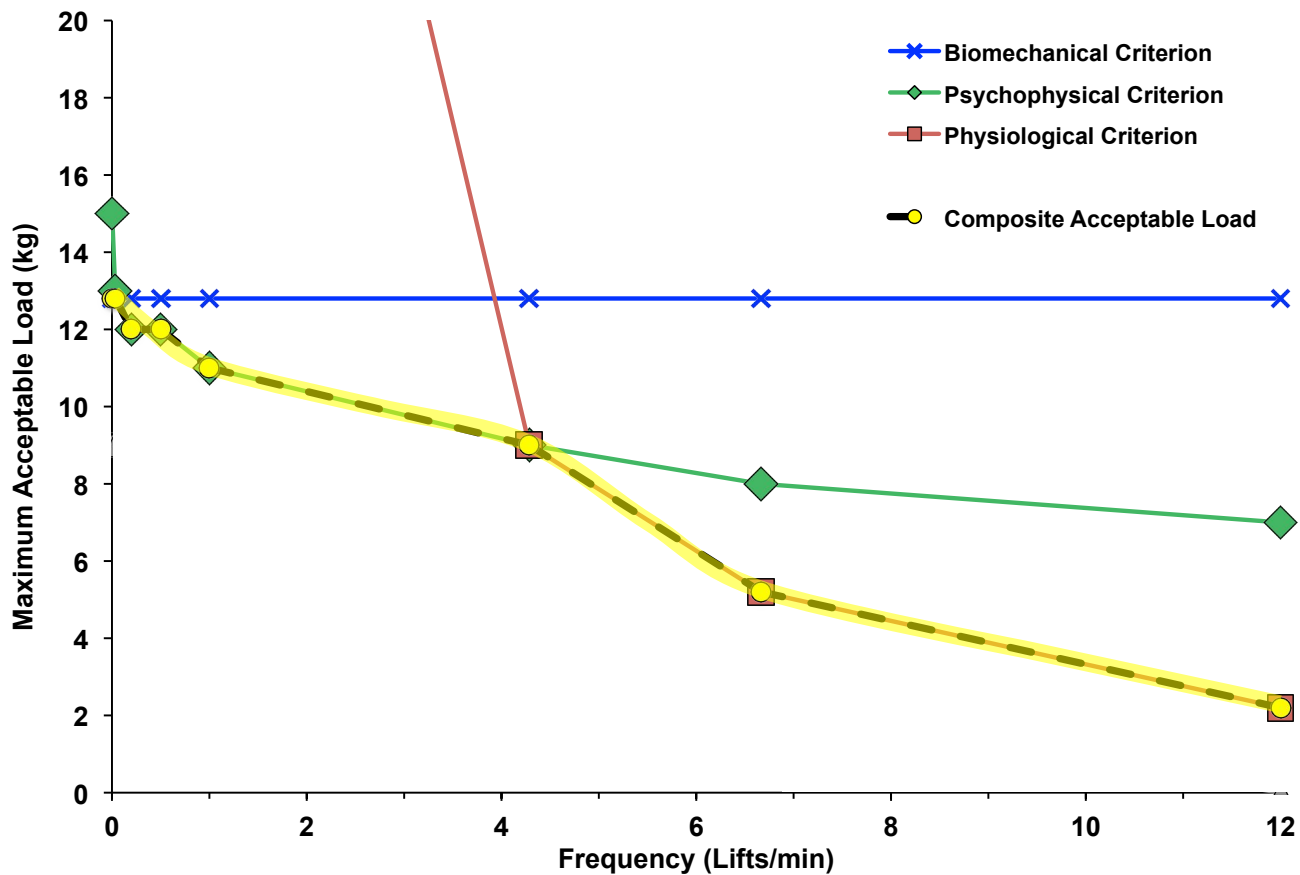
Snook = 75% Capable

Garg = 3.1 kcal/min (V ≤ 75 cm)
= 2.2 kcal/min (V > 75 cm)

Example:

- Knuckle-to-Shoulder Lift
- D = 51 cm
- box width = 75 cm

12.8 12.8 12 12 11 9 5.2 2.2

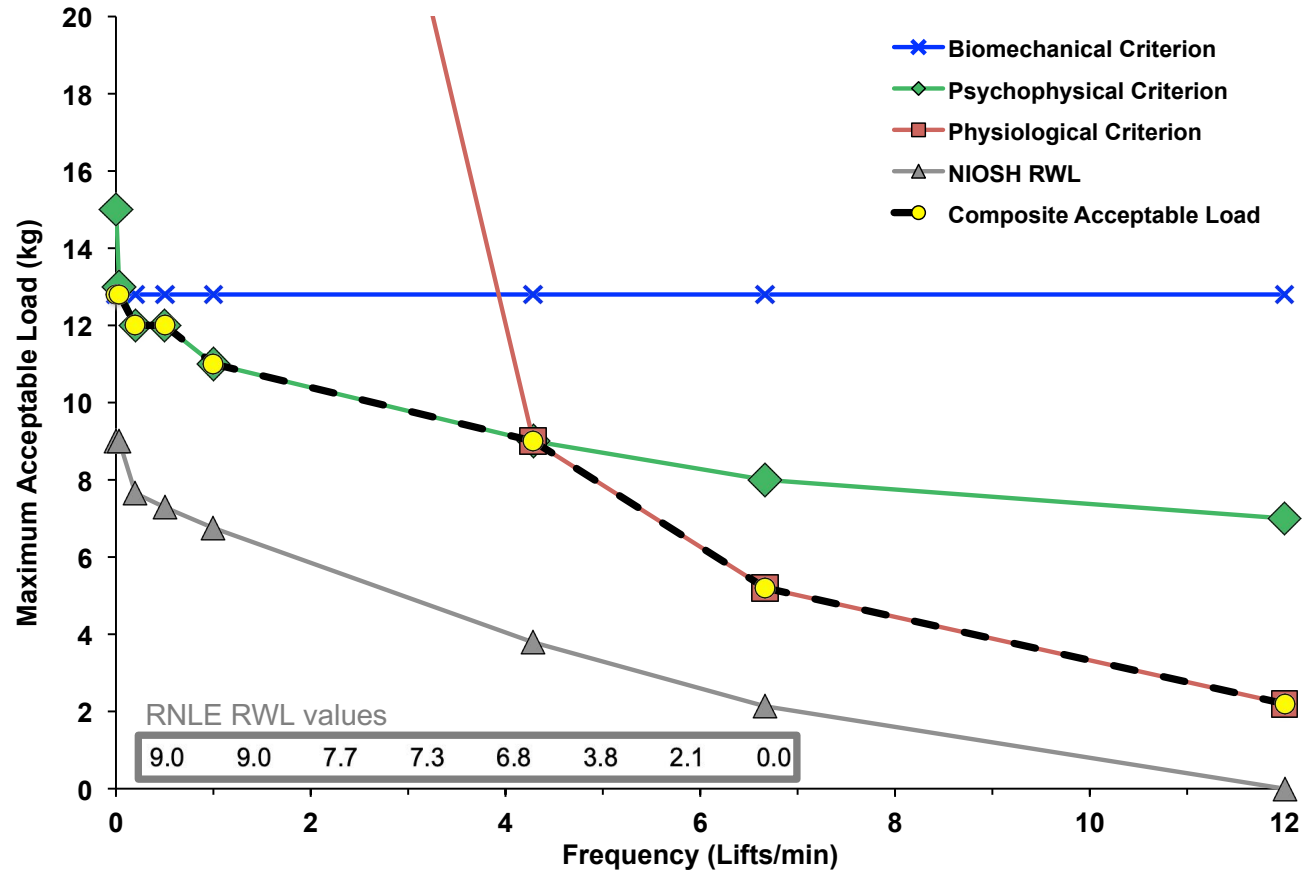


RNLE RWLs for Liberty Mutual Female Lift Table Conditions

| Range | V | D | Width | H | Frequency (Lifts/min) | | | | | | | |
|-----------------------------|-------|----|-------|------|-----------------------|-------|------|------|------|-----|-----|-----|
| | | | | | 0.002 | 0.033 | 0.2 | 0.5 | 1 | 4.3 | 6.7 | 12 |
| S-R | 128.0 | 76 | 75 | 57.5 | 7.2 | 7.2 | 6.1 | 5.8 | 5.4 | 3.0 | 1.7 | 0.0 |
| | 140.5 | 51 | 75 | 57.5 | 7.4 | 7.4 | 6.3 | 6.0 | 5.5 | 3.1 | 1.7 | 0.0 |
| | 153.5 | 25 | 75 | 57.5 | 7.7 | 7.7 | 6.6 | 6.3 | 5.8 | 3.3 | 1.8 | 0.0 |
| Shoulder to Arm Reach | 128.0 | 76 | 49 | 44.5 | 9.3 | 9.3 | 7.9 | 7.5 | 7.0 | 3.9 | 2.2 | 0.0 |
| | 140.5 | 51 | 49 | 44.5 | 9.5 | 9.5 | 8.1 | 7.7 | 7.1 | 4.0 | 2.3 | 0.0 |
| | 153.5 | 25 | 49 | 44.5 | 10.0 | 10.0 | 8.5 | 8.1 | 7.5 | 4.2 | 2.4 | 0.0 |
| | 128.0 | 76 | 34 | 37.0 | 11.2 | 11.2 | 9.5 | 9.1 | 8.4 | 4.7 | 2.7 | 0.0 |
| | 140.5 | 51 | 34 | 37.0 | 11.4 | 11.4 | 9.7 | 9.3 | 8.6 | 4.8 | 2.7 | 0.0 |
| | 153.5 | 25 | 34 | 37.0 | 12.0 | 12.0 | 10.2 | 9.7 | 9.0 | 5.1 | 2.8 | 0.0 |
| K-S | 66.0 | 76 | 75 | 57.5 | 8.7 | 8.7 | 7.4 | 7.1 | 6.5 | 3.7 | 2.1 | 0.0 |
| | 78.5 | 51 | 75 | 57.5 | 9.0 | 9.0 | 7.7 | 7.3 | 6.8 | 3.8 | 2.1 | 0.0 |
| | 91.5 | 25 | 75 | 57.5 | 9.5 | 9.5 | 8.1 | 7.7 | 7.1 | 4.0 | 2.3 | 0.0 |
| Knuckle to Shoulder | 66.0 | 76 | 49 | 44.5 | 11.3 | 11.3 | 9.6 | 9.1 | 8.4 | 4.7 | 2.7 | 0.0 |
| | 78.5 | 51 | 49 | 44.5 | 11.6 | 11.6 | 9.9 | 9.4 | 8.7 | 4.9 | 2.8 | 0.0 |
| | 91.5 | 25 | 49 | 44.5 | 12.3 | 12.3 | 10.5 | 10.0 | 9.2 | 5.2 | 2.9 | 0.0 |
| | 66.0 | 76 | 34 | 37.0 | 13.5 | 13.5 | 11.5 | 11.0 | 10.2 | 5.7 | 3.2 | 0.0 |
| | 78.5 | 51 | 34 | 37.0 | 14.0 | 14.0 | 11.9 | 11.3 | 10.5 | 5.9 | 3.3 | 0.0 |
| 91.5 | 25 | 34 | 37.0 | 14.8 | 14.8 | 12.6 | 12.0 | 11.1 | 6.2 | 3.5 | 0.0 | |
| F-K | 0.0 | 76 | 75 | 62.5 | 6.3 | 6.3 | 5.3 | 5.1 | 4.7 | 2.6 | 1.5 | 0.0 |
| | 12.5 | 51 | 75 | 62.5 | 6.7 | 6.7 | 5.7 | 5.5 | 5.1 | 2.8 | 1.6 | 0.0 |
| | 25.5 | 25 | 75 | 57.5 | 7.8 | 7.8 | 6.6 | 6.3 | 5.8 | 3.3 | 1.8 | 0.0 |
| Floor to Knuckle | 0.0 | 76 | 49 | 49.5 | 7.9 | 7.9 | 6.7 | 6.4 | 5.9 | 3.3 | 1.9 | 0.0 |
| | 12.5 | 51 | 49 | 49.5 | 8.5 | 8.5 | 7.2 | 6.9 | 6.4 | 3.6 | 2.0 | 0.0 |
| | 25.5 | 25 | 49 | 44.5 | 9.8 | 9.8 | 8.3 | 8.0 | 7.4 | 4.1 | 2.3 | 0.0 |
| | 0.0 | 76 | 34 | 42.0 | 9.3 | 9.3 | 7.9 | 7.6 | 7.0 | 3.9 | 2.2 | 0.0 |
| | 12.5 | 51 | 34 | 42.0 | 10.0 | 10.0 | 8.5 | 8.1 | 7.5 | 4.2 | 2.4 | 0.0 |
| | 25.5 | 25 | 34 | 37.0 | 11.6 | 11.6 | 9.8 | 9.4 | 8.7 | 4.9 | 2.7 | 0.0 |

Example:

- Knuckle-to-Shoulder Lift
- D = 51 cm
- box width = 75 cm



RNLE RWLs for Liberty Mutual Female Lift Table Conditions

Composite Acceptable Load
for Snook & Ciriello (1991) Conditions

| Range | V | D | Width | H | Frequency (Lifts/min) | | | | | | | |
|-----------------------|-------|-----|-------|------|-----------------------|-------|------|------|----|-----|-----|-----|
| | | | | | 0.002 | 0.033 | 0.2 | 0.5 | 1 | 4.3 | 6.7 | 12 |
| S-R | 128.0 | 76 | 75 | 57.5 | 10 | 8 | 8 | 8 | 7 | 5.4 | 2.8 | 0.6 |
| Shoulder to Arm Reach | 140.5 | 51 | 75 | 57.5 | 11 | 9 | 9 | 9 | 8 | 7.8 | 4.1 | 1.1 |
| | 153.5 | 25 | 75 | 57.5 | 12 | 10 | 9 | 9 | 9 | 8 | 7 | 2.9 |
| | 128.0 | 76 | 49 | 44.5 | 11 | 9 | 8 | 8 | 8 | 5.4 | 2.8 | 0.6 |
| | 140.5 | 51 | 49 | 44.5 | 12 | 10 | 9 | 9 | 9 | 7.8 | 4.1 | 1.1 |
| | 153.5 | 25 | 49 | 44.5 | 13 | 11 | 10 | 10 | 9 | 8 | 7 | 2.9 |
| | 128.0 | 76 | 34 | 37.0 | 13 | 11 | 10 | 10 | 9 | 5.4 | 2.8 | 0.6 |
| K-S | 140.5 | 51 | 34 | 37.0 | 14 | 12 | 11 | 11 | 11 | 7.8 | 4.1 | 1.1 |
| | 153.5 | 25 | 34 | 37.0 | 16 | 14 | 12 | 12 | 12 | 9 | 8 | 2.9 |
| | 66.0 | 76 | 75 | 57.5 | 12.3 | 12 | 11 | 11 | 10 | 8 | 4.6 | 1.3 |
| | 78.5 | 51 | 75 | 57.5 | 12.8 | 12.8 | 12 | 12 | 11 | 9 | 5.2 | 2.2 |
| | 91.5 | 25 | 75 | 57.5 | 14.0 | 14 | 13 | 13 | 12 | 9 | 8 | 5.8 |
| | 66.0 | 76 | 49 | 44.5 | 14 | 12 | 11 | 11 | 10 | 8 | 4.6 | 1.3 |
| Knuckle to Shoulder | 78.5 | 51 | 49 | 44.5 | 15 | 13 | 12 | 12 | 11 | 9 | 5.2 | 2.2 |
| | 91.5 | 25 | 49 | 44.5 | 17 | 14 | 13 | 13 | 12 | 9 | 8 | 5.8 |
| | 66.0 | 76 | 34 | 37.0 | 15 | 13 | 12 | 12 | 11 | 8.8 | 4.6 | 1.3 |
| | 78.5 | 51 | 34 | 37.0 | 17 | 14 | 13 | 13 | 12 | 9.0 | 5.2 | 2.2 |
| | 91.5 | 25 | 34 | 37.0 | 18 | 16 | 14 | 14 | 13 | 11 | 10 | 5.8 |
| | F-K | 0.0 | 76 | 75 | 62.5 | 10.9 | 10.9 | 10 | 10 | 9 | 9 | 2.5 |
| Floor to Knuckle | 12.5 | 51 | 75 | 62.5 | 11.0 | 11.0 | 11 | 11 | 10 | 9 | 7.5 | 0.0 |
| | 25.5 | 25 | 75 | 57.5 | 11.0 | 11.0 | 11.0 | 11.0 | 11 | 11 | 10 | 0.0 |
| | 0.0 | 76 | 49 | 49.5 | 13.6 | 12 | 10 | 10 | 10 | 9 | 2.5 | 0.0 |
| | 12.5 | 51 | 49 | 49.5 | 13.7 | 13.7 | 12 | 12 | 11 | 9 | 7.5 | 0.0 |
| | 25.5 | 25 | 49 | 44.5 | 13.8 | 13.8 | 13 | 12 | 12 | 11 | 10 | 0.0 |
| | 0.0 | 76 | 34 | 42.0 | 15.7 | 14 | 13 | 13 | 12 | 11 | 2.5 | 0.0 |
| H = 20 + Width / 2 | 12.5 | 51 | 34 | 42.0 | 15.8 | 15.8 | 15 | 15 | 14 | 12 | 7.5 | 0.0 |
| H = 25 + Width / 2 | 25.5 | 25 | 34 | 37.0 | 16.0 | 16.0 | 15 | 15 | 14 | 13 | 12 | 0.0 |

Compression = 3400 N

Snook = 75% Capable

Garg = 3.1 kcal/min (V ≤ 75 cm)
= 2.2 kcal/min (V > 75 cm)

RWL
for Snook & Ciriello (1991) Conditions

| Range | V | D | Width | H | Frequency (Lifts/min) | | | | | | | |
|-----------------------|-------|-----|-------|------|-----------------------|-------|------|------|------|-----|-----|-----|
| | | | | | 0.002 | 0.033 | 0.2 | 0.5 | 1 | 4.3 | 6.7 | 12 |
| S-R | 128.0 | 76 | 75 | 57.5 | 7.2 | 7.2 | 6.1 | 5.8 | 5.4 | 3.0 | 1.7 | 0.0 |
| Shoulder to Arm Reach | 140.5 | 51 | 75 | 57.5 | 7.4 | 7.4 | 6.3 | 6.0 | 5.5 | 3.1 | 1.7 | 0.0 |
| | 153.5 | 25 | 75 | 57.5 | 7.7 | 7.7 | 6.6 | 6.3 | 5.8 | 3.3 | 1.8 | 0.0 |
| | 128.0 | 76 | 49 | 44.5 | 9.3 | 9.3 | 7.9 | 7.5 | 7.0 | 3.9 | 2.2 | 0.0 |
| | 140.5 | 51 | 49 | 44.5 | 9.5 | 9.5 | 8.1 | 7.7 | 7.1 | 4.0 | 2.3 | 0.0 |
| | 153.5 | 25 | 49 | 44.5 | 10.0 | 10.0 | 8.5 | 8.1 | 7.5 | 4.2 | 2.4 | 0.0 |
| | 128.0 | 76 | 34 | 37.0 | 11.2 | 11.2 | 9.5 | 9.1 | 8.4 | 4.7 | 2.7 | 0.0 |
| K-S | 140.5 | 51 | 34 | 37.0 | 11.4 | 11.4 | 9.7 | 9.3 | 8.6 | 4.8 | 2.7 | 0.0 |
| | 153.5 | 25 | 34 | 37.0 | 12.0 | 12.0 | 10.2 | 9.7 | 9.0 | 5.1 | 2.8 | 0.0 |
| | 66.0 | 76 | 75 | 57.5 | 8.7 | 8.7 | 7.4 | 7.1 | 6.5 | 3.7 | 2.1 | 0.0 |
| | 78.5 | 51 | 75 | 57.5 | 9.0 | 9.0 | 7.7 | 7.3 | 6.8 | 3.8 | 2.1 | 0.0 |
| | 91.5 | 25 | 75 | 57.5 | 9.5 | 9.5 | 8.1 | 7.7 | 7.1 | 4.0 | 2.3 | 0.0 |
| | 66.0 | 76 | 49 | 44.5 | 11.3 | 11.3 | 9.6 | 9.1 | 8.4 | 4.7 | 2.7 | 0.0 |
| Knuckle to Shoulder | 78.5 | 51 | 49 | 44.5 | 11.6 | 11.6 | 9.9 | 9.4 | 8.7 | 4.9 | 2.8 | 0.0 |
| | 91.5 | 25 | 49 | 44.5 | 12.3 | 12.3 | 10.5 | 10.0 | 9.2 | 5.2 | 2.9 | 0.0 |
| | 66.0 | 76 | 34 | 37.0 | 13.5 | 13.5 | 11.5 | 11.0 | 10.2 | 5.7 | 3.2 | 0.0 |
| | 78.5 | 51 | 34 | 37.0 | 14.0 | 14.0 | 11.9 | 11.3 | 10.5 | 5.9 | 3.3 | 0.0 |
| | 91.5 | 25 | 34 | 37.0 | 14.8 | 14.8 | 12.6 | 12.0 | 11.1 | 6.2 | 3.5 | 0.0 |
| | F-K | 0.0 | 76 | 75 | 62.5 | 6.3 | 6.3 | 5.3 | 5.1 | 4.7 | 2.6 | 1.5 |
| Floor to Knuckle | 12.5 | 51 | 75 | 62.5 | 6.7 | 6.7 | 5.7 | 5.5 | 5.1 | 2.8 | 1.6 | 0.0 |
| | 25.5 | 25 | 75 | 57.5 | 7.8 | 7.8 | 6.6 | 6.3 | 5.8 | 3.3 | 1.8 | 0.0 |
| | 0.0 | 76 | 49 | 49.5 | 7.9 | 7.9 | 6.7 | 6.4 | 5.9 | 3.3 | 1.9 | 0.0 |
| | 12.5 | 51 | 49 | 49.5 | 8.5 | 8.5 | 7.2 | 6.9 | 6.4 | 3.6 | 2.0 | 0.0 |
| | 25.5 | 25 | 49 | 44.5 | 9.8 | 9.8 | 8.3 | 8.0 | 7.4 | 4.1 | 2.3 | 0.0 |
| | 0.0 | 76 | 34 | 42.0 | 9.3 | 9.3 | 7.9 | 7.6 | 7.0 | 3.9 | 2.2 | 0.0 |
| H = 20 + Width / 2 | 12.5 | 51 | 34 | 42.0 | 10.0 | 10.0 | 8.5 | 8.1 | 7.5 | 4.2 | 2.4 | 0.0 |
| H = 25 + Width / 2 | 25.5 | 25 | 34 | 37.0 | 11.6 | 11.6 | 9.8 | 9.4 | 8.7 | 4.9 | 2.7 | 0.0 |

