Establishing Acceptable Manual Forces in the Proactive Ergonomics Process:

Development and Implementation of the Arm Force Field Method

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Nick La Delfa, PhD
Assistant Professor
Faculty of Health Sciences
University of Ontario Institute of Technology
(now Ontario Tech University)
nicholas.ladelfa@uoit.ca

Presentation Order

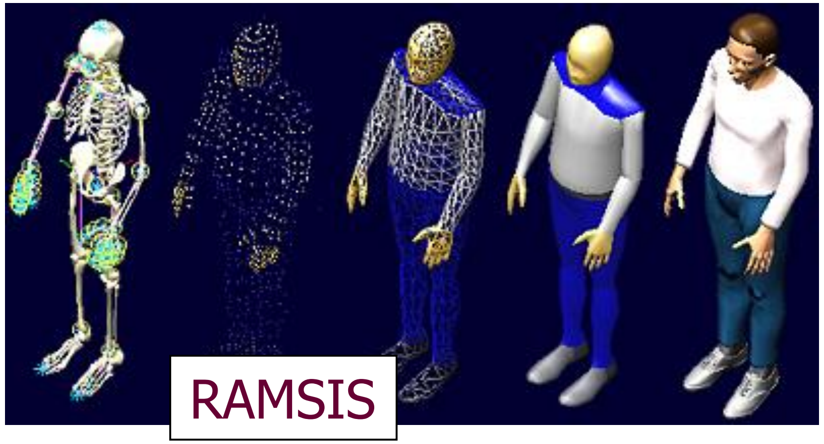
1. Digital Human Models in Ergonomics
   - Background and utilization
   - Estimating acceptable hand loads

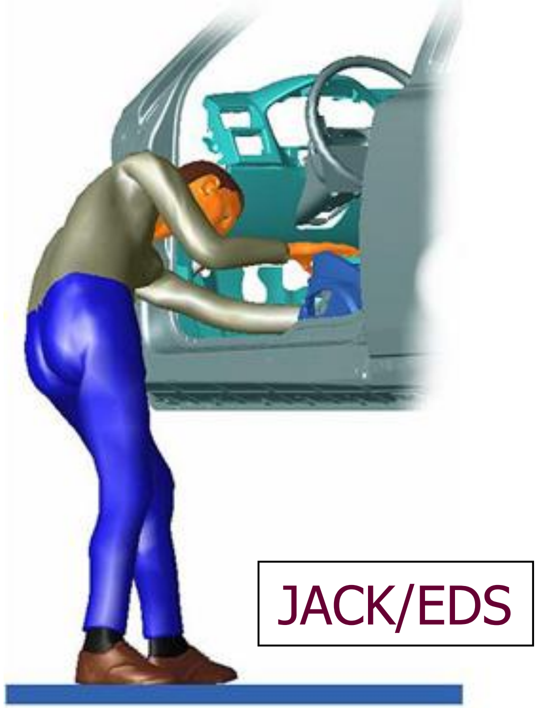
2. Evaluation of traditional strength prediction approaches

3. The Arm Force Field (AFF) Method
   - Theoretical development
   - Validation
   - Implementation within DHM

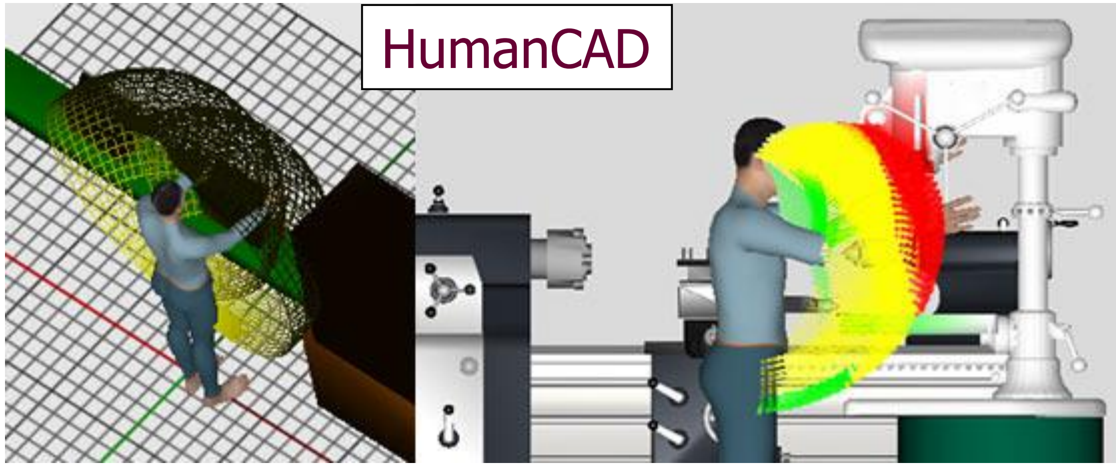
4. Using AFF to determine acceptable hand loads