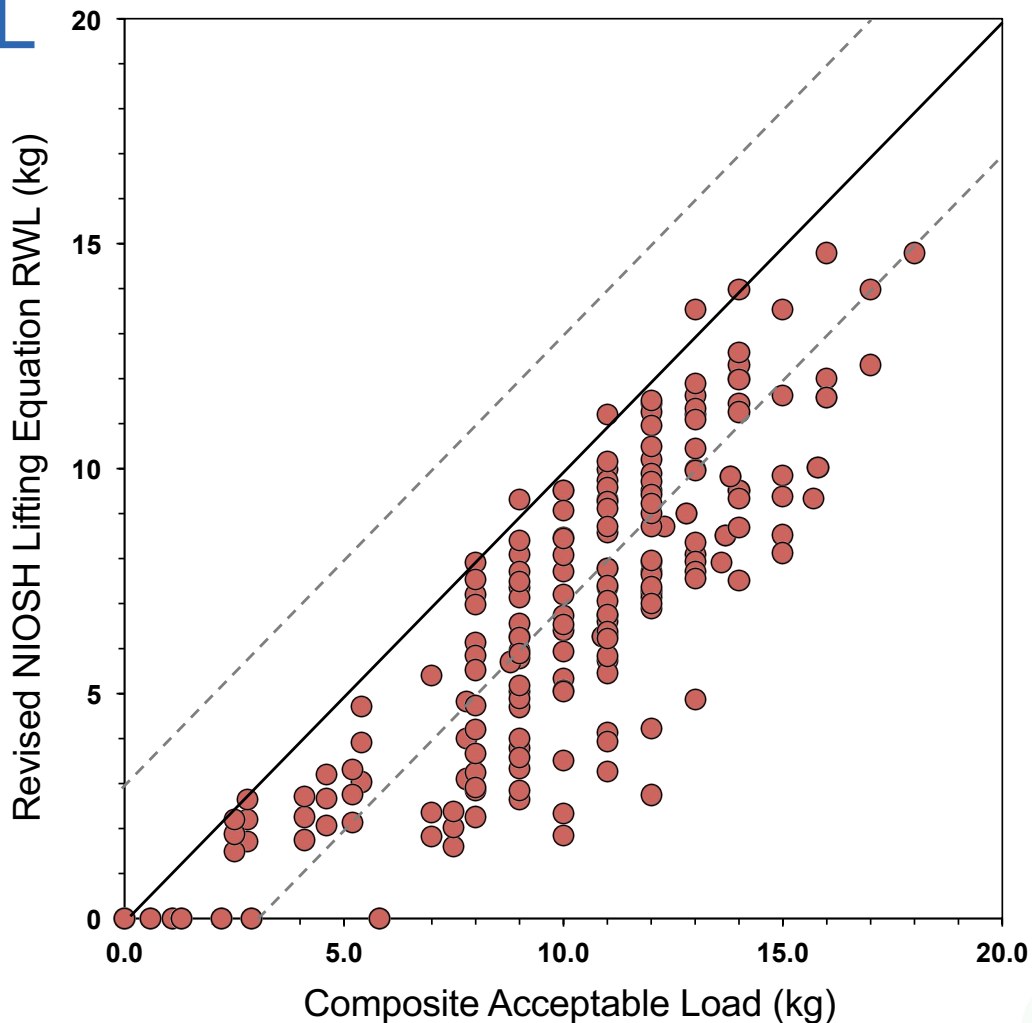
CAL vs RNLE RWL

RMS Error = 3.8 kg (8.4 lbs)
Mean Error = -3.30 kg (-7.3 lbs)

Explained variance = 78%

~95% of females would be capable
of the RNLE RWL Loads
- supposed to be 75% capable

If the RNLE must be used, use a
Lifting Index (LI) of 1.65
- supposed to be LI = 1.00



RNLE Lifting Index vs Risk: Fox et al (2019)

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Understanding outcome metrics of the revised NIOSH lifting equation

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| Lifting Index | Risk | Recommended Actions |
|---------------------|-----------|--|
| $LI \leq 1.0$ | Very Low | None, in general, for the healthy working population |
| $1.0 < LI \leq 1.5$ | Low | Pay attention to low frequency/high load conditions and extreme or static postures. Consider efforts to lower the LI |
| $1.5 < LI \leq 2.0$ | Moderate | Redesign tasks and workplaces according to priorities to reduce the LI |
| $2.0 < LI \leq 3.0$ | High | High priority for changes to the task to reduce the LI |
| $LI > 3.0$ | Very High | Immediate changes should be made to the task to reduce the LI |



New Assessment Tool: The Liberty Mutual Manual Materials Handling Equations



Liberty Mutual MMH Research: 1971 to 1991



Stover Snook

| Task | Participants | 1 |
|------|--------------------------|--------------|
| | | Snook (1971) |
| | | 28 |
| Lift | Conditions | 9 |
| | Box Widths | M |
| | Ranges | FK, KS, SR |
| | Distances per effort (m) | 0.51 |
| | Frequencies (per min) | 1 to 6.7 |
| | Distances per min (m) | 0.51 to 3.4 |

| Gender | Task | Participants | 1 |
|-----------------------|-------|--------------------------|-------------|
| Male | Lift | Conditions | 9 |
| | | Box Widths | M |
| | | Ranges | FK, KS, SR |
| | | Distances per effort (m) | 0.51 |
| | | Frequencies (per min) | 1 to 6.7 |
| | | Distances per min (m) | 0.51 to 3.4 |
| | Lower | Conditions | 9 |
| | | Box Widths | M |
| | | Ranges | FK, KS, SR |
| | | Distances per effort (m) | 0.51 |
| | | Distances per min (m) | 0.51 to 5.1 |
| | Push | Conditions | 12 |
| | | Heights | KnE |
| | | Distances per effort (m) | 2.1 to 30.5 |
| | | Frequencies (per min) | 0.6 to 10 |
| | | Distances per min (m) | 2.1 to 36.5 |
| | Pull | Conditions | 3 |
| | | Heights | KnE |
| | | Distances per effort (m) | 2.1 |
| | | Distances per min (m) | 2.1 to 21.3 |
| | Carry | Conditions | 18 |
| | | Box Widths | M |
| | | Carry Heights | K, E |
| | | Distances per effort (m) | 2.1 to 8.5 |
| Distances per min (m) | | 2.1 to 28.1 | |

Distances - Distance per minute = distance per effort x frequency. Box Widths - "S" = small (0.33 to 0.36 m), "M" = medium (0.49 m), "L" = large (0.75 to 0.76 m), "XL" = extra large (0.96 m), "NH" = no handles

Carry: Heights - "K" = knuckle, "E" = Elbow

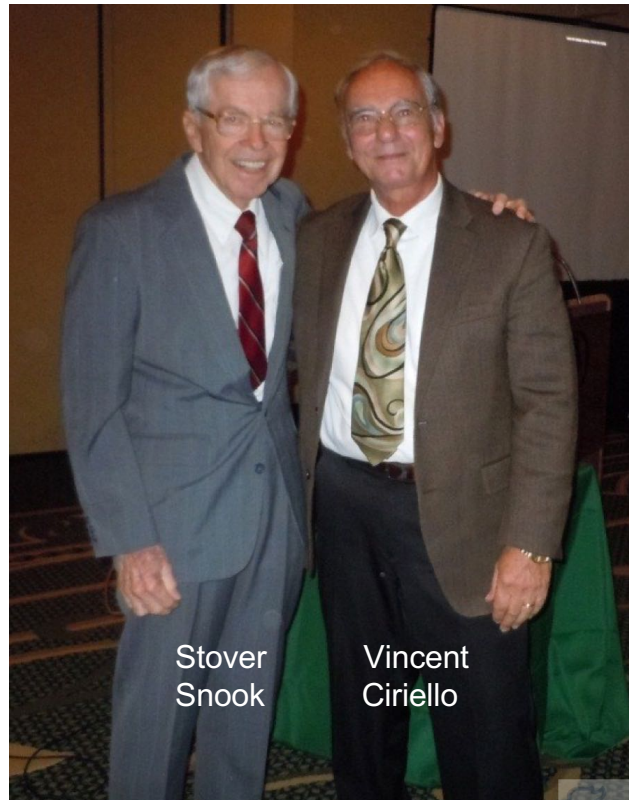
Lift & Lower: Ranges - "FK" = floor-to-knuckle, "KnE" = knee-to-elbow, "KS" = knuckle-to-shoulder, "SR" = shoulder-to-reach.

Pull & Push: Heights - "KnE" = between knee & elbow, "K-15" = knuckle minus 15 cm, "S" = shoulder

Liberty Mutual MMH Research: 1971 to 1991

n = 7

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|--------------------------|-------------|--------------------------|--------------------------|--------------------------|-------------------------|-------------------------|-------------------------------|-------------------------------|-------------|
| | | Snook (1971) | Snook & Ciriello (1974a) | Snook & Ciriello (1974b) | Ciriello & Snook (1978) | Ciriello & Snook (1983) | Ciriello, Snook et al. (1990) | Ciriello, Snook et al. (1993) | |
| Male | Lift | Participants | 28 | 16 | | 15 | 10 | 10 | 6 |
| | | Conditions | 9 | 1 | | 41 | 16 | 6 | 28 |
| | | Box Widths | M | M | | S, M, L | S, M, L | S | S, XL, NH |
| | | Ranges | FK, KS, SR | FK | | FK, KnE, KS | FK, KnE, KS | FK, KnE, KS | FK, KnE, KS |
| | | Distances per effort (m) | 0.51 | 0.51 | | 0.25 to 0.76 | 0.25 to 0.76 | 0.51 | 0.51 |
| | | Frequencies (per min) | 1 to 6.7 | 4.3 | | 1/day to 6.7 | 1/day to 12 | 1 to 4.3 | 1 to 4.3 |
| | Lower | Distances per min (m) | 0.51 to 3.4 | 2.2 | | 0.001 to 5.1 | 0.001 to 6.1 | 0.51 to 2.2 | 0.51 to 2.2 |
| | | Conditions | 9 | | | | 16 | 6 | |
| | | Box Widths | M | | | | S | S | |
| | | Ranges | FK, KS, SR | | | | FK, KS | FK, KnE, KS | |
| | | Distances per effort (m) | 0.51 | | | | 0.51 | 0.51 | |
| | | Frequencies (per min) | 1 to 10 | | | | 1/day to 12 | 1 to 4.3 | |
| | Push | Distances per min (m) | 0.51 to 5.1 | | | | 0.001 to 6.1 | 0.51 to 2.2 | |
| | | Conditions | 12 | 1 | | 16 | 12 | 1 | 1 |
| | | Heights | KnE | KnE | | K-15, KnE, S | KnE | KnE | KnE |
| | | Distances per effort (m) | 2.1 to 30.5 | 15.2 | | 2.1 to 61.0 | 7.6, 30.5 | 7.6 | 15.2 |
| | | Frequencies (per min) | 0.6 to 10 | 2.4 | | 1/day to 4 | 1/day to 4 | 1 | 1 |
| | | Distances per min (m) | 2.1 to 36.5 | 36.5 | | 0.004 to 36.5 | 0.016 to 30.5 | 7.6 | 15.2 |
| | Pull | Conditions | 3 | | | 4 | | 2 | 1 |
| | | Heights | KnE | | | K-15, KnE, S | | KnE | KnE |
| | | Distances per effort (m) | 2.1 | | | 2.1 | | 2.1, 7.6 | 15.2 |
| | | Frequencies (per min) | 1 to 10 | | | 1/day to 1 | | 1 | 1 |
| | | Distances per min (m) | 2.1 to 21.3 | | | 0.004 to 2.1 | | 2.1, 7.6 | 15.2 |
| | | Carry | Conditions | 18 | 1 | | | 7 | 1 |
| Box Widths | M | | M | | | S | S | S, L, NH | |
| Carry Heights | K, E | | K | | | K | K | K | |
| Distances per effort (m) | 2.1 to 8.5 | | 4.3 | | | 4.3 | 2.1 | 2.1 to 7.6 | |
| Frequencies (per min) | 1 to 10 | | 6 | | | 1/day to 6 | 1 | 1 to 4.3 | |
| Distances per min (m) | 2.1 to 28.1 | | 25.6 | | | 0.01 to 25.6 | 2.1 | 2.1 to 9.1 | |
| Female | Lift | Participants | | | 15 | | 12 | 12 | |
| | | Conditions | | | 6 | | 58 | 6 | |
| | | Box Widths | | | M | | S, M, L | S | |
| | | Ranges | | | FK, KS, SR | | FK, KnE, KS | FK, KnE, KS | |
| | | Distances per effort (m) | | | 0.51 | | 0.25 to 0.76 | 0.51 | |
| | | Frequencies (per min) | | | 1 to 6.7 | | 1/day to 12 | 1 to 4.3 | |
| | Lower | Distances per min (m) | | | 0.51 to 3.4 | | 0.001 to 6.1 | 0.51 to 2.2 | |
| | | Conditions | | | 6 | | 16 | 6 | |
| | | Box Widths | | | M | | S | S | |
| | | Ranges | | | FK, KS, SR | | FK, KS | FK, KnE, KS | |
| | | Distances per effort (m) | | | 0.51 | | 0.51 | 0.51 | |
| | | Frequencies (per min) | | | 1 to 10 | | 1/day to 12 | 1 to 4.3 | |
| | Push | Distances per min (m) | | | 0.51 to 5.1 | | 0.001 to 6.1 | 0.51 to 2.2 | |
| | | Conditions | | | 8 | | 27 | 1 | |
| | | Heights | | | KnE | | K-15, KnE, S | KnE | |
| | | Distances per effort (m) | | | 2.1 to 30.5 | | 2.1 to 61.0 | 7.6 | |
| | | Frequencies (per min) | | | 0.5 to 5 | | 1/day to 4 | 1 | |
| | | Distances per min (m) | | | 2.1 to 26.1 | | 0.016 to 36.5 | 7.6 | |
| | Pull | Conditions | | | 2 | | 3 | 2 | |
| | | Heights | | | KnE | | K-15, KnE, S | KnE | |
| | | Distances per effort (m) | | | 2.1 | | 2.1 | 2.1, 7.6 | |
| | | Frequencies (per min) | | | 1 to 5 | | 1 | 1 | |
| | | Distances per min (m) | | | 2.1 to 10.7 | | 2.1 | 2.1, 7.6 | |
| | | Carry | Conditions | | | 12 | | 7 | 1 |
| Box Widths | | | | M | | S | S | | |
| Carry Heights | | | | K, E | | K | K | | |
| Distances per effort (m) | | | | 2.1 to 8.5 | | 4.3 | 2.1 | | |
| Frequencies (per min) | | | | 1 to 10 | | 1/day to 6 | 1 | | |
| Distances per min (m) | | | | 2.1 to 28.1 | | 0.01 to 25.6 | 2.1 | | |



Stover Snook

Vincent Ciriello



The design of manual handling tasks: revised tables of maximum acceptable weights and forces

Stover H. Snook and Vincent M. Ciriello

Liberty Mutual Insurance Company, 71 Frankland Road, Hopkinton, MA 01748, USA

Table 3. Maximum acceptable weight of lift for females (kg).

| Width† | Distances‡ | Percent§ | Floor level to knuckle height One lift every | | | | | | Knuckle height to shoulder height One lift every | | | | | | | | | |
|--------|------------|----------|---|----|----|-----|-----|----|---|----|----|-----|-----|-----|----|----|----|----|
| | | | 5 | 9 | 14 | 1 | 2 | 5 | 30 | 8 | 5 | 9 | 14 | 1 | 2 | 5 | 30 | 8 |
| | | | s | s | | min | min | h | h | s | s | min | min | min | h | h | h | |
| 76 | 90 | | 5 | 6 | 7 | 7 | 8 | 8 | 9 | 12 | 5 | 6 | 7 | 9 | 9 | 9 | 10 | 12 |
| | 75 | | 7 | 8 | 9 | 9 | 10 | 10 | 11 | 14 | 6 | 7 | 8 | 10 | 11 | 11 | 12 | 14 |
| | 50 | | 8 | 10 | 10 | 11 | 12 | 12 | 13 | 17 | 7 | 8 | 9 | 11 | 12 | 12 | 13 | 16 |
| | 25 | | 9 | 11 | 12 | 13 | 14 | 14 | 15 | 21 | 8 | 9 | 10 | 13 | 14 | 14 | 15 | 18 |
| | 10 | | 11 | 13 | 14 | 14 | 15 | 16 | 17 | 23 | 9 | 10 | 11 | 14 | 15 | 15 | 17 | 20 |
| 75 | 90 | | 6 | 7 | 8 | 8 | 9 | 9 | 10 | 14 | 6 | 7 | 8 | 9 | 10 | 10 | 11 | 13 |
| | 75 | | 7 | 9 | 9 | 10 | 11 | 11 | 13 | 17 | 7 | 8 | 9 | 11 | 12 | 12 | 13 | 15 |
| | 50 | | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 21 | 9 | 9 | 11 | 13 | 14 | 14 | 15 | 17 |
| | 25 | | 10 | 12 | 13 | 15 | 16 | 16 | 18 | 24 | 10 | 11 | 12 | 14 | 16 | 16 | 17 | 20 |
| | 10 | | 11 | 14 | 15 | 17 | 18 | 18 | 20 | 27 | 11 | 12 | 14 | 16 | 17 | 17 | 19 | 22 |
| 25 | 90 | | 6 | 8 | 8 | 9 | 9 | 9 | 11 | 14 | 6 | 7 | 8 | 10 | 11 | 11 | 12 | 14 |
| | 75 | | 8 | 10 | 11 | 11 | 12 | 12 | 13 | 18 | 7 | 8 | 9 | 12 | 13 | 13 | 14 | 17 |
| | 50 | | 10 | 12 | 13 | 13 | 14 | 14 | 16 | 21 | 9 | 10 | 11 | 14 | 15 | 15 | 16 | 19 |
| | 25 | | 11 | 14 | 15 | 15 | 16 | 17 | 19 | 25 | 10 | 11 | 12 | 16 | 17 | 17 | 19 | 22 |
| | 10 | | 13 | 16 | 17 | 17 | 19 | 19 | 21 | 29 | 11 | 12 | 14 | 18 | 19 | 19 | 21 | 24 |

Liberty Mutual MMH Research: 1971 to 2011

| Gender | Task | Participants | 1 Snook (1971) | 2 Snook & Ciriello (1974a) | 3 Snook & Ciriello (1974b) | 4 Ciriello & Snook (1978) | 5 Ciriello & Snook (1983) | 6 Ciriello, Snook et al. (1990) | 7 Ciriello, Snook et al. (1993) | 8 Ciriello et al. (1999) | 9 Ciriello (2001) | 10 Ciriello (2002) | 11 Ciriello (2003) | 12 Ciriello (2004a) | 13 Ciriello (2004b) | 14 Ciriello (2005) | 15 Ciriello (2007a) | 16 Ciriello (2007b) | 17 Ciriello (2008) | 18 Ciriello et al. (2010) | 19 Ciriello et al. (2011) | |
|-----------------------|--------------------------|--------------------------|----------------------|-------------------------------------|-------------------------------------|------------------------------------|------------------------------------|--|--|--------------------------------|-------------------------|--------------------------|--------------------------|---------------------------|---------------------------|--------------------------|---------------------------|---------------------------|--------------------------|---------------------------------|---------------------------------|-------------|
| Male | Lift | Conditions | 28 | 16 | | 15 | 10 | 10 | 6 | 6 | 6 | 8 | 8 | | | | | 14 | 23 | | | |
| | | Box Widths | 9 | 1 | | 41 | 16 | 6 | 28 | | 4 | 4 | 15 | | | | | | 6 | | | |
| | | Ranges | M | M | | S, M, L | S, M, L | S | S, XL, NH | | L | | S, XL | | | | | | S | | | |
| | | Distances per effort (m) | FK, KS, SR | FK | | FK, KnE, KS | FK, KnE, KS | FK, KnE, KS | FK, KnE, KS | | FK | | FK, KnE, KS | | | | | | FK, KS | | | |
| | | Frequencies (per min) | 0.51 | 0.51 | | 0.25 to 0.76 | 0.25 to 0.76 | 0.51 | 0.51 | | 0.25 to 0.76 | | 0.51 | | | | | | 0.51 | | | |
| | | Distances per min (m) | 1 to 6.7 | 4.3 | | 1/day to 6.7 | 1/day to 12 | 1 to 4.3 | 1 to 4.3 | | 4.3 | | 1/day to 20 | | | | | | 1 to 12 | | | |
| | Lower | Conditions | 9 | 2.2 | | 0.001 to 5.1 | 0.001 to 6.1 | 0.51 to 2.2 | 0.51 to 2.2 | | 1.1 to 3.3 | | 0.001 to 10.2 | | | | | | 6 | | | |
| | | Box Widths | M | | | | | | | | 12 | | | | | | | | S | | | |
| | | Ranges | FK, KS, SR | | | | FK, KS | FK, KnE, KS | | | FK, KS | | | | | | | | FK, KS | | | |
| | | Distances per effort (m) | 0.51 | | | | 0.51 | 0.51 | | | 0.25 to 0.76 | | | | | | | | 0.51 | | | |
| | | Frequencies (per min) | 1 to 10 | | | | 1/day to 12 | 1 to 4.3 | | | 4.3 | | | | | | | | 1 to 12 | | | |
| | | Distances per min (m) | 0.51 to 5.1 | | | | 0.001 to 6.1 | 0.51 to 2.2 | | | 1.1 to 3.3 | | | | | | | | 0.51 to 6.1 | | | |
| | Push | Conditions | 12 | 1 | | 16 | 12 | 1 | 1 | | 2 | | 2 | | | | | | 2 | | | |
| | | Heights | KnE | KnE | | K-15, KnE, S | KnE | KnE | KnE | | KnE | | KnE | | | | | | KnE | | | |
| | | Distances per effort (m) | 2.1 to 30.5 | 15.2 | | 2.1 to 61.0 | 7.6, 30.5 | 7.6 | 15.2 | | 7.6 | | 7.6, 15.2 | | | | | | 7.6 | | | |
| | | Frequencies (per min) | 0.6 to 10 | 2.4 | | 1/day to 4 | 1/day to 4 | 1 | 1 | | 1 | | 1 | | | | | | 1 | | | |
| | | Distances per min (m) | 2.1 to 36.5 | 36.5 | | 0.004 to 36.5 | 0.016 to 30.5 | 7.6 | 15.2 | | 7.6 | | 7.6, 15.2 | | | | | | 7.6 | | | |
| | | Pull | Conditions | 3 | 4 | | 4 | 2 | 1 | 1 | | | | | | | | | | 2 | | |
| | Heights | | KnE | | | K-15, KnE, S | KnE | KnE | KnE | | KnE | | KnE | | | | | | KnE | | | |
| | Distances per effort (m) | | 2.1 | | | 2.1 | 2.1, 7.6 | 15.2 | 15.2 | | 7.6 to 15.2 | | | | | | | | 7.6 | | | |
| Frequencies (per min) | 1 to 10 | | | | 1/day to 1 | 1 | 1 | 1 | | 1 | | 1 | | | | | | 1.4 | | | | |
| Distances per min (m) | 2.1 to 21.3 | | | | 0.004 to 2.1 | 2.1, 7.6 | 15.2 | 15.2 | | 7.6 to 15.2 | | | | | | | | 7.6, 30.5 | | | | |
| Carry | Conditions | | 18 | 1 | | 7 | 1 | 12 | | | | | | | | | | | 2 | | | |
| | Box Widths | M | M | | S | S | S, L, NH | | | | | | | | | | | S | | | | |
| | Carry Heights | K, E | K | | K | K | K | | | | | | | | | | | K | | | | |
| | Distances per effort (m) | 2.1 to 8.5 | 4.3 | | 4.3 | 2.1 | 2.1 to 7.6 | | | | | | | | | | | 4.3 | | | | |
| | Frequencies (per min) | 1 to 10 | 6 | | 1/day to 6 | 1 | 1 to 4.3 | | | | | | | | | | | 1.4, 3 | | | | |
| | Distances per min (m) | 2.1 to 28.1 | 25.6 | | 0.01 to 25.6 | 2.1 | 2.1 to 9.1 | | | | | | | | | | | 4.3, 18.3 | | | | |
| Female | Lift | Conditions | | | 15 | | 12 | 12 | | | | | | 10 | 11 | 10 | 10 | | 19 | 24 | | |
| | | Box Widths | | | | | 6 | 6 | | | | | | | | | | | 4 | 15 | | |
| | | Ranges | | | | | S | S | | | | | | | | | | | S, L, XL | | | |
| | | Distances per effort (m) | | | | | FK, KnE, KS | FK, KnE, KS | | | | | | | | | | | FK, KnE, KS | | | |
| | | Frequencies (per min) | | | | | 0.51 | 1 to 4.3 | | | | | | | | | | | 0.25 to 0.76 | 0.51 | | 0.51 |
| | | Distances per min (m) | | | | | 0.51 to 2.2 | 0.51 to 2.2 | | | | | | | | | | | 4.3 | 1/day to 20 | | 1 to 12 |
| | Lower | Conditions | | | | | 6 | 6 | | | | | | | | | | | 1.1 to 3.3 | 0.001 to 10.2 | | 0.51 to 6.1 |
| | | Box Widths | | | | | S | S | | | | | | | | | | | S | | | |
| | | Ranges | | | | | FK, KnE, KS | FK, KnE, KS | | | | | | | | | | | FK, KS | | | |
| | | Distances per effort (m) | | | | | 0.51 | 1 to 4.3 | | | | | | | | | | | 0.25 to 0.76 | 0.51 | | 0.51 |
| | | Frequencies (per min) | | | | | 1 to 4.3 | 0.51 to 2.2 | | | | | | | | | | | 4.3 | 1/day to 20 | | 1 to 12 |
| | | Distances per min (m) | | | | | 0.51 to 2.2 | 0.51 to 2.2 | | | | | | | | | | | 1.1 to 3.3 | 0.001 to 10.2 | | 0.51 to 6.1 |
| | Push | Conditions | | | | | 1 | 1 | | | | | | | | | | | 2 | | 2 | |
| | | Heights | | | | | KnE | KnE | KnE | | KnE | | KnE | | | | | | KnE | | KnE | |
| | | Distances per effort (m) | | | | | 7.6 | 7.6 | | | 7.6, 15.2 | | 7.6 | | | | | | 7.6 | | 7.6 | |
| | | Frequencies (per min) | | | | | 1 | 1 | | | 1 | | 1 | | | | | | 0.2, 1 | | 1 | 1.4 |
| | | Distances per min (m) | | | | | 0.01 to 25.6 | 2.1 | 2.1 to 9.1 | | | | 7.6, 15.2 | | | | | | 7.6 | | 7.6 | |
| | | Pull | Conditions | | | | | 2 | 2 | | | | | | | | | | | 2 | | 2 |
| | Heights | | | | | | KnE | KnE | KnE | | KnE | | KnE | | | | | | KnE | | KnE | |
| | Distances per effort (m) | | | | | | 2.1 | 2.1 | 2.1, 7.6 | | 7.6 to 15.2 | | 7.6 | | | | | | 2.1 | | 7.6 | |
| Frequencies (per min) | | | | | | 1 to 5 | 1 | 1 | | 1 | | 1 | | | | | | 1 | | 1 | 1.4 | |
| Distances per min (m) | | | | | | 2.1 to 10.7 | 2.1 | 2.1, 7.6 | | 7.6 to 15.2 | | 7.6 | | | | | | 7.6 | | 7.6 | | |
| Carry | Conditions | | | | | | 12 | 12 | | | | | | | | | | | 2 | | 2 | |
| | Box Widths | | | | | M | M | S | | S | | S | | | | | | S | | S | | |
| | Carry Heights | | | | | K, E | K | K | | K | | K | | | | | | K | | K | | |
| | Distances per effort (m) | | | | | 2.1 to 8.5 | 4.3 | 2.1 | | | | 2.1, 4.3 | | | | | | 2.1, 4.3 | | 4.3 | | |
| | Frequencies (per min) | | | | | 1 to 10 | 1/day to 6 | 1 | | | | 1, 4.3 | | | | | | 1, 4.3 | | 1, 4.3 | | |
| | Distances per min (m) | | | | | 2.1 to 28.1 | 0.01 to 25.6 | 2.1 | | | | 4.3, 9.1 | | | | | | 4.3, 9.1 | | 4.3, 18.3 | | |

1. Snook (1971)
2. Snook & Ciriello (1974a)
3. Snook & Ciriello (1974b)
4. Ciriello & Snook (1978)
5. Ciriello & Snook (1983)
6. Ciriello, Snook et al. (1990)
7. Ciriello, Snook et al. (1993)

8. Ciriello et al. (1999)
9. Ciriello (2001)
10. Ciriello (2002)
11. Ciriello (2003)
12. Ciriello (2004a)
13. Ciriello (2004b)
14. Ciriello (2005)
15. Ciriello (2007a)
16. Ciriello (2007b)
17. Ciriello (2008)
18. Ciriello et al. (2010)
19. Ciriello et al. (2011)

The Liberty Mutual manual materials handling (LM-MMH) equations

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Procedures

- Original Data
 - summarized by task and gender
 - total of 612 MAL values, average of 14 participants per MAL
 - Lift, Lower, Push (initiate & sustain), Pull (initiate & sustain) and Carry
 - female and male



Conditions: 19 Studies from 1971 to 2011

| Task | | Gender | Conditions with MAL Values | | |
|-------------------------|-----------|--------|----------------------------|---------|--------|
| | | | Conditions | Total n | Mean n |
| Lift | | Female | 95 | 1,192 | 12.5 |
| | | Male | 126 | 1,510 | 12.0 |
| Lower | | Female | 46 | 618 | 13.4 |
| | | Male | 49 | 706 | 14.4 |
| Push | Inittal | Female | 39 | 499 | 12.8 |
| | | Male | 47 | 788 | 16.8 |
| | Sustained | Female | 46 | 604 | 13.1 |
| | | Male | 48 | 804 | 16.8 |
| Pull | Inittal | Female | 11 | 153 | 13.9 |
| | | Male | 14 | 226 | 16.1 |
| | Sustained | Female | 12 | 168 | 14.0 |
| | | Male | 14 | 226 | 16.1 |
| Carry | | Female | 24 | 344 | 14.3 |
| | | Male | 41 | 718 | 17.5 |
| Total per Gender | | Female | 273 | 3,578 | 13.1 |
| | | Male | 339 | 4,978 | 14.7 |
| Totals per Task | | Lift | 221 | 2,702 | 12.2 |
| | | Lower | 95 | 1,324 | 13.9 |
| | | Push | 180 | 2,695 | 15.0 |
| | | Pull | 51 | 773 | 15.2 |
| | | Carry | 65 | 1,062 | 16.3 |
| 19 Studies (Equations) | | | 612 | 8,556 | 14.0 |
| 7 Studies (1991 Tables) | | | 472 | 6,580 | 13.9 |

+30%

| Unique Combinations | |
|---------------------|--------|
| Combinations | Mean n |
| 54 | 22.1 |
| 58 | 26.0 |
| 34 | 18.2 |
| 37 | 19.1 |
| 26 | 19.2 |
| 32 | 24.6 |
| 30 | 20.1 |
| 32 | 25.1 |
| 6 | 25.5 |
| 9 | 25.1 |
| 7 | 24.0 |
| 9 | 25.1 |
| 22 | 15.6 |
| 32 | 22.4 |
| 179 | 20.0 |
| 209 | 23.8 |
| 112 | 24.1 |
| 71 | 18.6 |
| 120 | 22.5 |
| 31 | 24.9 |
| 54 | 19.7 |
| 388 | 22.1 |
| 338 | 19.5 |

+15%

| Liberty Mutual Tables | |
|-----------------------|-------------|
| Combinations | % with Data |
| 216 | 25% |
| 216 | 27% |
| 216 | 16% |
| 216 | 17% |
| 105 | 25% |
| 105 | 30% |
| 105 | 29% |
| 105 | 30% |
| 105 | 6% |
| 105 | 9% |
| 105 | 7% |
| 105 | 9% |
| 42 | 52% |
| 42 | 76% |
| 894 | 20% |
| 894 | 23% |
| 432 | 26% |
| 432 | 16% |
| 420 | 29% |
| 420 | 7% |
| 84 | 64% |
| 1,788 | 21.7% |
| 1,788 | 18.9% |

Procedures

TECHNICAL REPORT
NATICK/TR-15/007



AD _____

Gordon et al. (2014)

2012 ANTHROPOMETRIC SURVEY OF U.S. ARMY PERSONNEL: METHODS AND SUMMARY STATISTICS

• Original Data

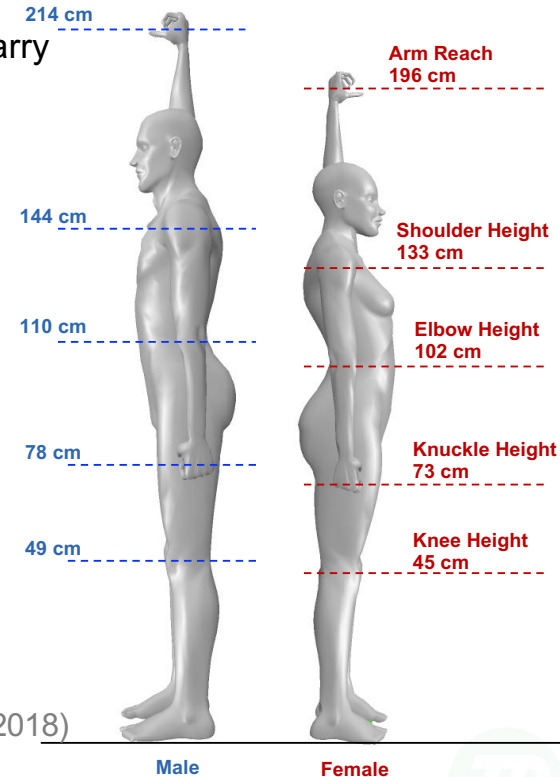
- summarized by task and gender
 - total of 612 MAL values, average of 14 participants per MAL
 - Lift, Lower, Push (initiate & sustain), Pull (initiate & sustain) and Carry
 - female and male

• Anthropometry

- estimated heights with ANSUR II database
 - knee, knuckle height, elbow, shoulder, stature, and arm reach
 - note: very close to the Liberty Mutual participant averages

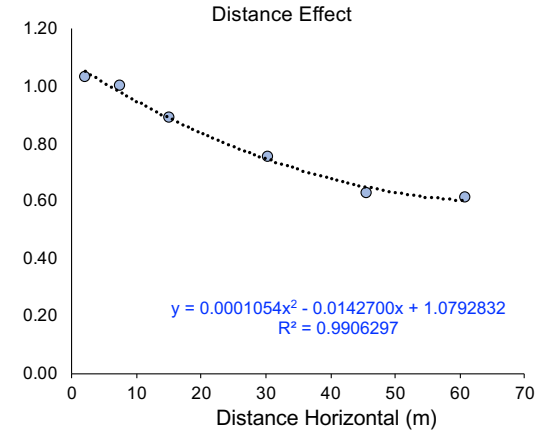
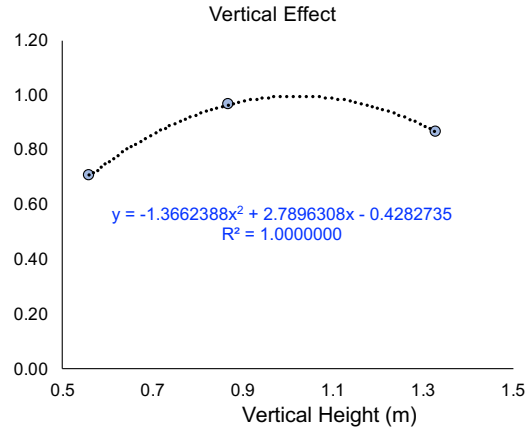
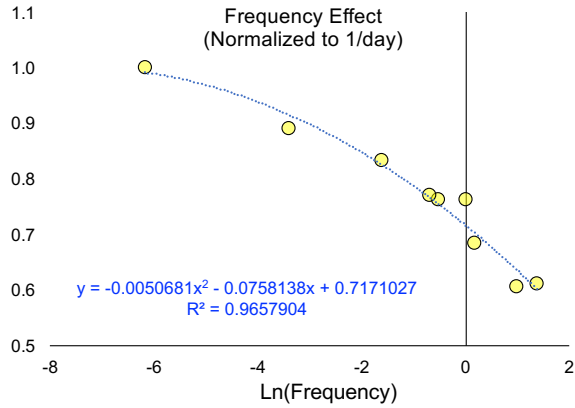
• Equation Development

- input variables
 - **V** (vertical), **D** (vertical or horizontal), **F & H** (for Lift & Lower)
 - independent effects of changes in each variable on the MAL
 - normalize each scale factor to 1.00
 - determine the maximum/reference load for best fit
 - Lifting & Lowering
 - extrapolated Box Width back to 0 m
 - based on compression limits of 3,100 N (F) & 4,000 N (M) (Jager, 2018)
 - extrapolated to 2 and 3 vertical ranges
 - NIOSH (2018) & Mital et al (1993)

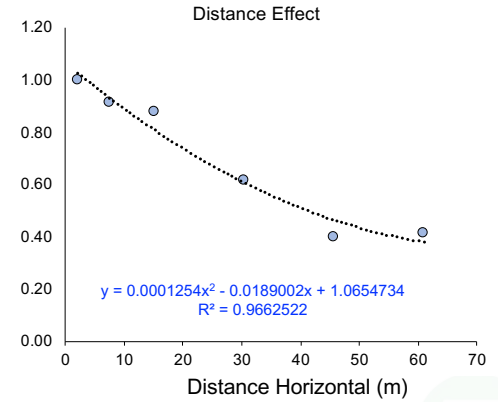
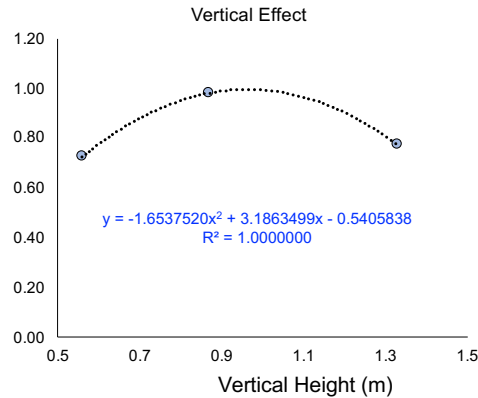
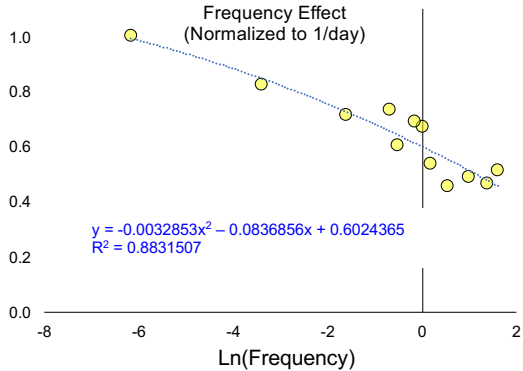


Analysis Example: Scale Factors (Push & Pull Female)