Digital Human Models (DHMs)



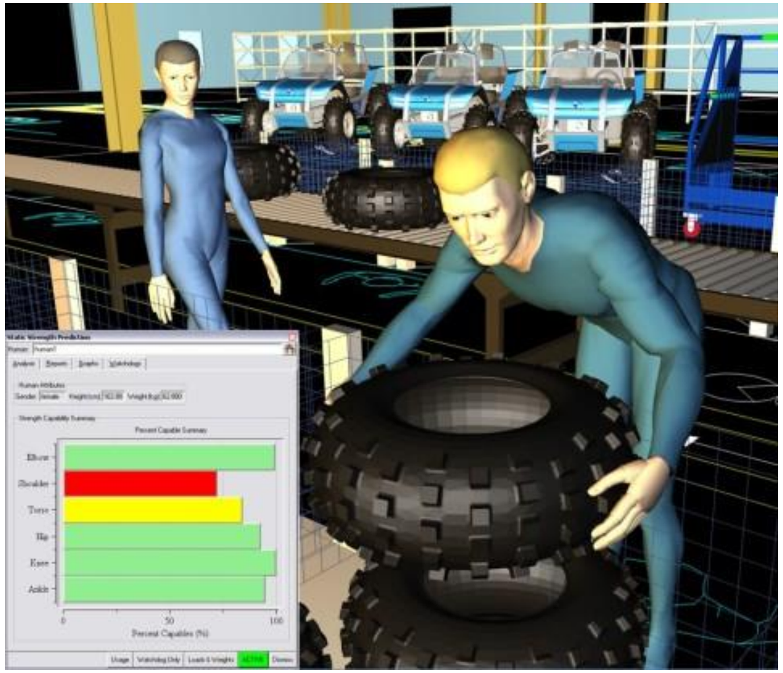


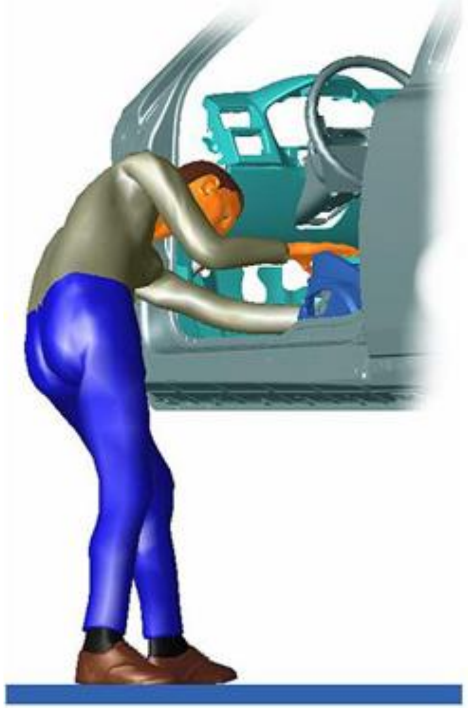
- **As a technology:**
  - Provides a means to create, control and manipulate human representations in a digital environment
- **As a fundamental area of study:**
  - Development of mathematical models that predict the biomechanics, physiology and behaviour of humans