Initiate



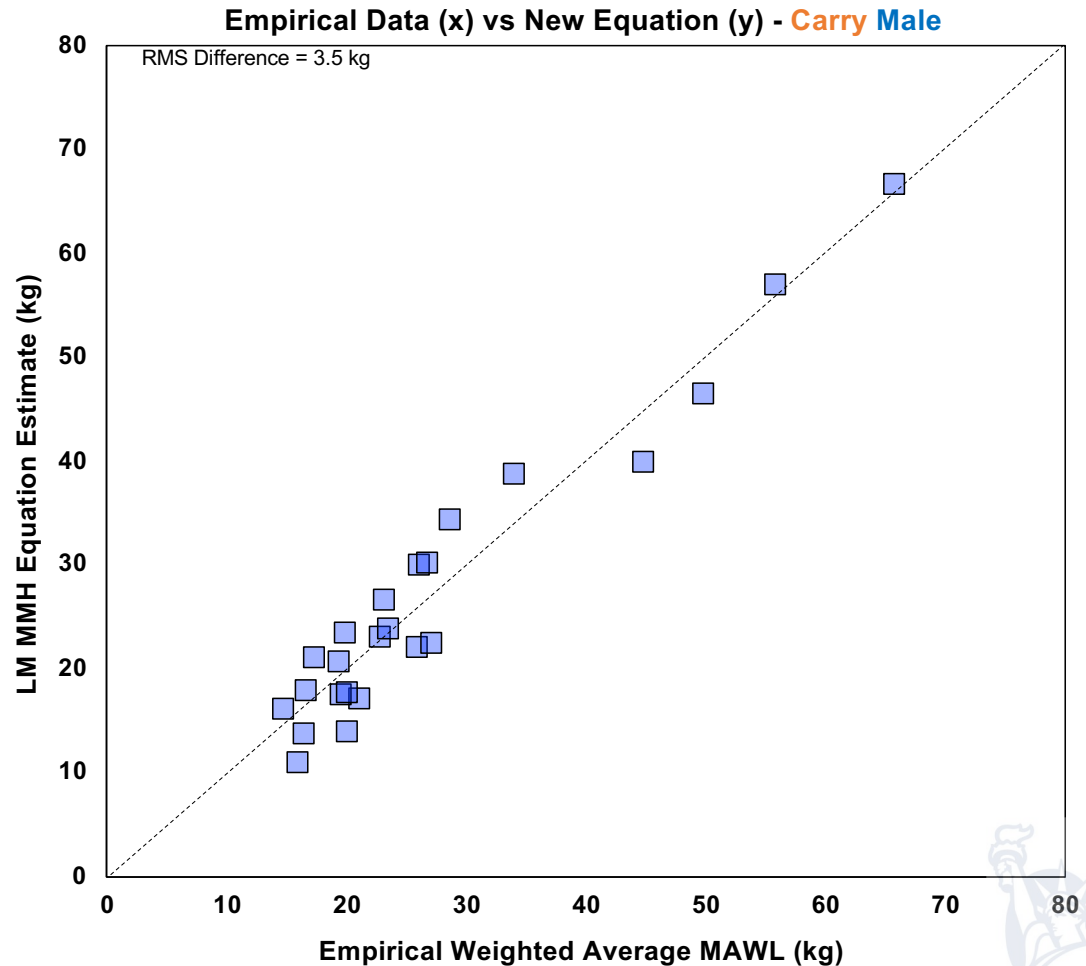
Sustain



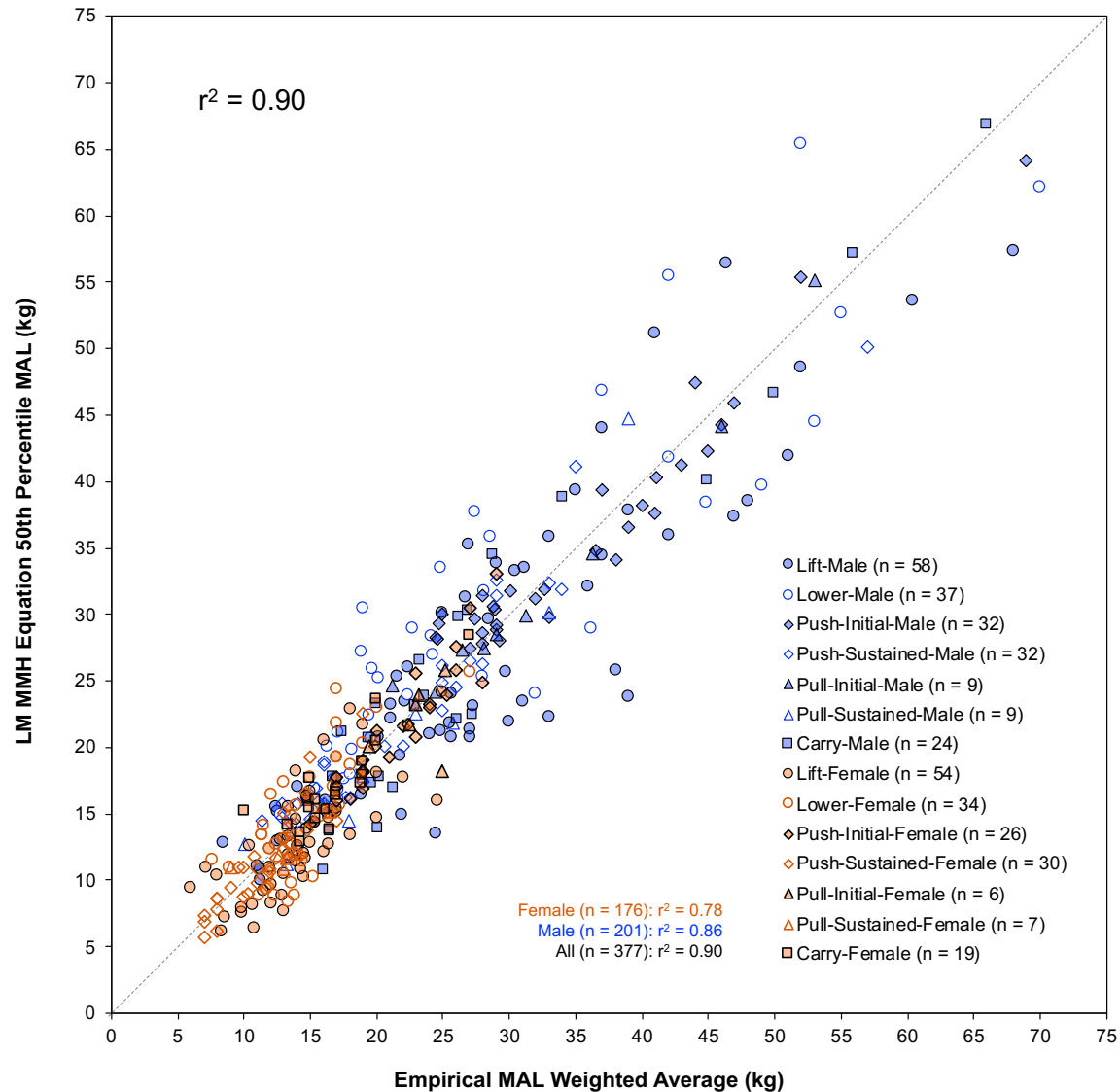
Reference Load: Example – Carry Male

The Scale Factors all had a maximum of 1.0

To predict the actual MAWL, I found the “Reference Load” multiplier (within 0.1 kg) that minimized the RMS difference between: the Empirical Weighted Average MAWL and the LM MMH Equation

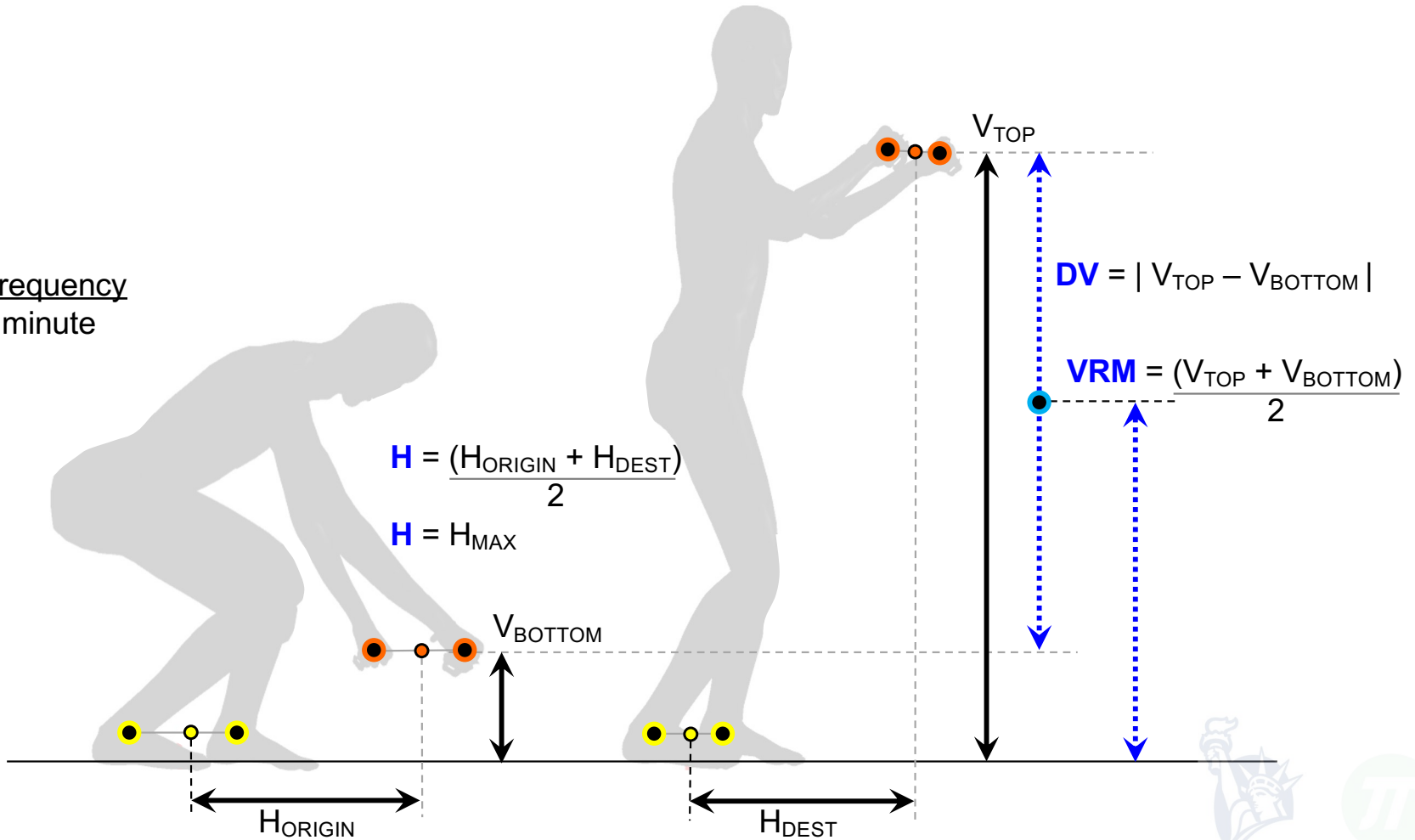


Combined Data



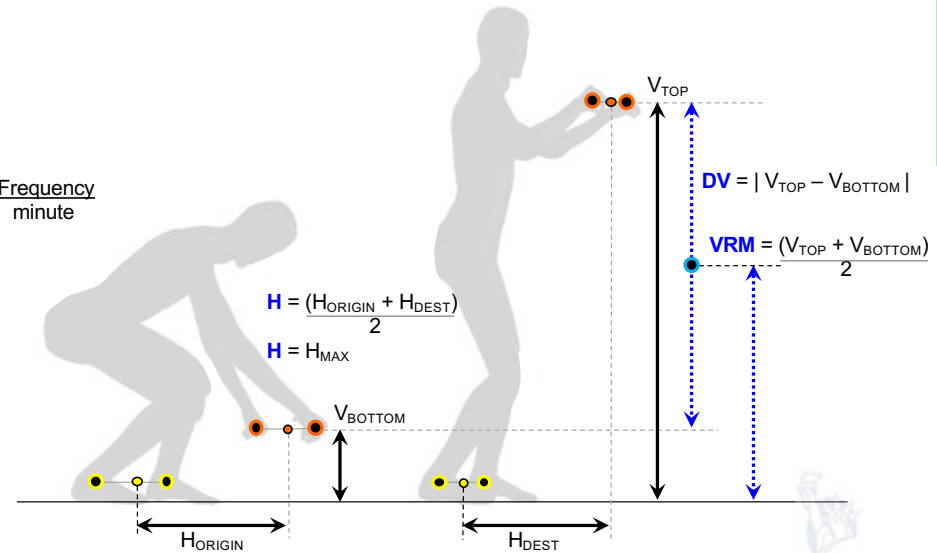
Inputs: Lift & Lower Equations

$F = \frac{\text{Frequency}}{\text{minute}}$



Lift & Lower: Female

F = Frequency
minute



$$MAL = RL [H_{SF}] [VRM_{SF}] [DV_{SF}] [F_{SF}]$$

Lift - Female

$$MAL = 34.9 \left[1.2602 - \frac{H}{0.7686} \right] \left[0.9877 + \frac{VRM}{13.69} - \frac{VRM^2}{9.221} \right] \left[0.8199 - \frac{\ln(DV)}{7.696} \right] \left[0.6767 - \frac{\ln(F)}{12.59} - \frac{\ln(F)^2}{228.2} \right]$$

CV = 0.260

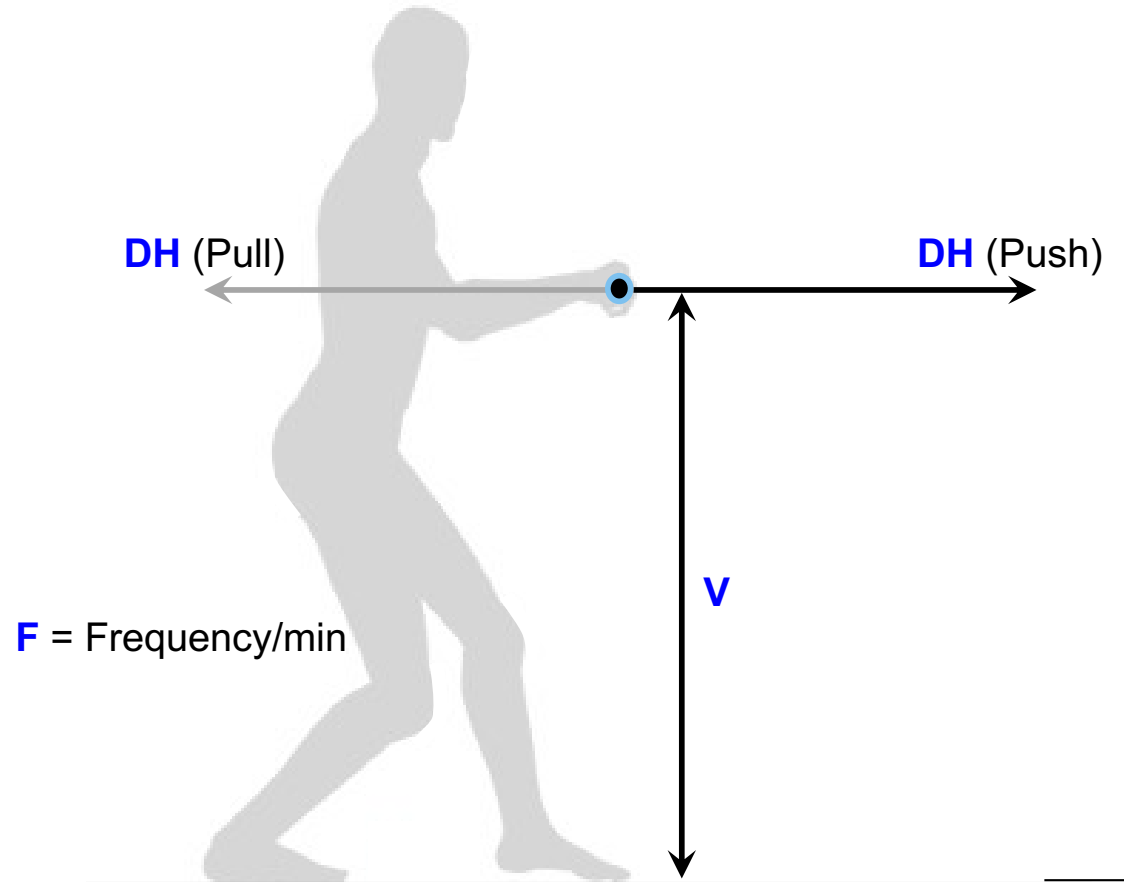
Lower - Female

$$MAL = 37.0 \left[1.2602 - \frac{H}{0.7686} \right] \left[0.9877 + \frac{VRM}{13.69} - \frac{VRM^2}{9.221} \right] \left[0.8199 - \frac{\ln(DV)}{7.696} \right] \left[0.6767 - \frac{\ln(F)}{12.59} - \frac{\ln(F)^2}{228.2} \right]$$

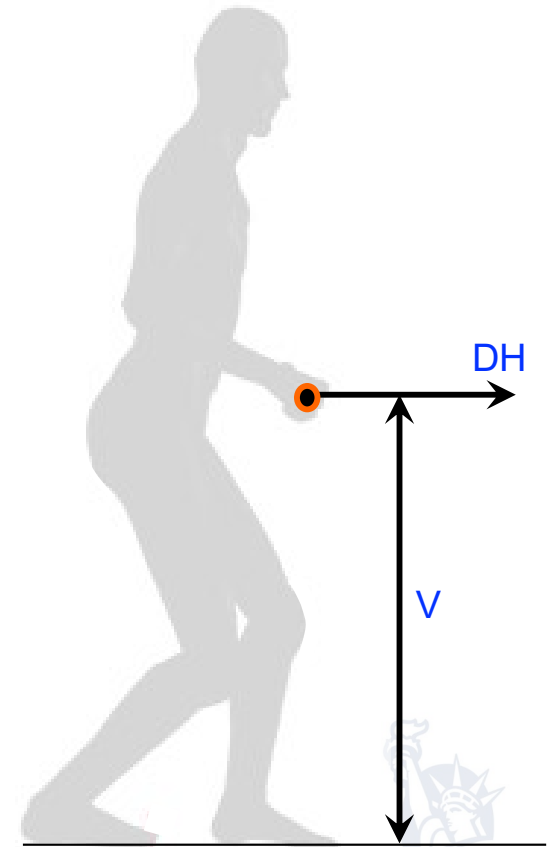
CV = 0.307



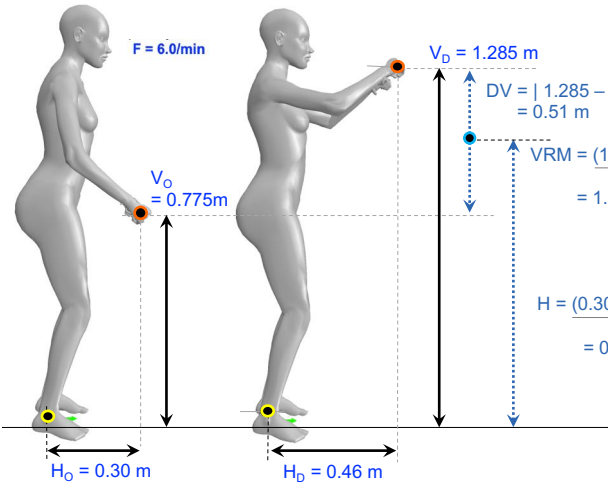
Inputs: Push & Pull Equations



Carry Equations



Excel App Modules: Female Lift & Lower - Outputs



| Inputs | |
|---------------------|------------|
| H | 0.380 m |
| V _{TOP} | 1.285 m |
| V _{BOTTOM} | 0.775 m |
| F | 6 /min |
| Actual Load | 10.00 kg |
| %Capable | 75 |
| VRM | 1.030 m |
| DV | 0.510 m |
| DV/min | 3.06 m/min |

| | | Lift | Lower |
|---------------------------|---------------------|---------|---------|
| MAL (75% capable) | | 9.9 kg | 10.1 kg |
| %Capable (of Actual Load) | | 73.6% | 75.4% |
| Scale Factors (SF) | RL | 34.9 kg | 37.0 kg |
| | H _{SF} | 0.766 | 0.766 |
| | VRM _{SF} | 0.948 | 0.948 |
| | DV _{SF} | 0.907 | 0.907 |
| | F _{SF} | 0.520 | 0.520 |
| | Net _{SF} | 0.343 | 0.343 |
| | Total _{SF} | 0.283 | 0.272 |



Liberty Mutual ErgoValuator™



Liberty Mutual ErgoValuator™

Business

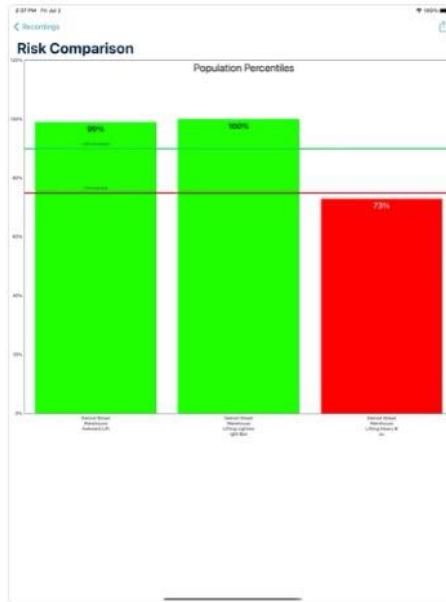
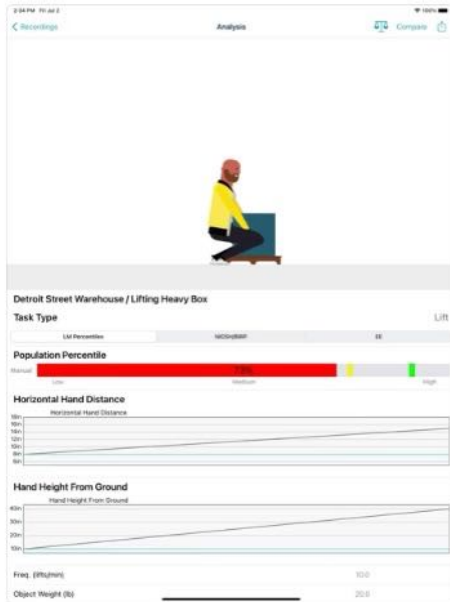
Designed for iPad. Not verified for macOS.



AGE
4+
Years Old

CATEGORY
Business

DEVELOPER
Kinetica Labs, Inc



◀ Back Analysis ⚖️ Compare ↗️

Test1 / Trial1

Task Type Lift

LM Percentiles | NIOSH/BIRP | EE

Population Percentile

AI >90% (High)

Low Medium High

Horizontal Hand Distance

Horizontal Hand Distance

20in. 16in. 12in. 8in. 4in. 0in.

:02 :04 :06 :08

Set Start Set End

Hand Height From Ground

Advantages of the LM-MMH Equations

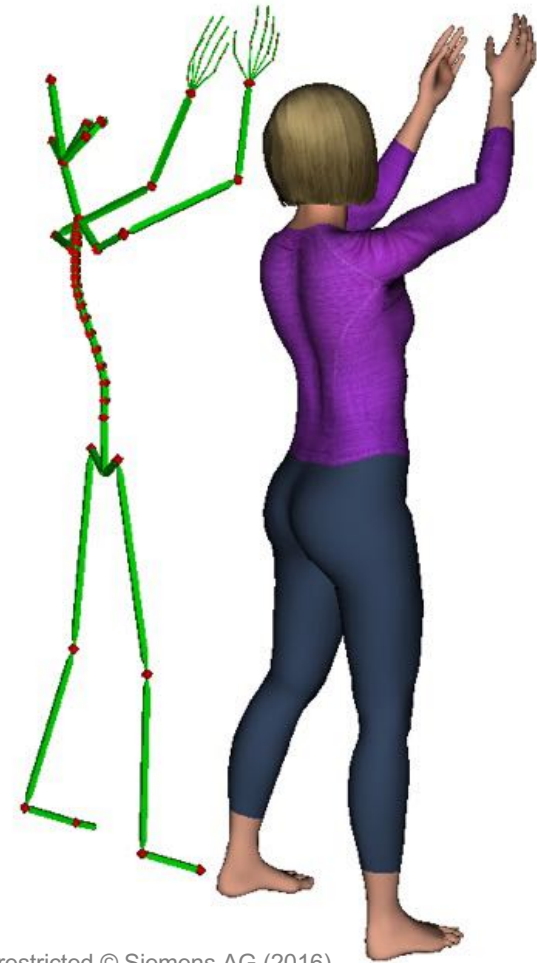
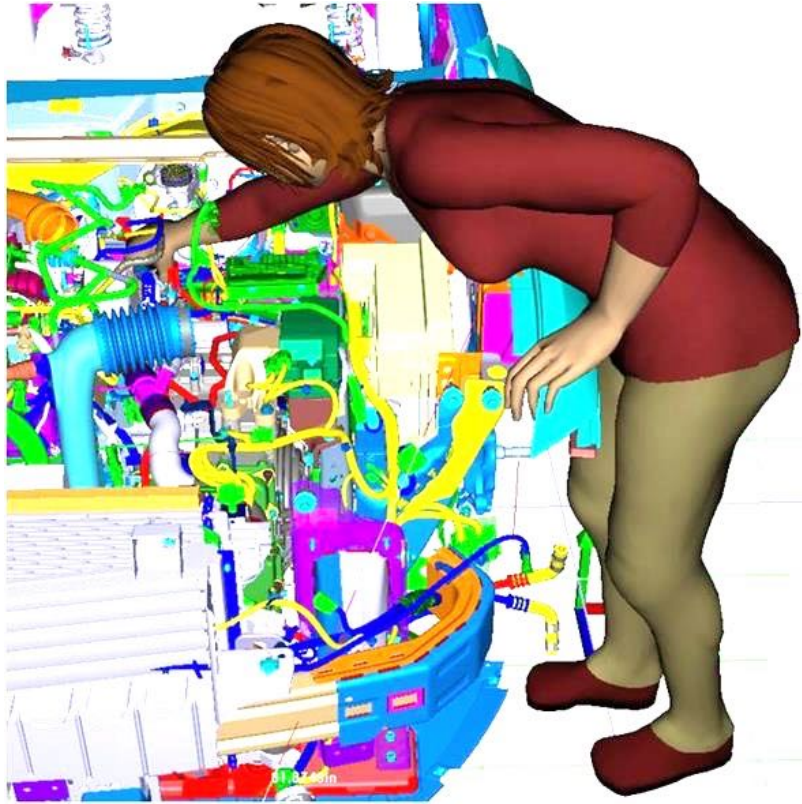
1. Based on 12 more recent studies than The Snook & Ciriello (1991) Tables
 - 30% more MAL conditions, 15% more unique conditions
2. Based on more participants
 - 129% in total, 141% more females
3. Wider range of Lift & Lower conditions
 - Box Width down to 0 m (minimum was ~36 cm or 14")
 - all vertical lifting ranges
4. Do not require interpolations
 - Much easier integration into software
5. Provides task parameter scale factors to guide design
6. Versus the RNLE
 - Better reflection of the RNLE criteria than the RNLE
 - also includes pushes, pulls and carries



Challenging the Validity of 3DSSPP for Estimating Manual Arm Strength



Digital Human Models & Work Simulation



Unrestricted © Siemens AG (2016)



3D Static Strength Prediction Program (3DSSPP)

The screenshot displays the 3DSSPP software interface. At the top, there are three 3D stick-figure views: 'Top - View from Z Axis', 'Front - View from Y Axis', and 'Side - View from X Axis'. Below these is a 3D rendering of a female human model in a bent posture. The main window is titled '3DSSPP - Strength Capabilities Report' and contains the following information:

Description:
 Company: Unknown Company, Analyst: Unknown, Date: 12/10/18
 Task: Untitled Task - Frame 0
 Gender: Female, Percentile: 50th, Height: 162.8 cm, Weight: 72.1 Kg
 Comment:

Hand Forces (N)
 Left: 93.5 Right: 93.5

Hand Locations (cm)

| | Left | Right |
|-------------|-------|-------|
| Horizontal: | 41.6 | 41.6 |
| Vertical: | 58.0 | 58.0 |
| Lateral: | -18.6 | 18.6 |

Strength Capabilities Report Table:

| | | Demand Left Capacity | | | | Demand Right Capacity | | | |
|-------|------------------|----------------------|---------------|---------------------|------------------|-----------------------|---------------|---------------------|------------------|
| | | Required | | Population Strength | | Required | | Population Strength | |
| | | Moment (N-m) | Muscle Effect | Mean (N-m) | SD Cap (N-m) (%) | Moment (N-m) | Muscle Effect | Mean (N-m) | SD Cap (N-m) (%) |
| Wrist | Flex/Ext | 2.8 | EXTEN | 5.5 | 1.8 93.5 | 2.8 | EXTEN | 5.9 | 1.9 94.8 |
| | Ulnar/Radial Dev | -4.1 | RDLDEV | 7.6 | 2.4 92.1 | -4.1 | RDLDEV | 8.1 | 2.6 93.7 |
| | Forearm Rot | -0.2 | SUPIN | 7.1 | 2.4 99.8 | -0.2 | SUPIN | 7.6 | 2.6 99.8 |
| Elbow | Flex/Ext | -16.6 | FLEXN | 31.7 | 8.3 96.5 | -16.6 | FLEXN | 34.1 | 9.0 97.5 |
| | Shoulder | Humeral Rot | -5.1 | LATERL | 22.5 | 5.9 99.8 | -5.1 | LATERL | 24.1 |
| | Rot'n Bk/Fd | -0.7 | FORWRD | 42.9 | 14.6 99.8 | -0.7 | FORWRD | 46.1 | 15.7 99.8 |
| | Abduc/Adduc | -33.6 | ABDUCT | 37.7 | 9.9 65.8 | -33.6 | ABDUCT | 40.5 | 10.6 74.0 |

Below the report is a balance scale diagram with a green box labeled 'Demand' on the left and a blue box labeled 'Capacity' on the right, indicating that capacity is greater than demand.



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journal homepage: <http://www.elsevier.com/locate/apergo>

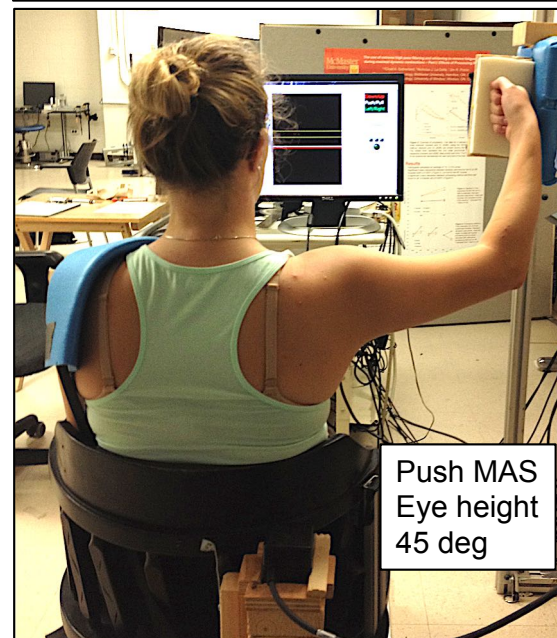
A comparison between measured female linear arm strengths and estimates from the 3D Static Strength Prediction Program (3DSSPP)

Andrew D. Hall ^a, Nicholas J. La Delfa ^b, Chris Loma ^c, Jim R. Potvin ^{a,*}

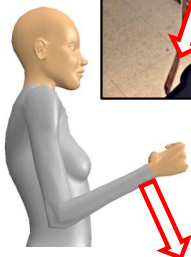


Data Collection

- 15 university age females
- 2 data collections
 - JAS: joint axis strengths
 - 8 axes, replicate Stobbe (1982)
 - MAS: right manual arm strength
 - 4 hand locations
- 6 MAS directions:
 - anterior, posterior, superior, inferior, medial & lateral
- modifications:
 - eliminate wrist/forearm as a limiting joint
 - see La Delfa & Potvin (2014)
- 3DSSPP analysis with two Raters
 - used mean of the two
 - 360 conditions
 - 15 subjects x 4 hand locations x 6 directions

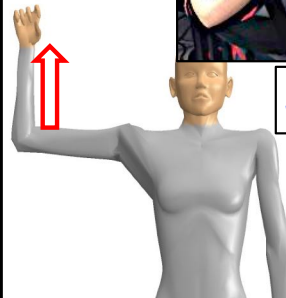


Elbow: Extension



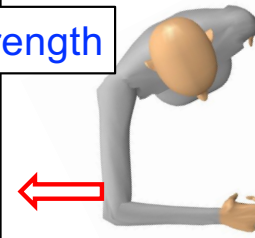
EF: 120°
SV: 5°
SH: 0°

Shoulder: Abduction



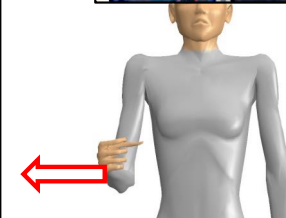
EF: 90°
SV: 90°
SH: 0°

Shoulder: Backward Horizontal



EF: 90°
SV: 90°
SH: 60°

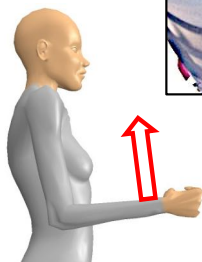
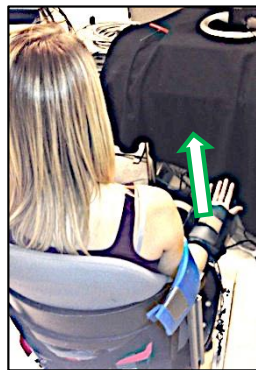
Shoulder: Lateral Humeral



EF: 90°
SV: 5°
SH: 0°

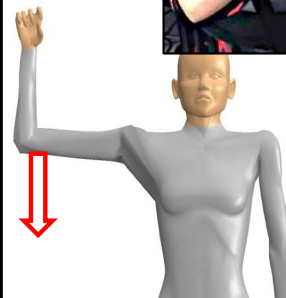
Stobbe Strength

Elbow: Flexion



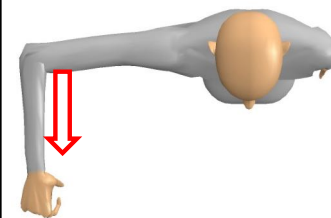
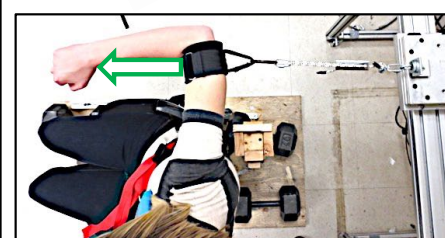
EF: 90°
SV: 5°
SH: 0°

Shoulder: Adduction



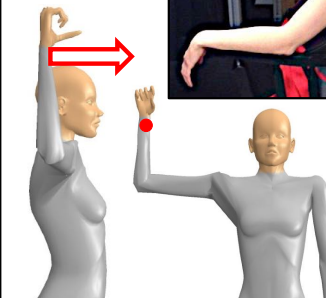
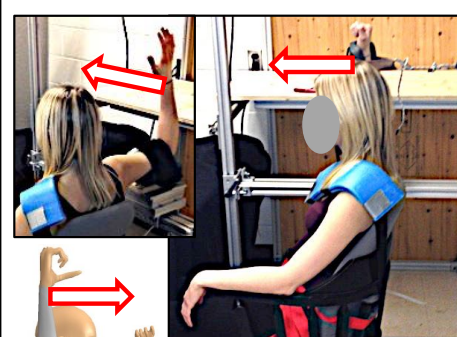
EF: 90°
SV: 90°
SH: 0°

Shoulder: Forward Horizontal



EF: 90°
SV: 90°
SH: 0°

Shoulder: Medial Humeral



EF: 90°
SV: 90°
SH: 0°

Manual Arm Strength: Conditions

45 deg

90 deg

~Eye
Height



Data Collection

- 4 Hand Locations
- 6 Force Directions
- 24 trials per participant

~Umbilical
Height



Data Analysis

Compare measured strength to that estimated with 3DSSPP



Measured vs 3DSSPP Manual Arm Strength

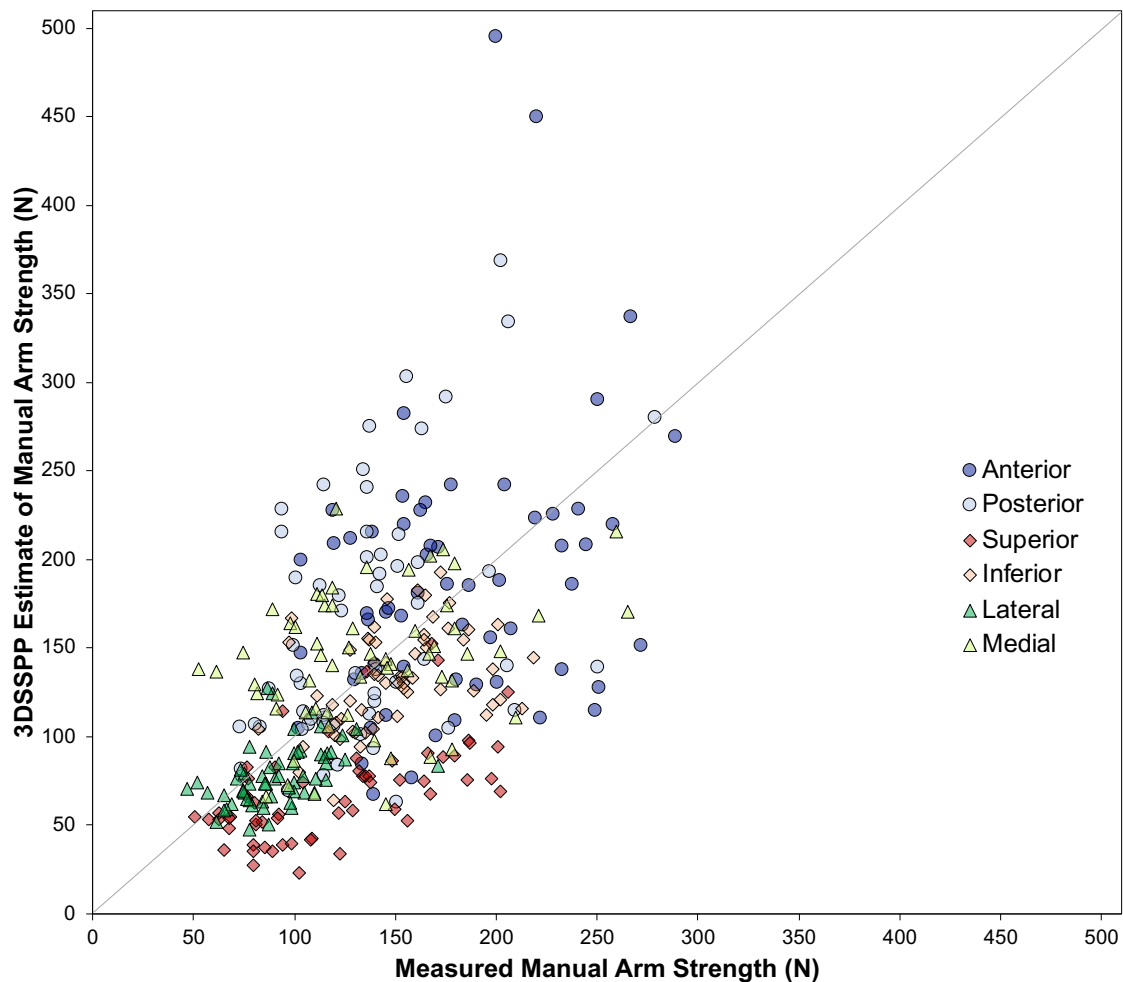
Average Error

-6.7 N (-1.5 lbs) & **-2.5%**

RMS Error

56.0 N (12.6 lbs) & **40.4%**

Overall explained variance = **29.2%**



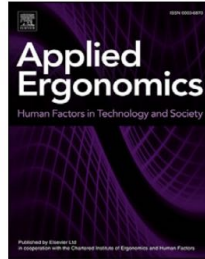
New Assessment Tool: The Arm Force Field (AFF) Method to Predict Manual Arm Strength



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journal homepage: www.elsevier.com/locate/apergo



The ‘Arm Force Field’ method to predict manual arm strength based on only hand location and force direction

Nicholas J. La Delfa ^a, Jim R. Potvin ^{b,*}

^a Department of Kinesiology, University of Waterloo, Waterloo, Ontario, Canada

^b Department of Kinesiology, McMaster University, Hamilton, Ontario, Canada

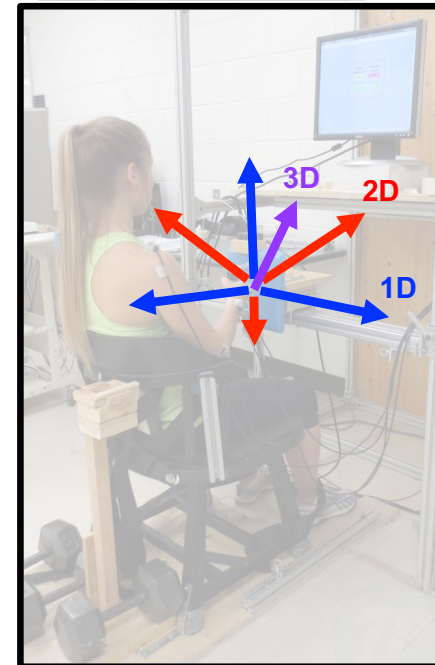


Dr. Nick La Delfa
Assistant Professor
Ontario Tech

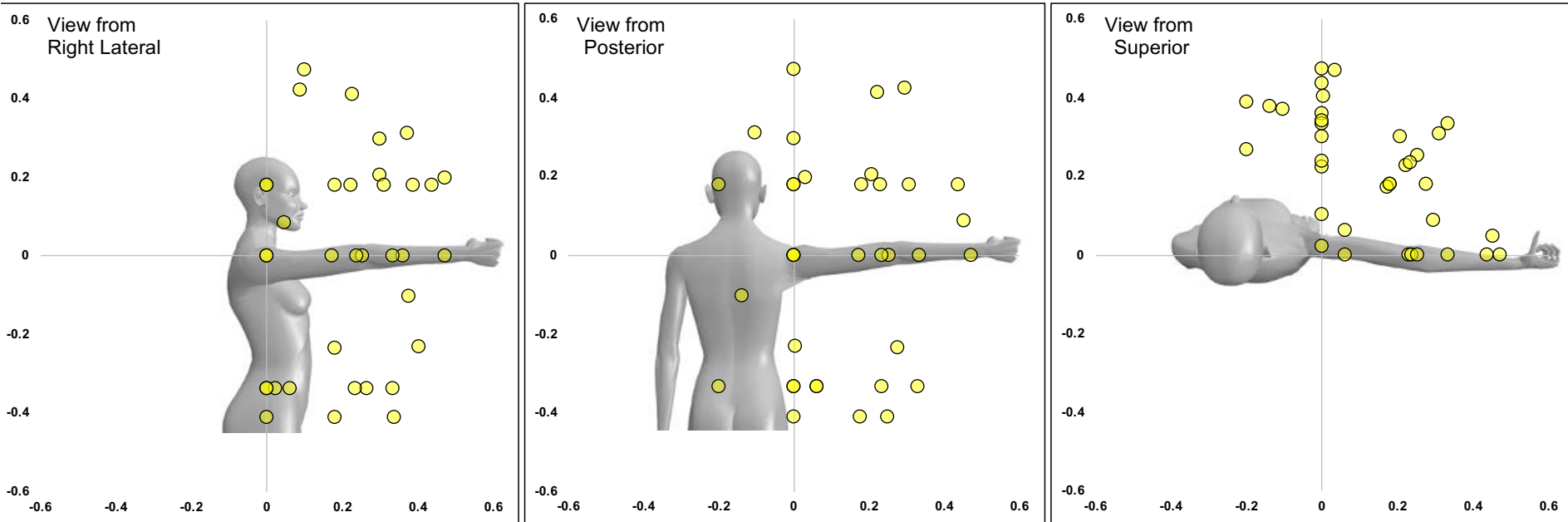


La Delfa & Potvin (2017)