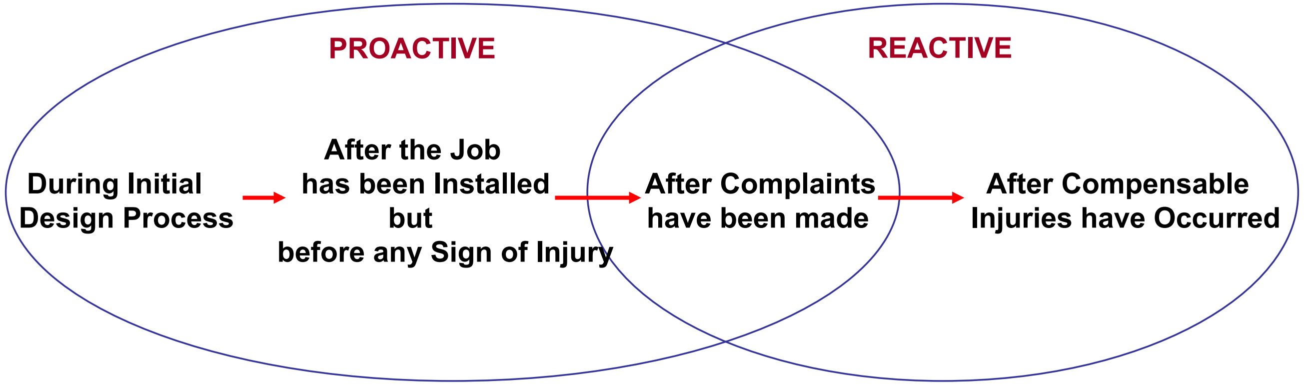
Why use DHMs

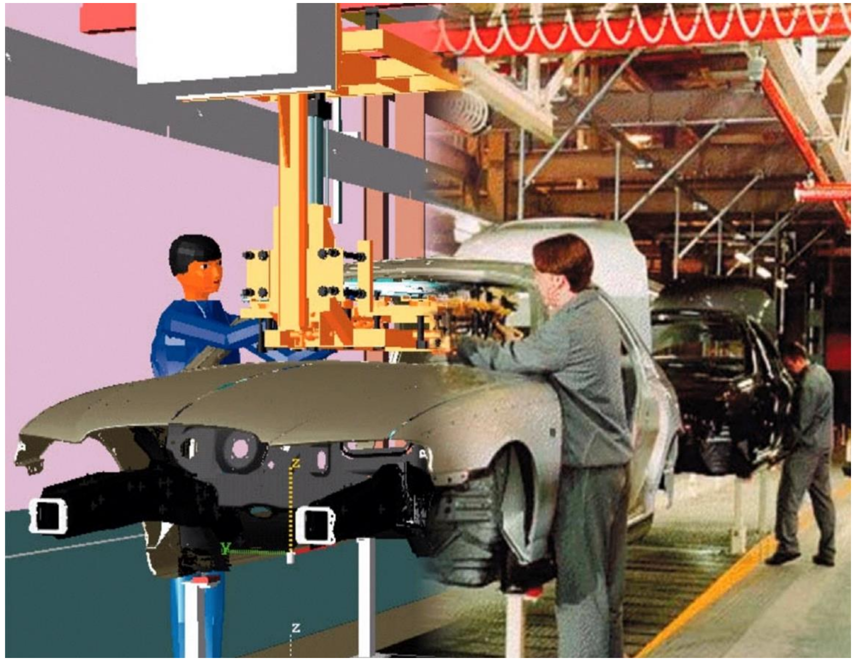
- Analysis of disorders, impairments, surgical techniques
  - Integration and interaction of biomechanical models
- Injury analysis
  - Crash testing, impacts, falls
- Product & Method Testing
- **Work simulation & Process Design**
  - Anthropometric considerations
  - Reach envelopes
  - Hand clearance
  - Tooling
  - Vision requirements
- **Ergonomics/Human Factors**
  - Posture Prediction
  - Strength demands
  - Fatigue estimation