- compiled data from 4 studies
 - collected over a 12 year period
 - 135 females
 - age range: 20 to 60 yrs
 - 36 hand locations
 - 6 or 26 force directions
 - 536 conditions
 - 13,460 strength trials

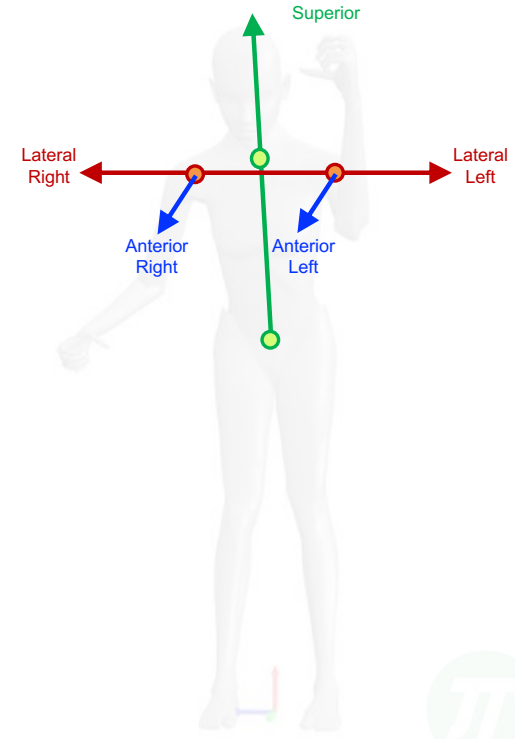
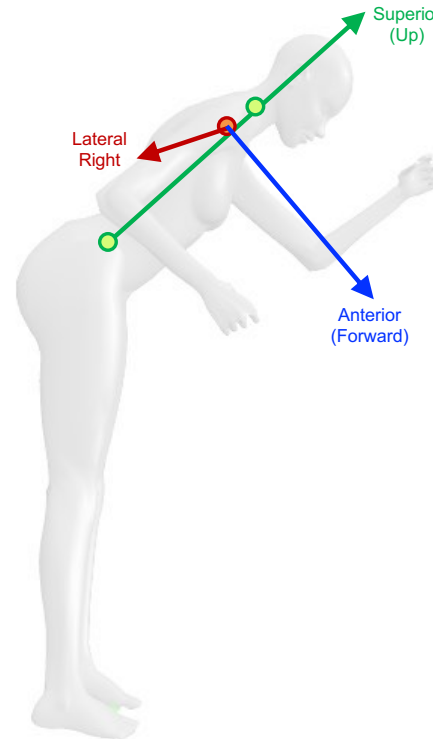


Hand Locations Across Studies



La Delfa & Potvin (2017)

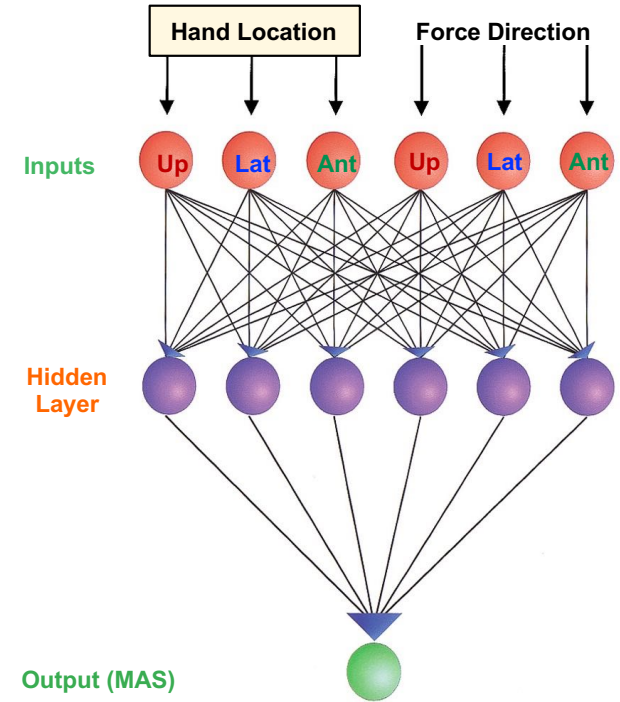
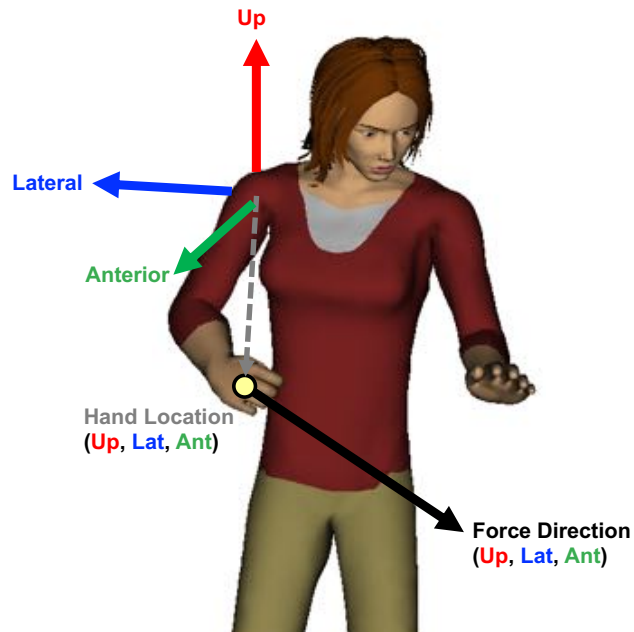
- ANN predicts manual arm strength in 0g
 - relative to axis system defined at the shoulder
- gravity effects added after
 - can enter arm posture
 - or it is predicted
- Axes
 - create axis system at shoulders
- Inputs
 - hand location relative to shoulder
 - force direction in global frame



The Arm Force Field: Predicting MAS

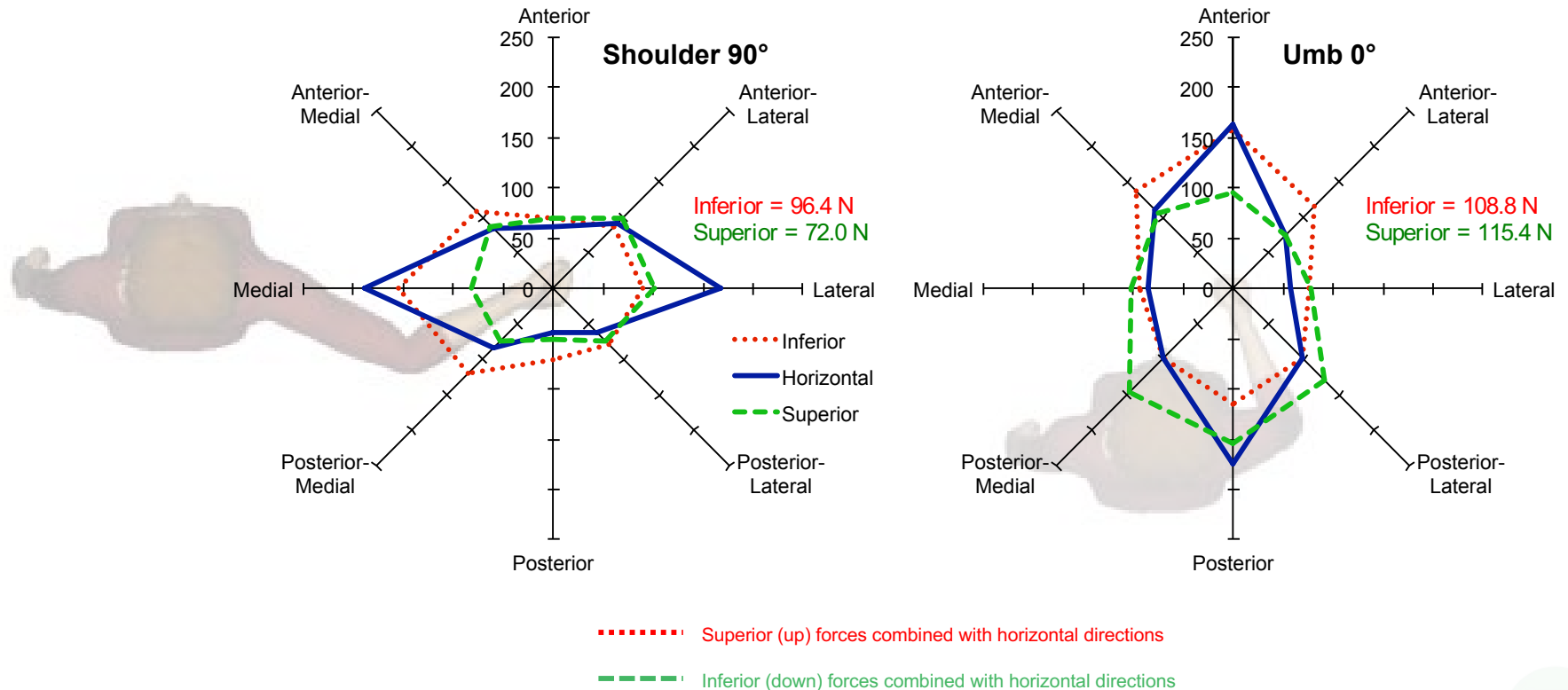
La Delfa & Potvin (2016)

- Artificial Neural Network (ANN)
 - 3 hand location coordinates
 - 3 force directions
 - produced 18 inputs



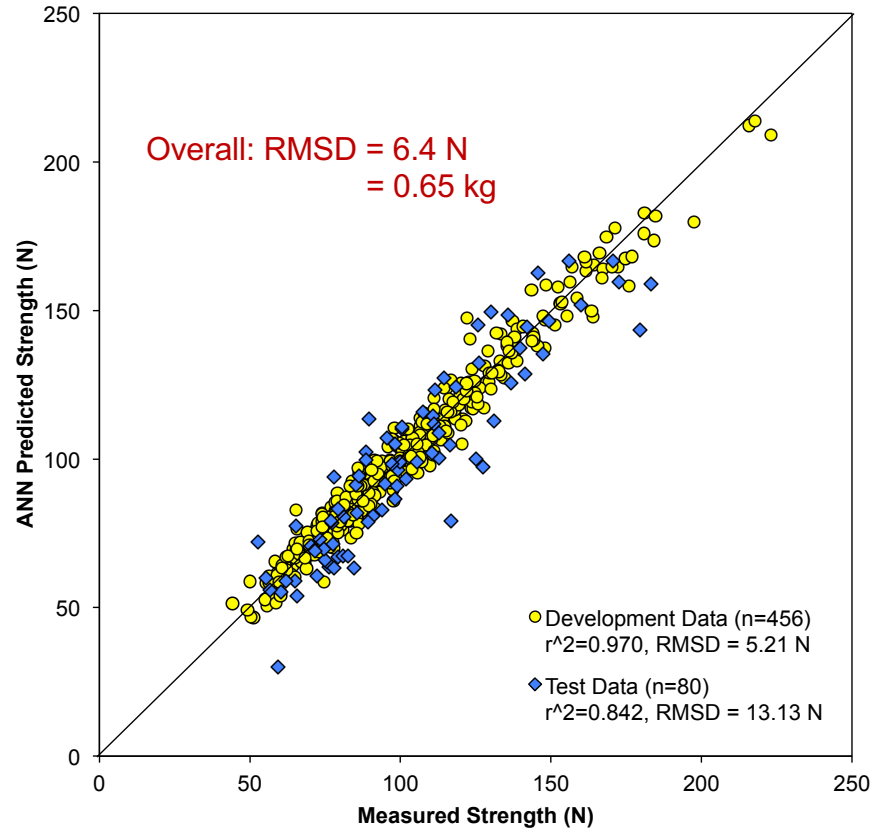
Results: Manual Arm Strength

La Delfa & Potvin (2016)



AFF vs 3DSSPP: Errors

La Delfa & Potvin (2017)

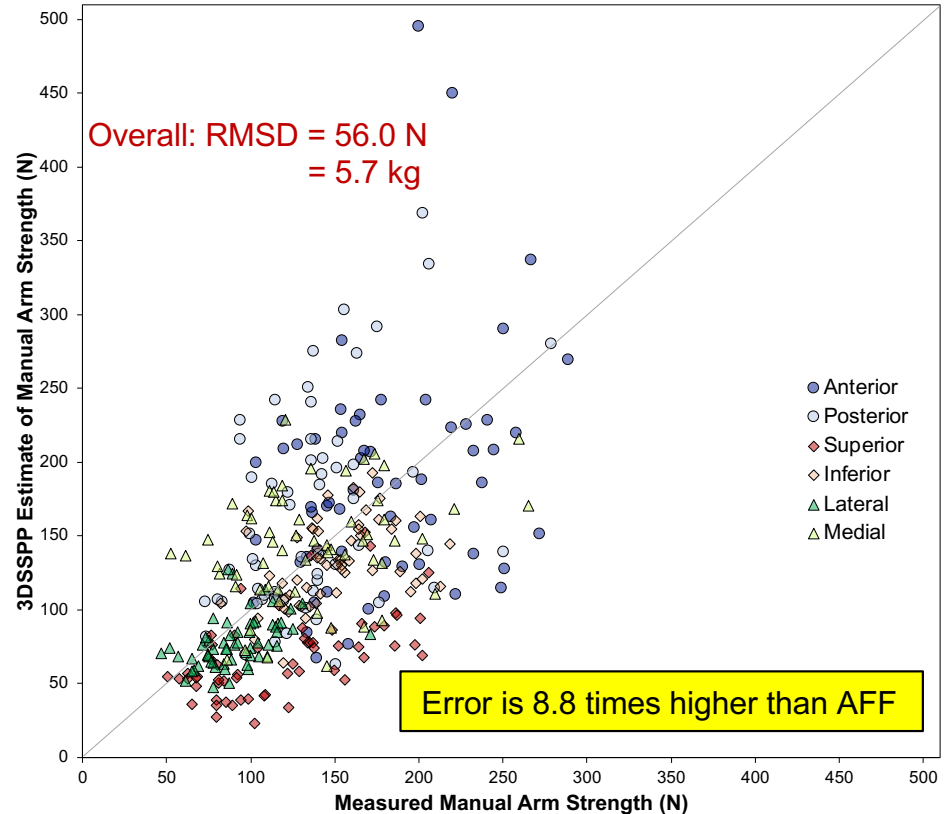
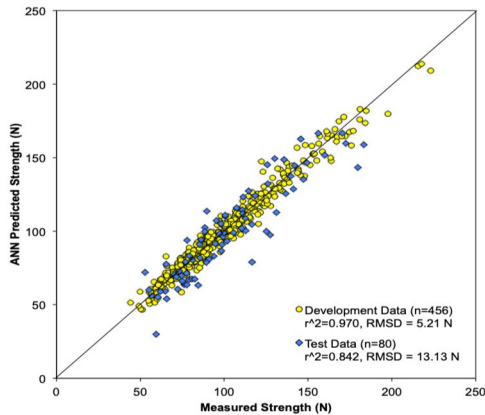


AFF vs 3DSSPP: Errors

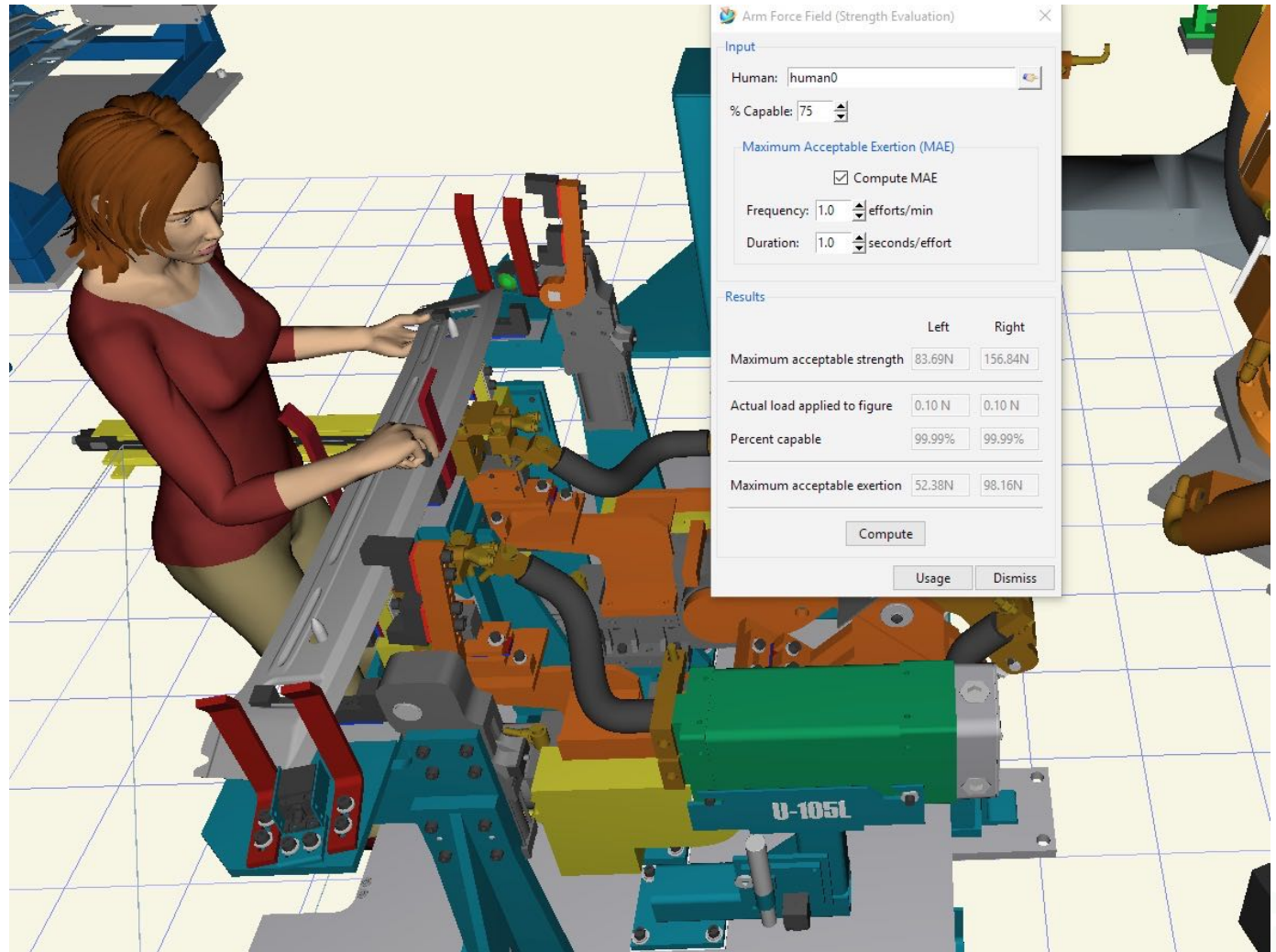
La Delfa & Potvin (2017)

3DSSPP 7.1

Overall: RMSD = 6.4 N
= 0.65 kg



The AFF: in Jack



The AFF: in Process Simulate

The screenshot shows a software interface for simulating arm strength. The main window displays a 3D model of a person in a bent posture, with two yellow arrows indicating force vectors: $d(kgf) = 10.20$ (downward) and $d(kgf) = 5.15$ (upward).

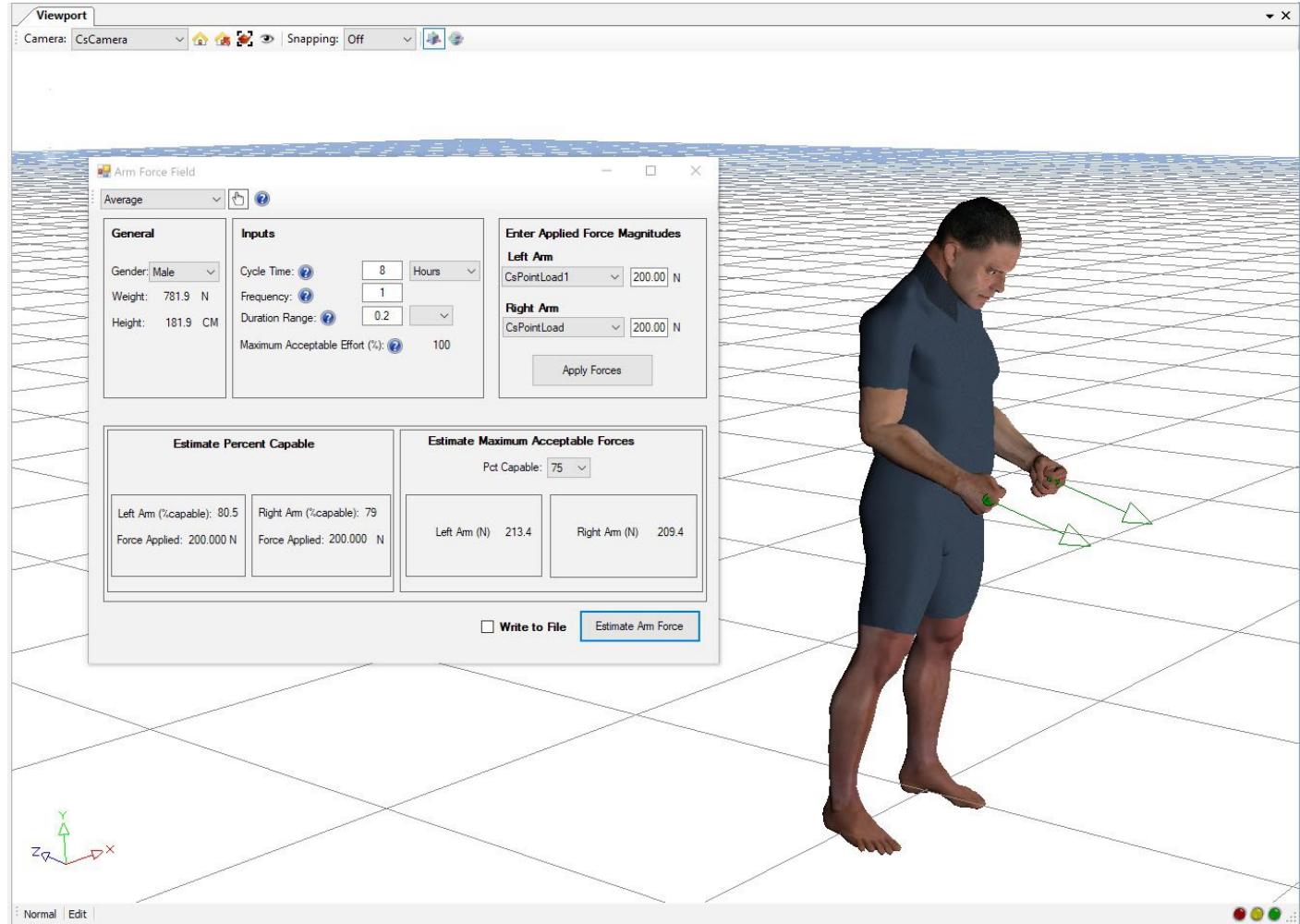
The dialog box, titled "Arm Strength Evaluation (Arm Force Field)-Jack", contains the following settings:

- Manual arm strength:**
 - Percent capable: 75 %
 - Arm strength for this scenario is:
 - Left: 253.39 N
 - Right: 192.14 N
 - Current load:
 - Left: 50.00 N
 - Right: 100.00 N
 - Percent capable:
 - Left: 99.88 %
 - Right: 98.53 %
- Maximum acceptable force (MAF):**
 - Compute MAF based on effort frequency and duration
 - Frequency: 1 efforts/minute
 - Duration: 1 seconds/efforts
 - Maximum acceptable force:
 - Left: - N
 - Right: - N

Buttons: Update Results, Close



The AFF: in Santos



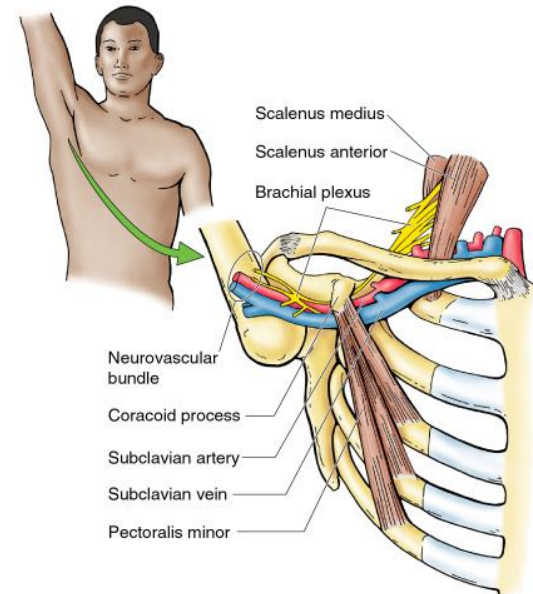
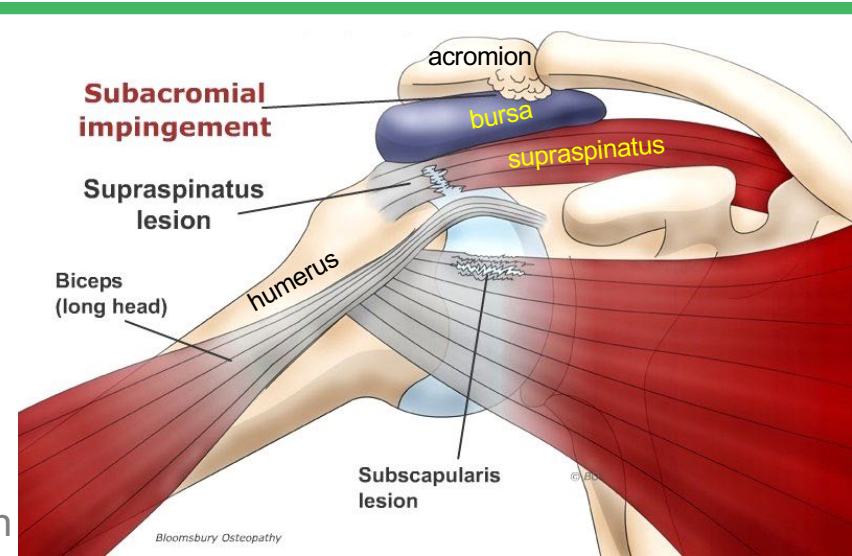
New Assessment Tool: Above-Shoulder Model & Assessment Tool

David Rempel & Jim R. Potvin
DRAFT: Under Review

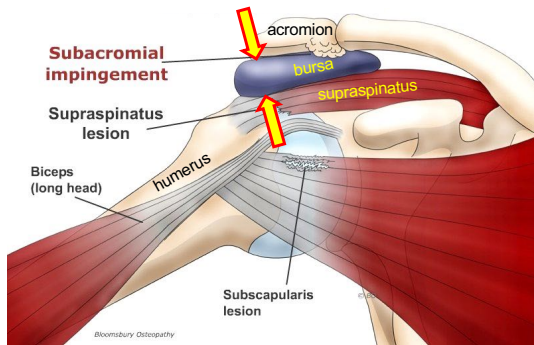
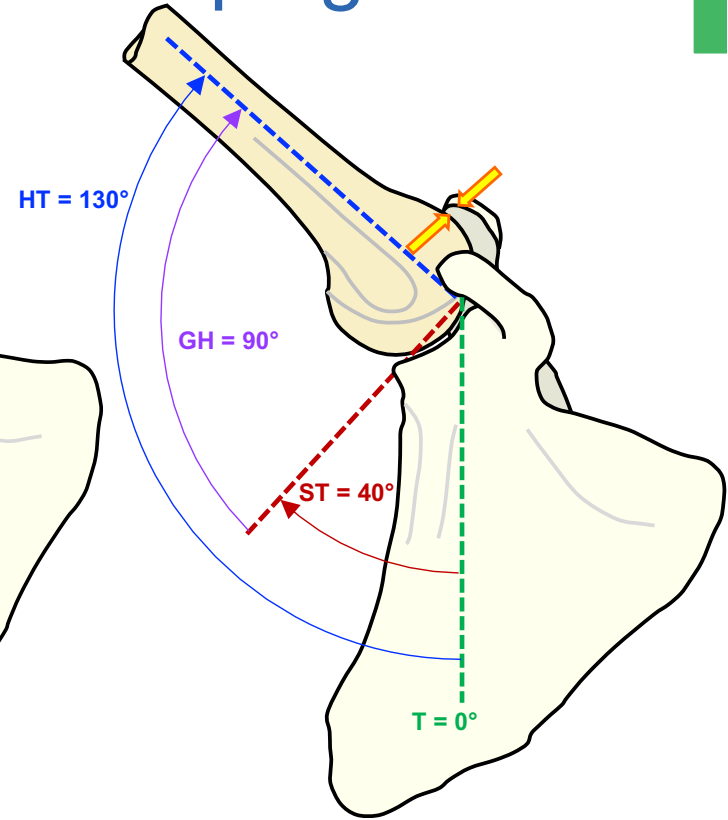
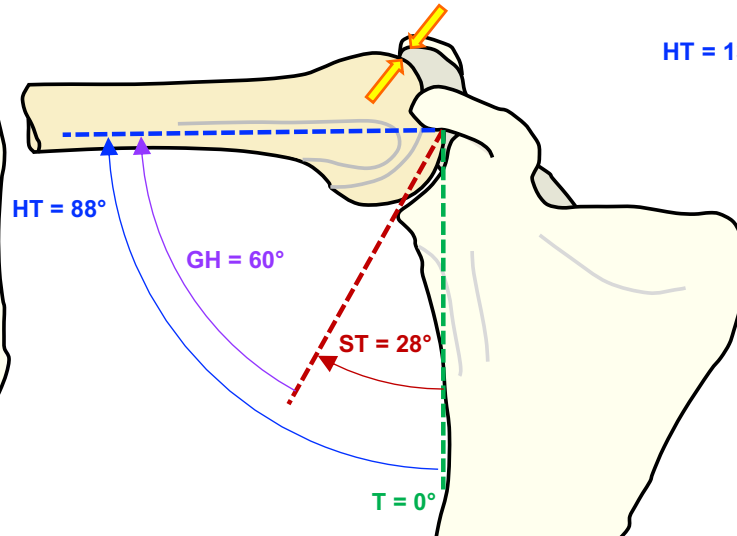
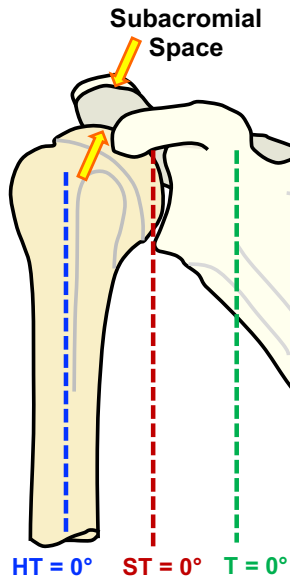


Above-Shoulder Work

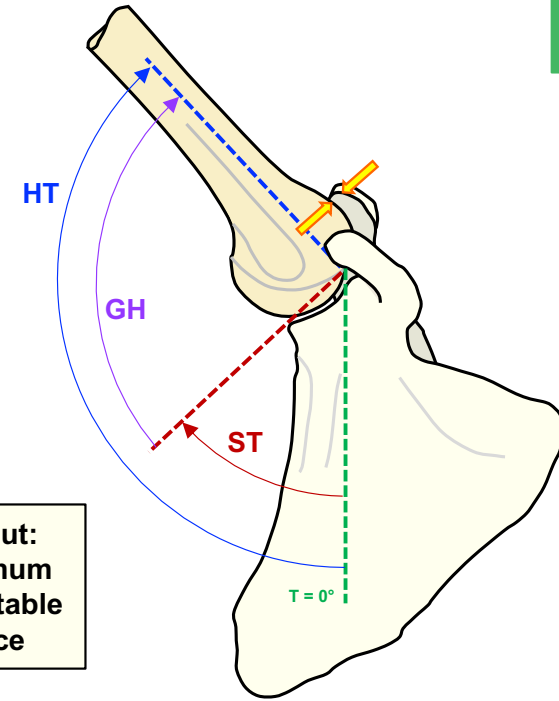
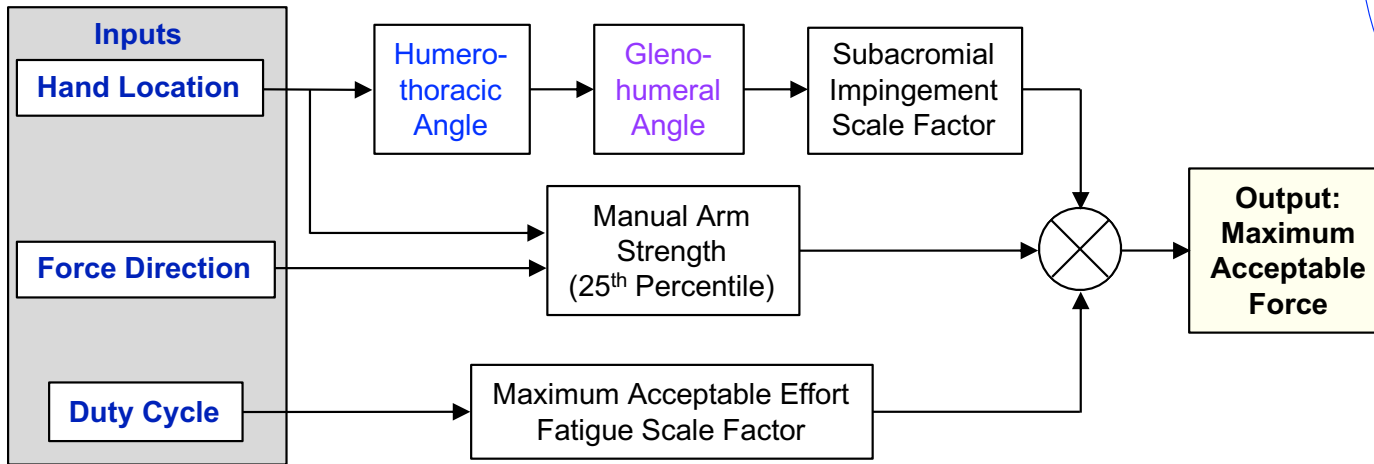
- Above-shoulder risk factors
 - hand above the shoulder
 - forceful hand exertions
 - shoulder load
- Supraspinatus tendon tears
 - repeated forceful impingement of the tendon
 - glenohumeral rotation
 - deltoid fatigue
 - degenerative changes to the tendon
- Bursitis
- Thoracic Outlet Syndrome
- No Ergonomic Tools to specifically assess the risk of work above the shoulder



Shoulder Rhythm & Subacromial Impingement

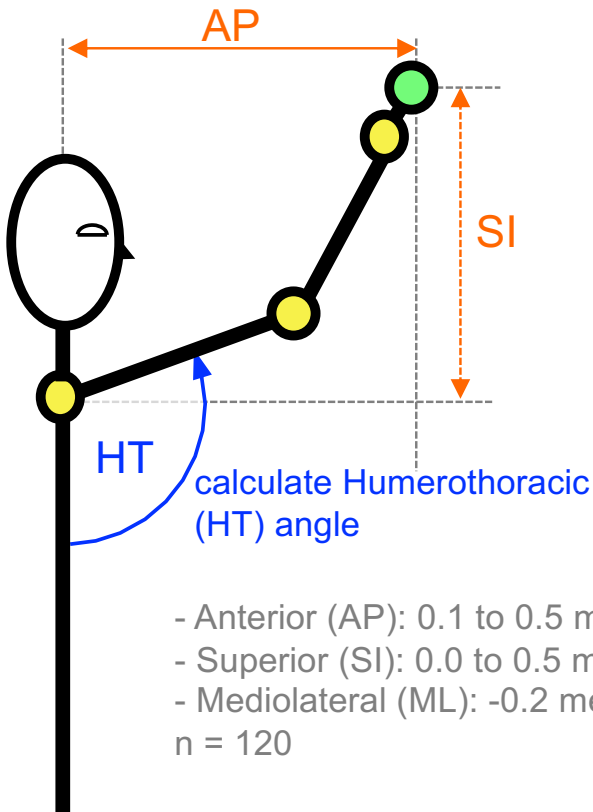


Model Development: Flowchart



Model Development: Hand Location Matrix

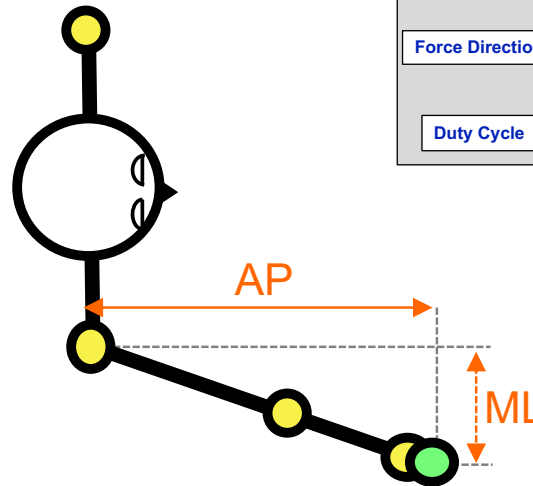
Lateral View



- Anterior (AP): 0.1 to 0.5 m (by 0.1 M)
 - Superior (SI): 0.0 to 0.5 m (by 0.1)
 - Mediolateral (ML): -0.2 medial to 0.4 m lateral (by 0.2)
- n = 120

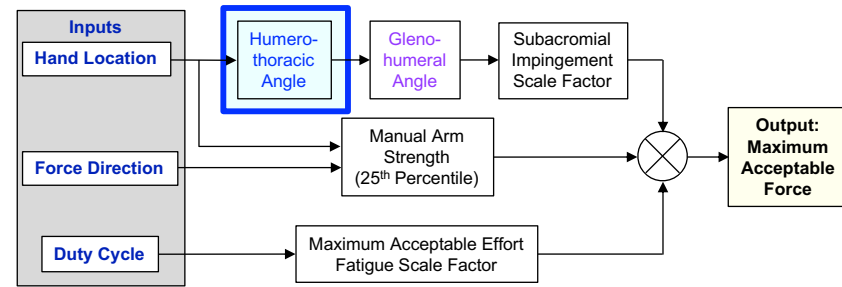
Limit reach to 0.20 to 0.55 m (n = 77)

Superior View

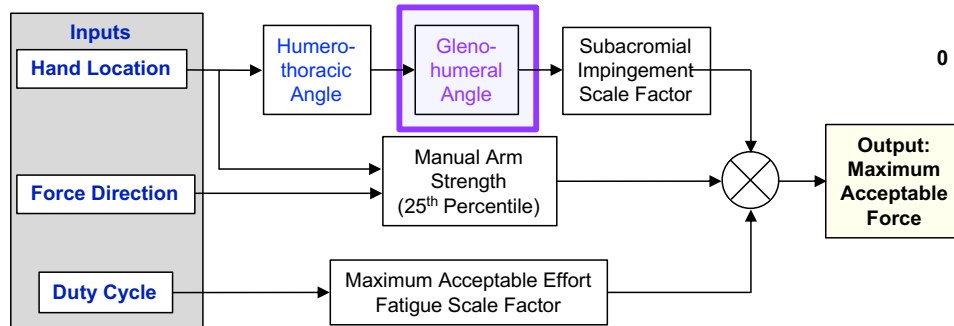
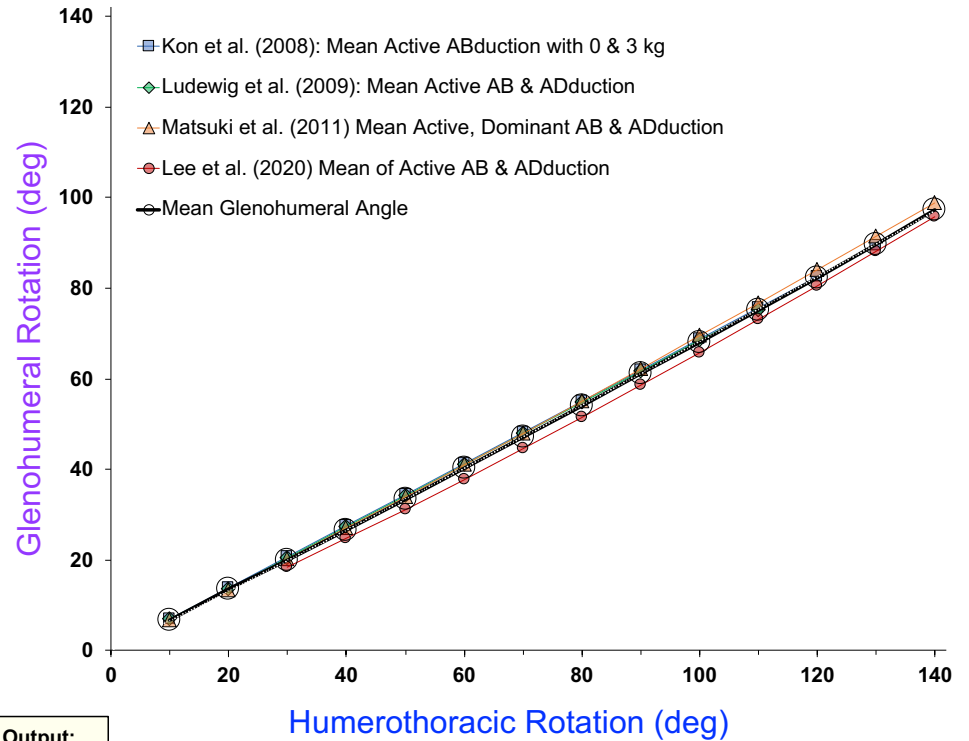
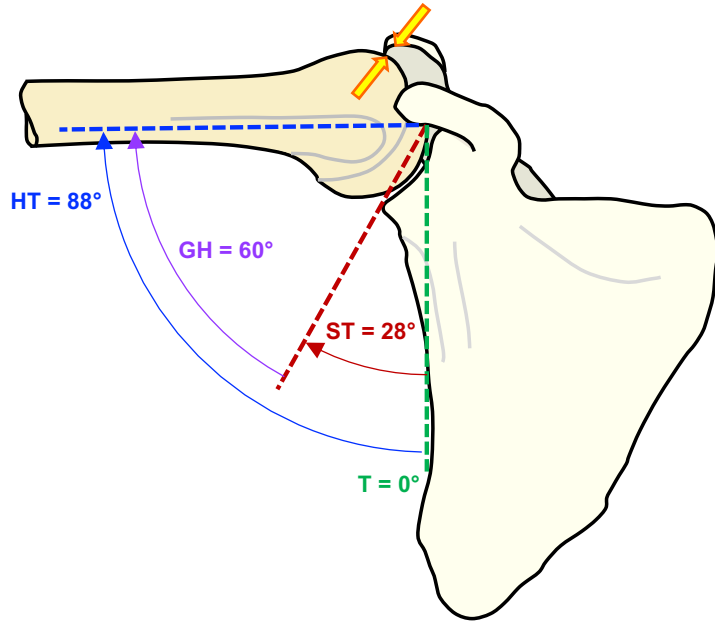