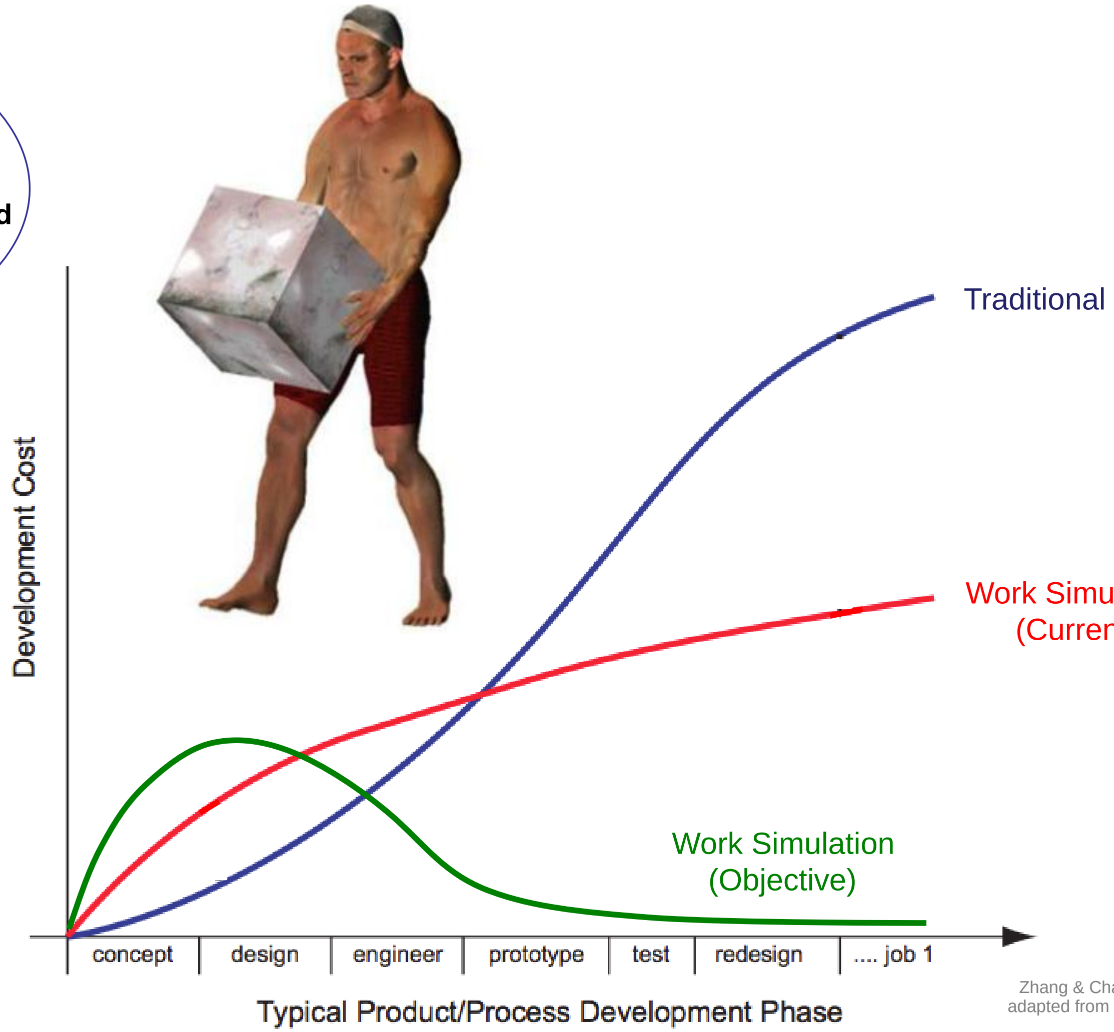




Proactive vs. Reactive Ergonomics

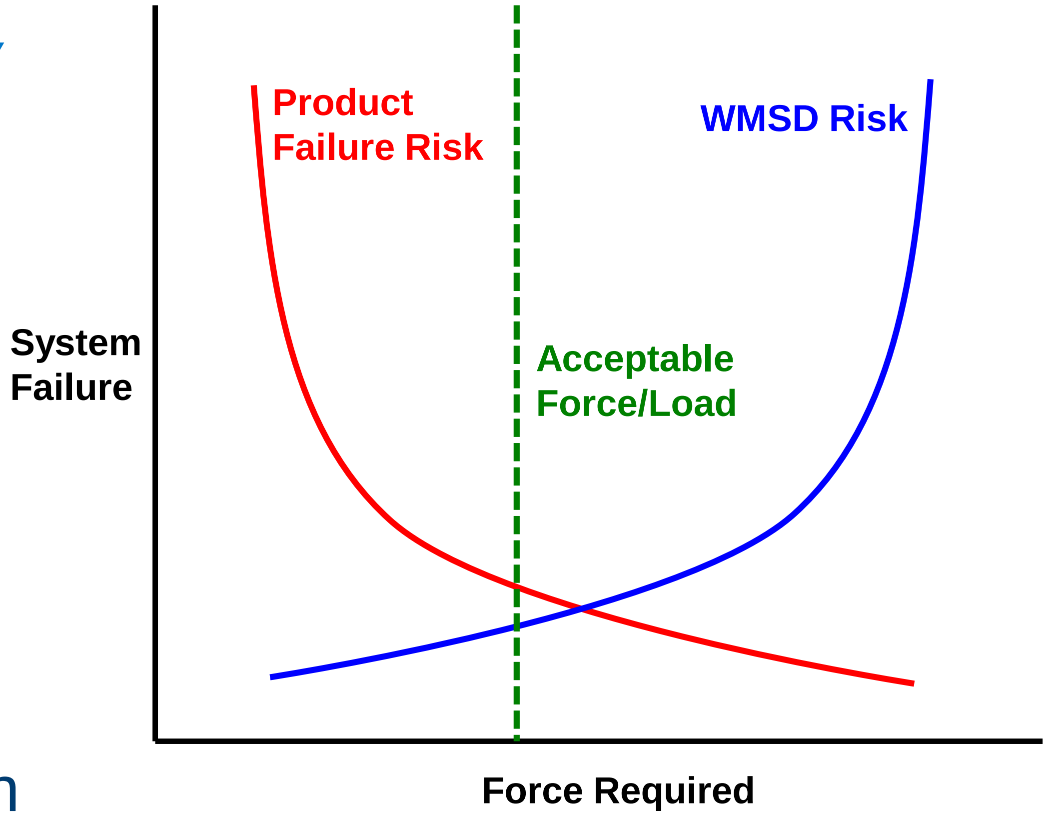






Zhang & Chaffin (2005)
adapted from Chaffin 2001

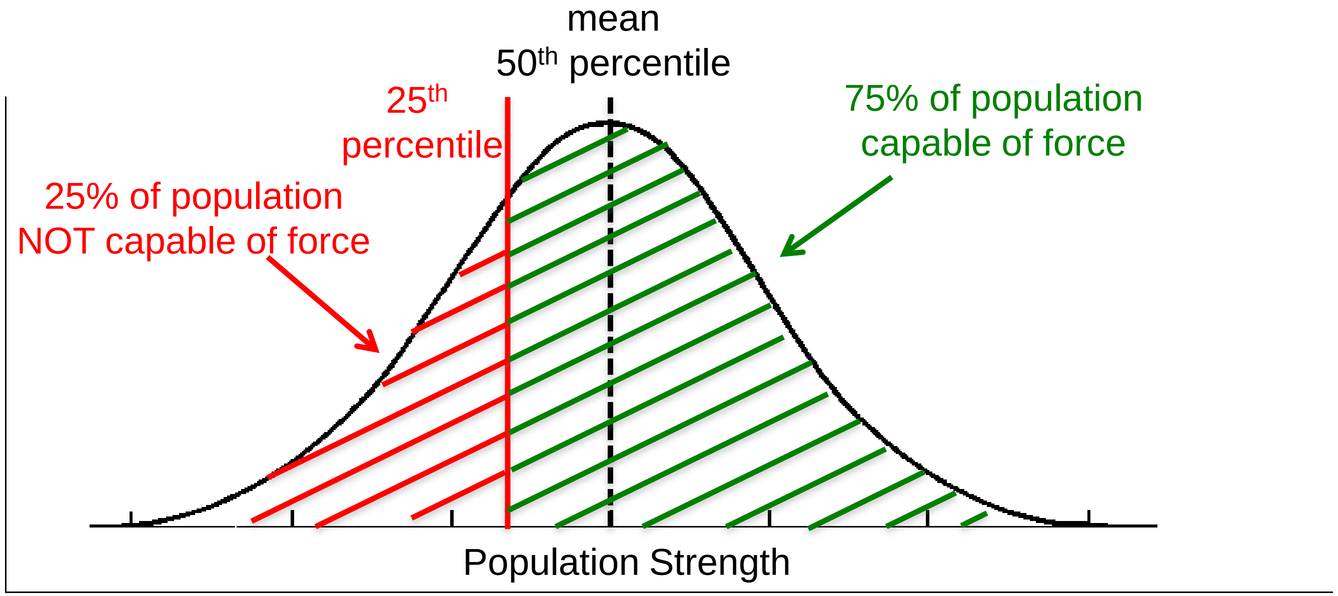
Strength Demands & Capacity

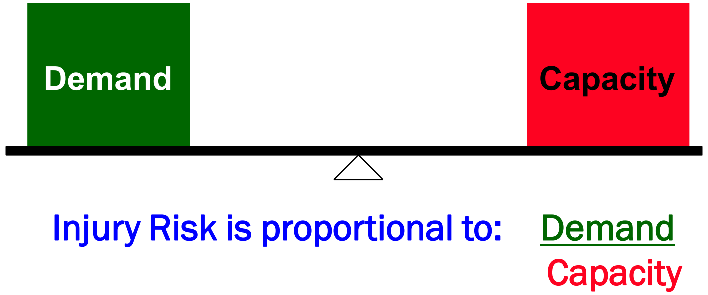


- Most types of jobs: require force/torque production
- So... make required forces as low as possible... problem solved??
  - quality/safety issues for end user of product (and expensive)
- So… make required forces as high as possible…
  - WMSD risk will increase

Determining acceptable loads

- ***How do we set force levels so that people do not get hurt?***
  - Design for the strength capability of 75% of females
    - *"a worker is three times more susceptible to low back injury if performing a manual handling task that is acceptable to less than 75% of the working population"*
      - Snook 1978