50th female segment lengths

assume the plane of shoulder/elbow/knuckle is vertical



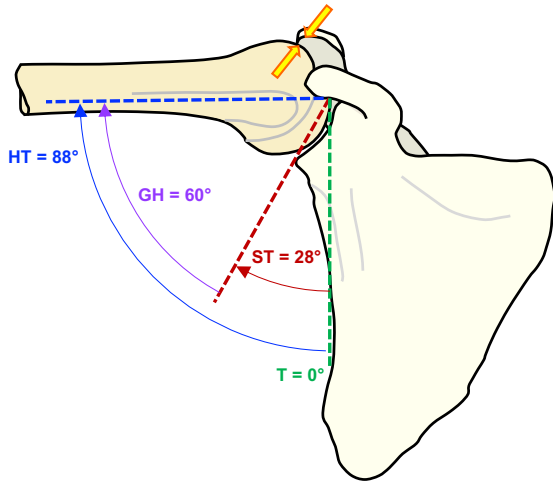
Model Development: Scapulohumeral Rhythm



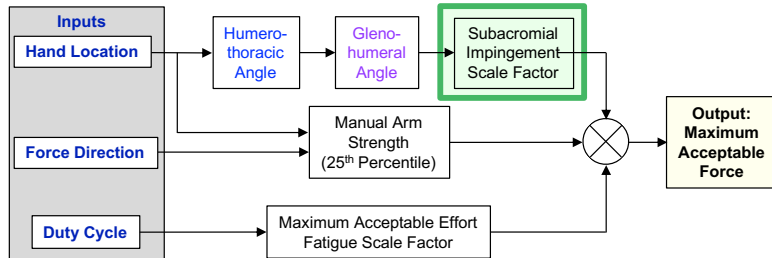
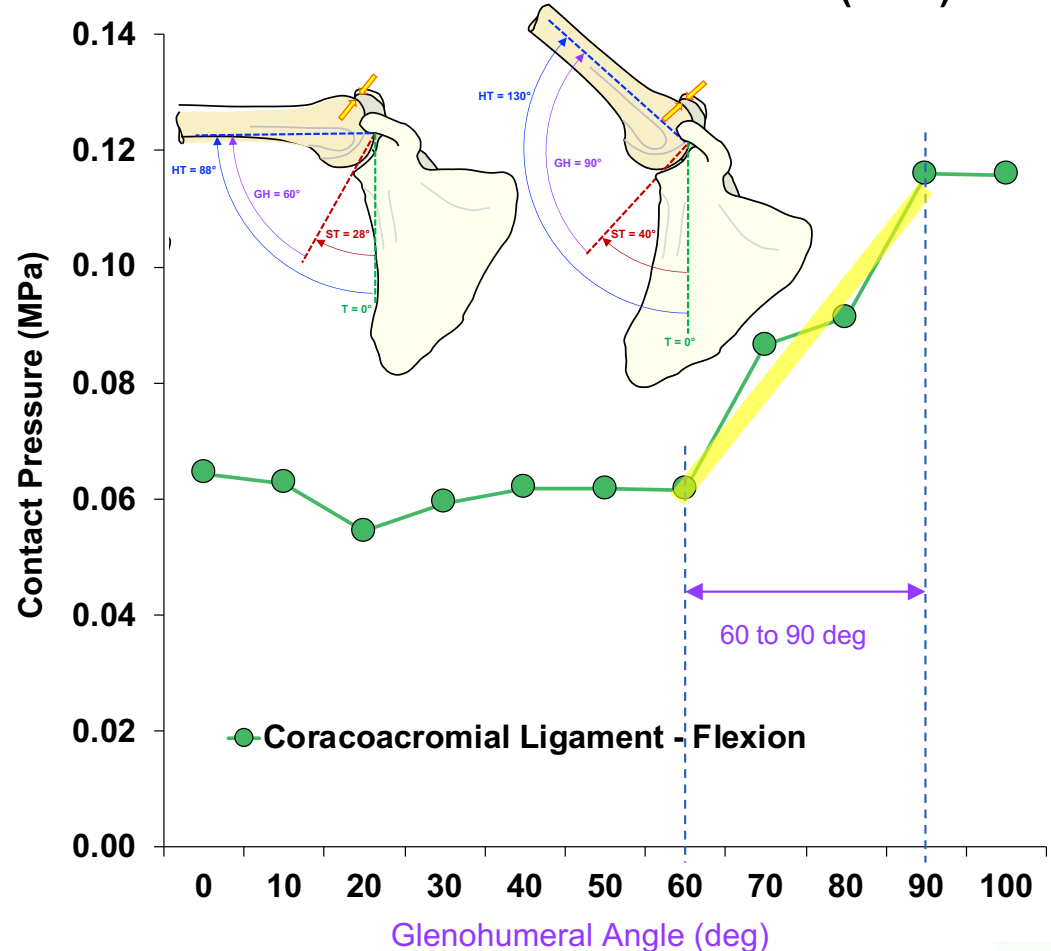
Model Development: Subacromial Impingement

Contact between the coracoacromial arch and the rotator cuff tendons in nonpathologic situations: A cadaveric study

Nobuyuki Yamamoto, MD^a, Takayuki Muraki, PhD^a, John W. Sperling, MD^b, Scott P. Steinmann, MD^b, Eiji Itoi, MD^c, Robert H. Coffield, MD^b, Kai-Nan An, PhD^{b,*}



Absolute Pressures - Yamamoto et al (2010)



Model Development: AFF Manual Arm Strength

Superior

| | | ML = -0.2 m (Medial) | | | | |
|------|-----|----------------------|------|------|------|------|
| AP > | | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
| SI | 0.5 | 98.5 | | | | |
| | 0.4 | 44.4 | 52.7 | 66.0 | | |
| | 0.3 | 48.9 | 57.2 | 57.7 | 66.4 | |
| | 0.2 | 44.8 | 59.9 | 59.3 | 54.2 | |
| | 0.1 | 57.8 | 62.4 | 63.7 | 49.9 | 45.2 |
| | 0.0 | 71.0 | 69.9 | 68.6 | 50.6 | 43.2 |

| ML = 0 m | | | | | |
|----------|-------|------|------|------|--|
| 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | |
| 104.2 | 101.5 | | | | |
| 59.6 | 53.7 | 52.3 | | | |
| 54.8 | 63.1 | 56.4 | 55.0 | | |
| 45.8 | 60.6 | 65.5 | 51.4 | 47.7 | |
| | 54.1 | 67.8 | 50.5 | 45.8 | |
| | 59.2 | 68.4 | 48.6 | 43.2 | |

| ML = +0.2 m (Lateral) | | | | | |
|-----------------------|------|------|------|------|--|
| 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | |
| 101.7 | | | | | |
| 66.7 | 58.9 | 54.2 | | | |
| 67.9 | 65.8 | 52.9 | 49.8 | | |
| 59.2 | 65.5 | 60.2 | 49.0 | | |
| 58.5 | 59.5 | 64.2 | 47.5 | 46.9 | |
| 58.5 | 57.4 | 64.7 | 46.6 | 43.2 | |

| ML = +0.4 m | | | | | |
|-------------|------|------|-----|-----|--|
| 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | |
| | | | | | |
| | | | | | |
| | | | | | |
| 72.5 | 62.9 | | | | |
| 80.5 | 70.6 | 50.8 | | | |
| 101.1 | 82.1 | 56.7 | | | |
| 102.5 | 89.8 | 62.0 | | | |

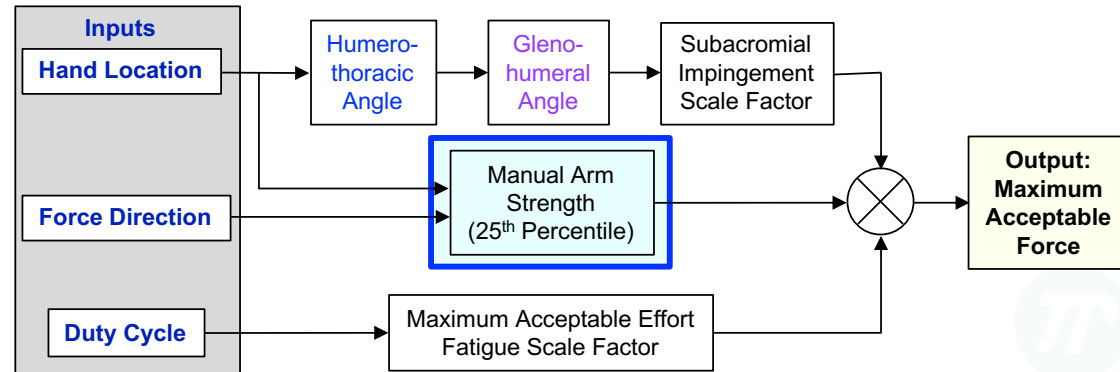
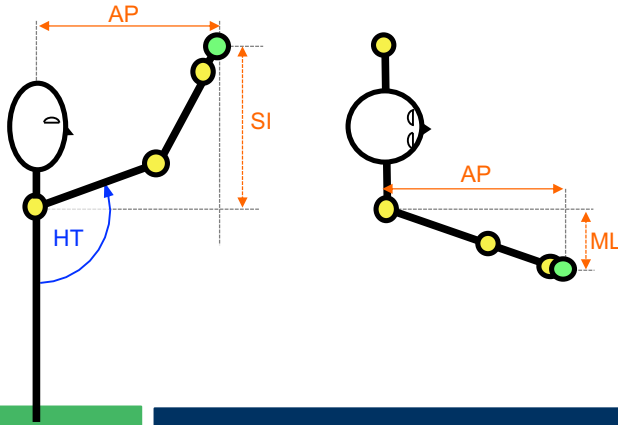
Anterior

| | | ML = -0.2 m (Medial) | | | | |
|------|-----|----------------------|------|------|------|------|
| AP > | | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
| SI | 0.5 | 70.1 | | | | |
| | 0.4 | 69.7 | 68.0 | 79.1 | | |
| | 0.3 | 82.8 | 71.8 | 69.6 | 82.8 | |
| | 0.2 | 85.8 | 75.7 | 64.9 | 69.1 | |
| | 0.1 | 97.0 | 83.4 | 69.3 | 65.3 | 73.6 |
| | 0.0 | 108.4 | 98.7 | 82.8 | 73.7 | 77.4 |

| ML = 0 m | | | | | |
|----------|------|------|------|------|--|
| 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | |
| 58.0 | 80.0 | | | | |
| 71.6 | 64.8 | 69.5 | | | |
| 75.6 | 72.1 | 65.7 | 72.8 | | |
| 62.4 | 69.4 | 64.6 | 61.5 | 68.2 | |
| | 64.7 | 68.5 | 58.9 | 59.4 | |
| | 80.3 | 84.7 | 68.8 | 59.6 | |

| ML = +0.2 m (Lateral) | | | | | |
|-----------------------|------|------|------|------|--|
| 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | |
| 51.0 | | | | | |
| 61.5 | 58.0 | 64.7 | | | |
| 67.9 | 63.5 | 61.3 | 70.9 | | |
| 62.7 | 65.9 | 62.1 | 64.5 | | |
| 69.4 | 71.0 | 69.2 | 65.9 | 70.3 | |
| 91.2 | 87.7 | 83.3 | 75.5 | 74.8 | |

| ML = +0.4 m | | | | | |
|-------------|-------|------|-----|-----|--|
| 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | |
| | | | | | |
| | | | | | |
| | | | | | |
| 60.4 | 53.6 | | | | |
| 78.1 | 63.9 | 56.7 | | | |
| 114.5 | 84.9 | 65.5 | | | |
| 132.3 | 105.8 | 79.2 | | | |



Recommended Above-Shoulder Acceptable Forces

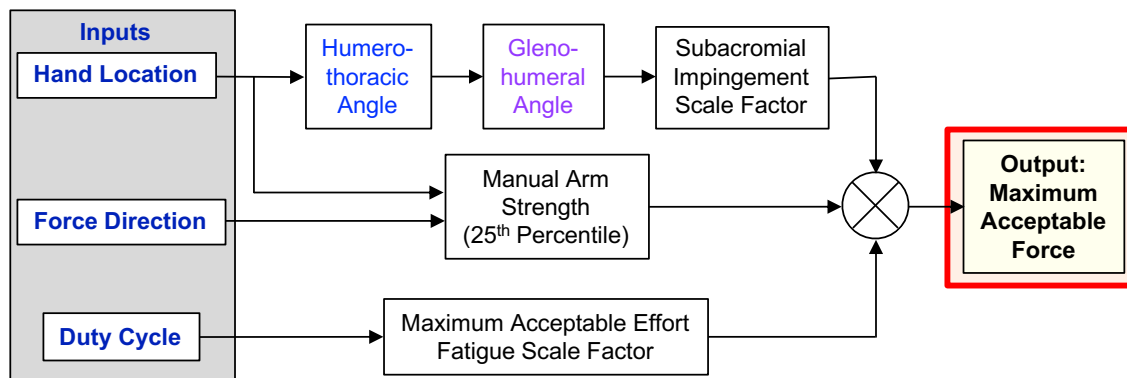
Recommended Anterior Maximum Forces (N)

| | | ML = -0.2 m (Medial) | | | | | ML = 0 m | | | | | ML = +0.2 m (Lateral) | | | | | ML = +0.4 m | | |
|----|-----|-----------------------|-----|-----|-----|-----|----------|-----|-----|-----|-----|-----------------------|-----|-----|-----|-----|-------------|-----|-----|
| | | AP > | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.1 | 0.2 |
| SI | 0.5 | redacted (for now) | | | | | | | | | | | | | | | | | |
| | 0.4 | | | | | | | | | | | | | | | | | | |
| | 0.3 | | | | | | | | | | | | | | | | | | |
| | 0.2 | | | | | | | | | | | | | | | | | | |
| | 0.1 | | | | | | | | | | | | | | | | | | |
| | 0.0 | | | | | | | | | | | | | | | | | | |

DRAFT

Recommended Superior Maximum Forces (N)

| | | ML = -0.2 m (Medial) | | | | | ML = 0 m | | | | | ML = +0.2 m (Lateral) | | | | | ML = +0.4 m | | |
|----|-----|-----------------------|-----|-----|-----|-----|----------|-----|-----|-----|-----|-----------------------|-----|-----|-----|-----|-------------|-----|-----|
| | | AP > | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.1 | 0.2 |
| SI | 0.5 | redacted (for now) | | | | | | | | | | | | | | | | | |
| | 0.4 | | | | | | | | | | | | | | | | | | |
| | 0.3 | | | | | | | | | | | | | | | | | | |
| | 0.2 | | | | | | | | | | | | | | | | | | |
| | 0.1 | | | | | | | | | | | | | | | | | | |
| | 0.0 | | | | | | | | | | | | | | | | | | |



Correct for Duty Cycle: MAE Equation or TLV

100
90
80
70
60
50
40
30
20
10
0

Table Value
for Single Effort

Predicting Maximum Acceptable Efforts for Repetitive Tasks: An Equation Based on Duty Cycle

Jim R. Potvin, McMaster University, Hamilton, Ontario, Canada

HUMAN FACTORS

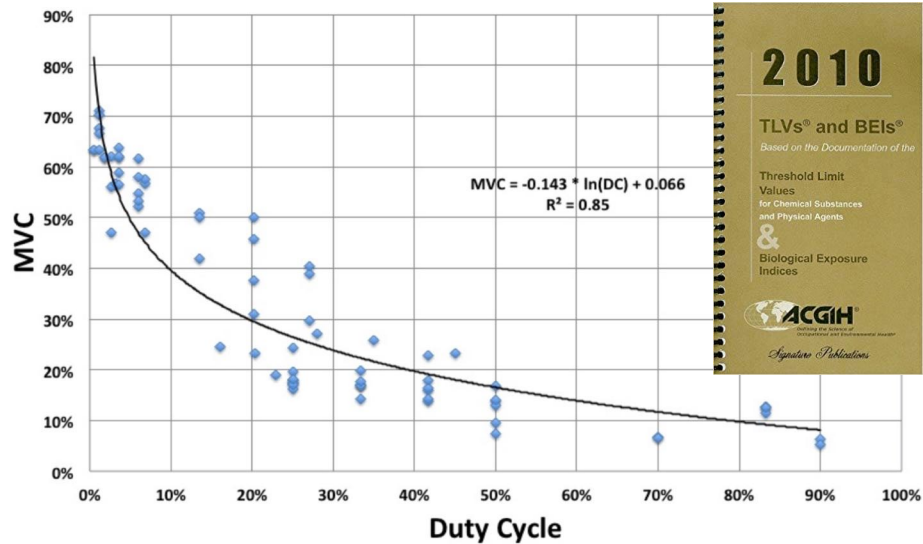
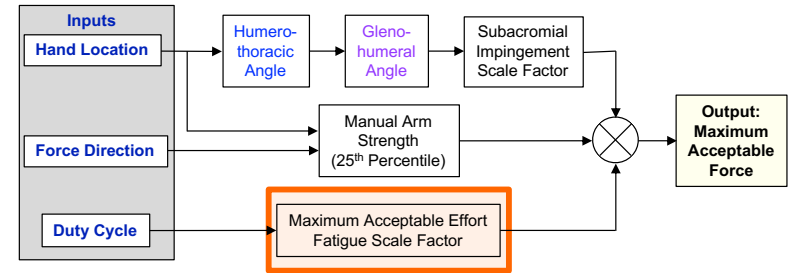
Vol. 54, No. 2, April 2012, pp. 175-188

Maximum Acceptable Effort (%)

Table Value scaled to
account for duty cycle

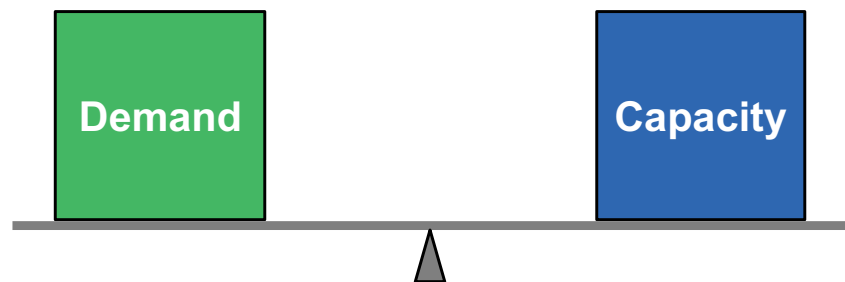
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Duty Cycle (Percent)



Summary

- For the 21 years from 1991 to 2012
 - very few new ergonomics assessment tools were introduced
- Ergonomists became dependent on their familiar tools
 - easy to use
 - however, many older tools may not be valid
 - [The Liberty Mutual MMH Equations](#) should replace the Revised NLE
 - adds pushes, pulls & carries
 - [The Arm Force Field](#) should replace the methods currently used in digital human models like 3DSSPP
- There is a future need for:
 - more validation studies
 - new assessment tools
 - eg. the [Above-Shoulder Tool](#)
 - we must look beyond biomechanics
 - ie. tools to assess [peak demand](#) (with [peak capacity](#))
 - more tools needed that combine the risks of multiple tasks (eg. [RCRA by Gibson & Potvin, 2016](#))
 - decreased [capacity](#)
 - muscle fatigue & cumulative passive tissue damage



Thank You!

jim.potvin@gmail.com

[Link to Cloud Folder with Ergonomics Tools](#)