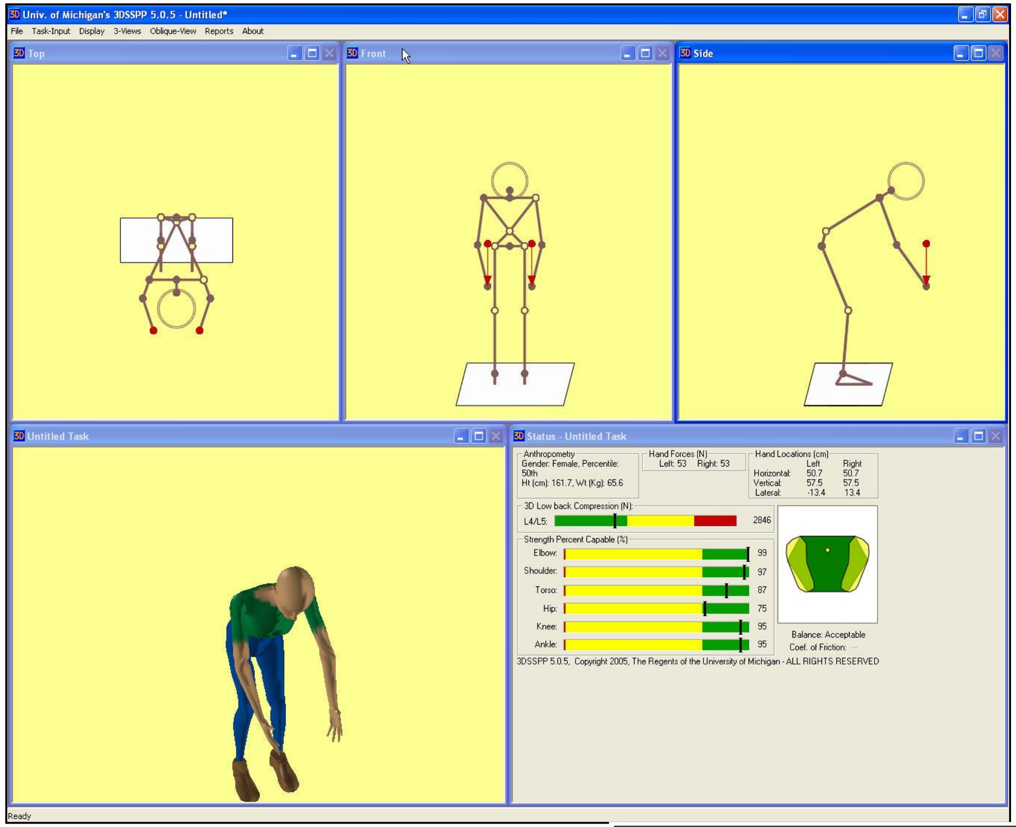




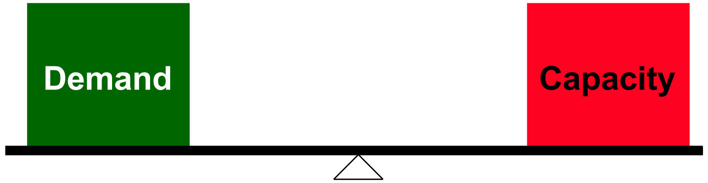
Strength Prediction in DHMs

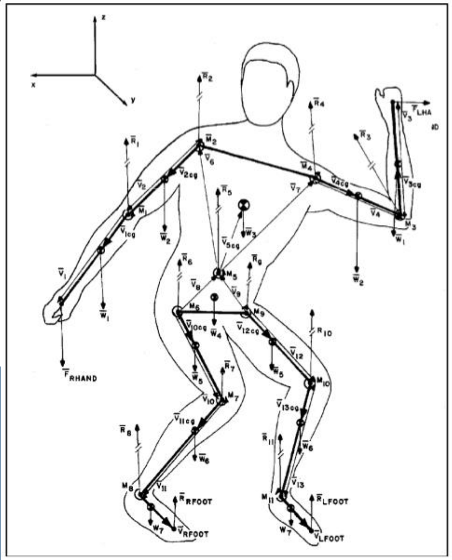
- Linked-segment biomechanical models
  - – determine moment demand on each joint
    - given posture & external force

- Compare joint demand to joint strength capacity
  - – estimated from equations

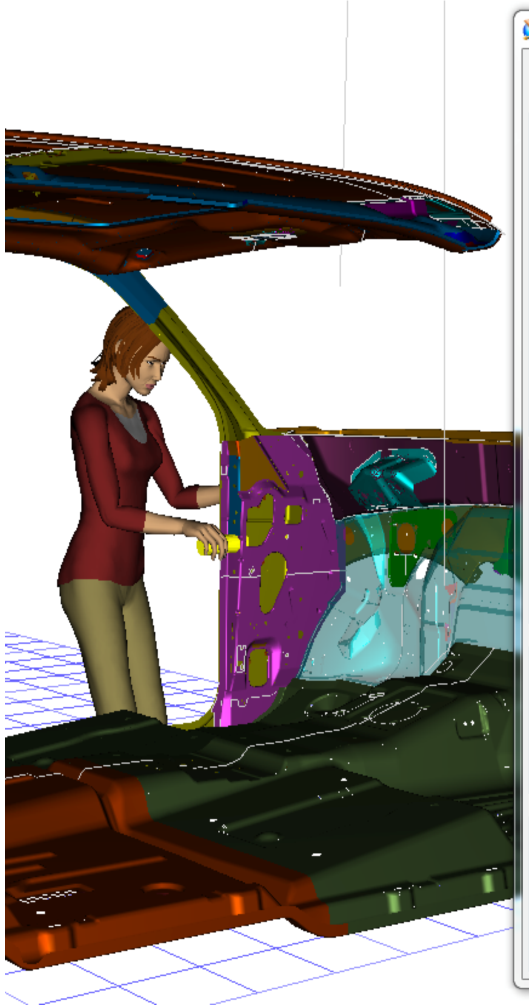


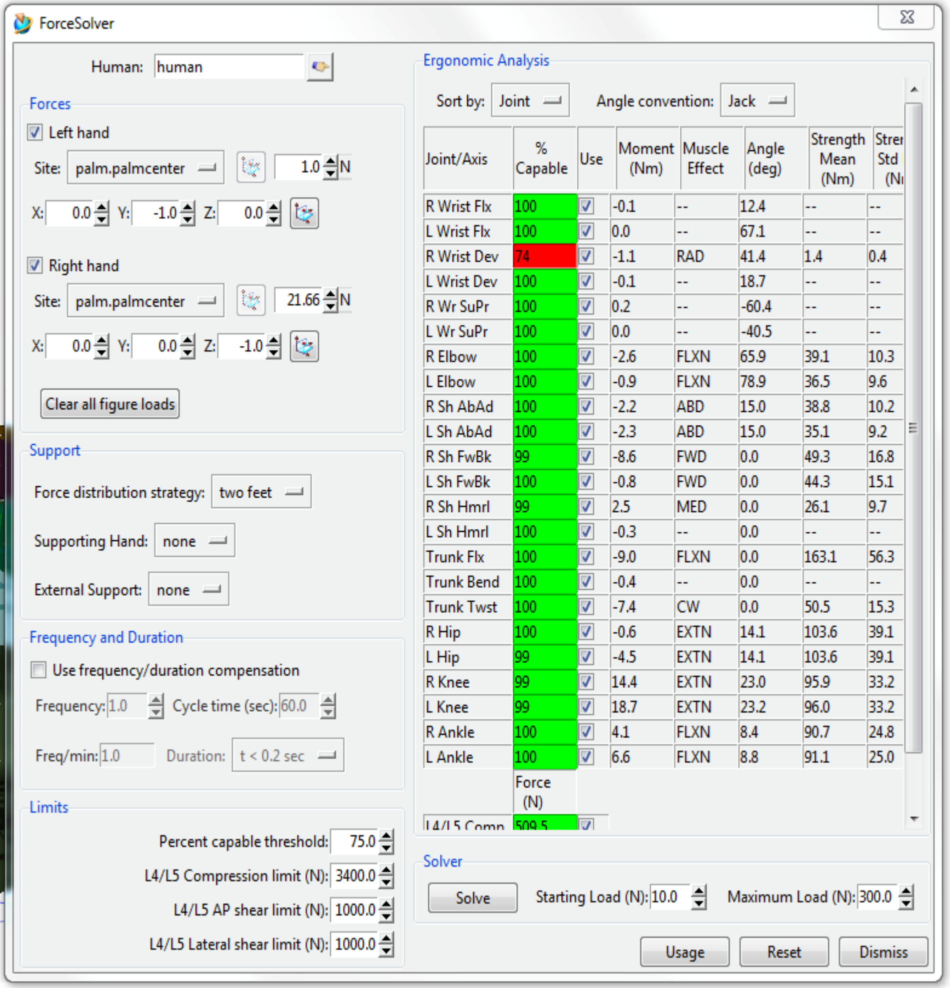
3DSSPP (University of Michigan)

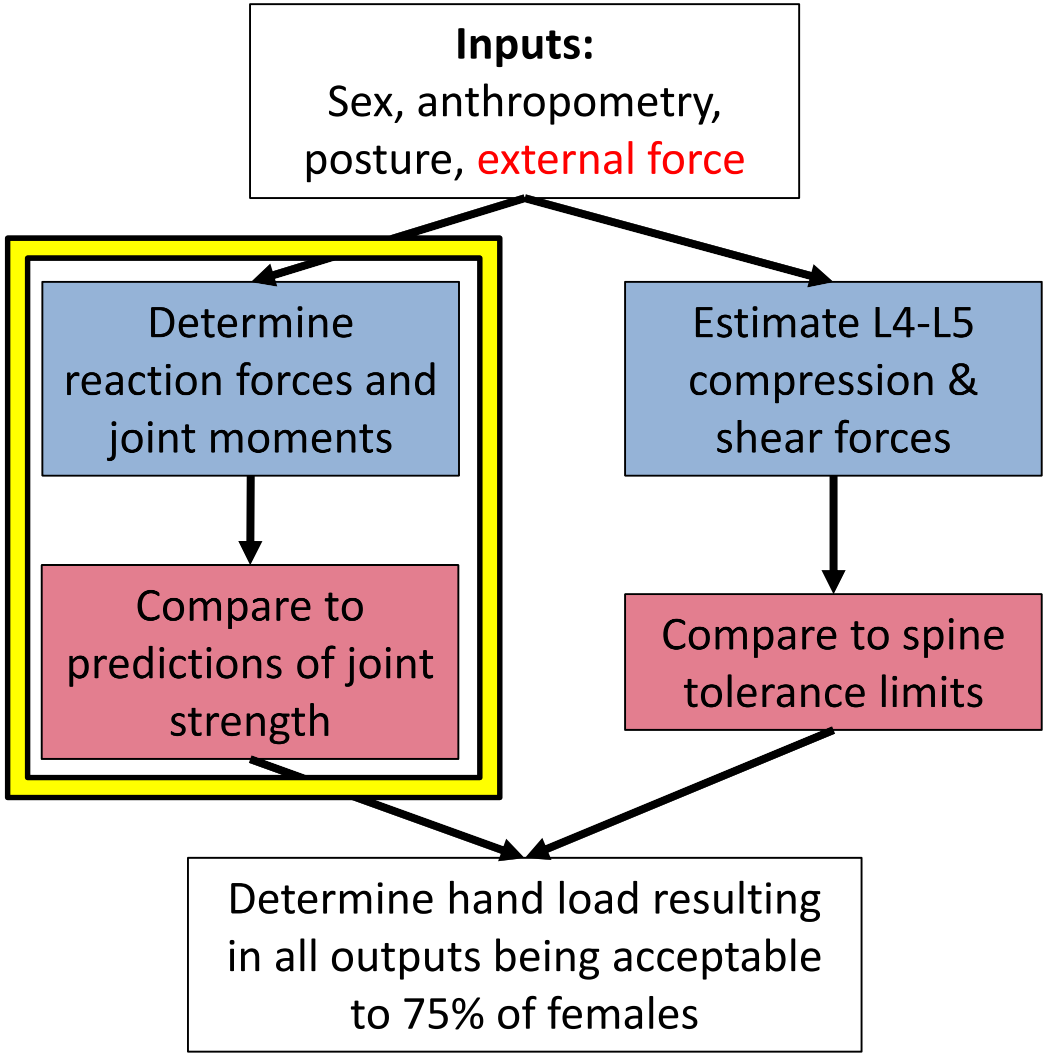




Strength Prediction in DHMs

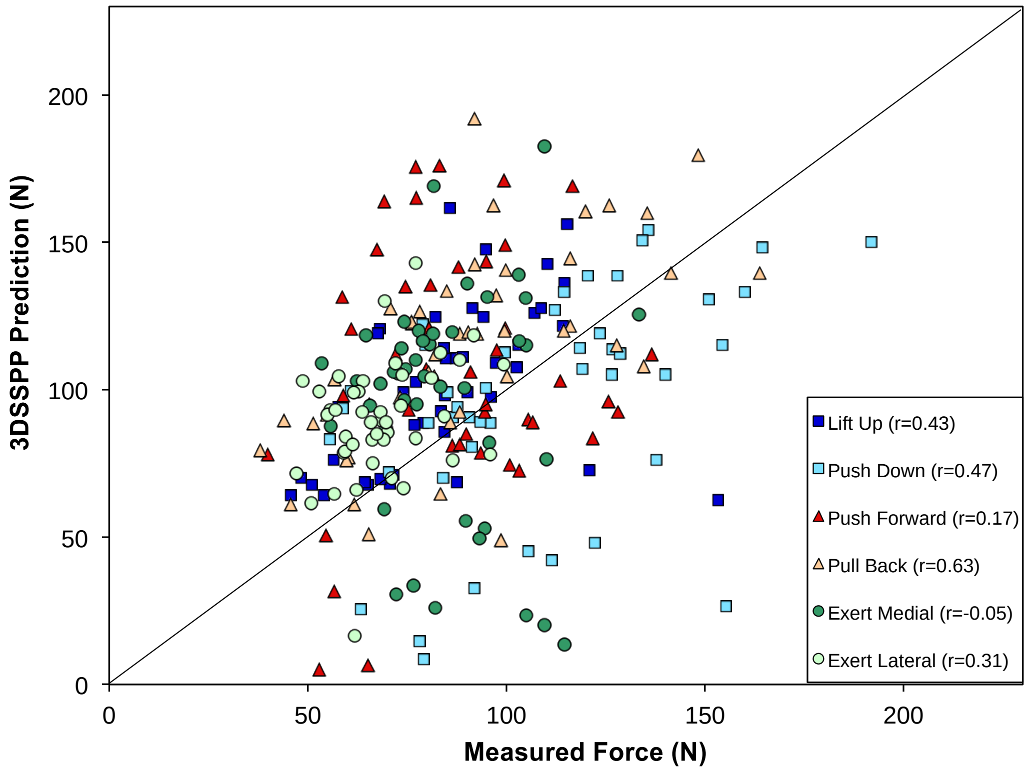




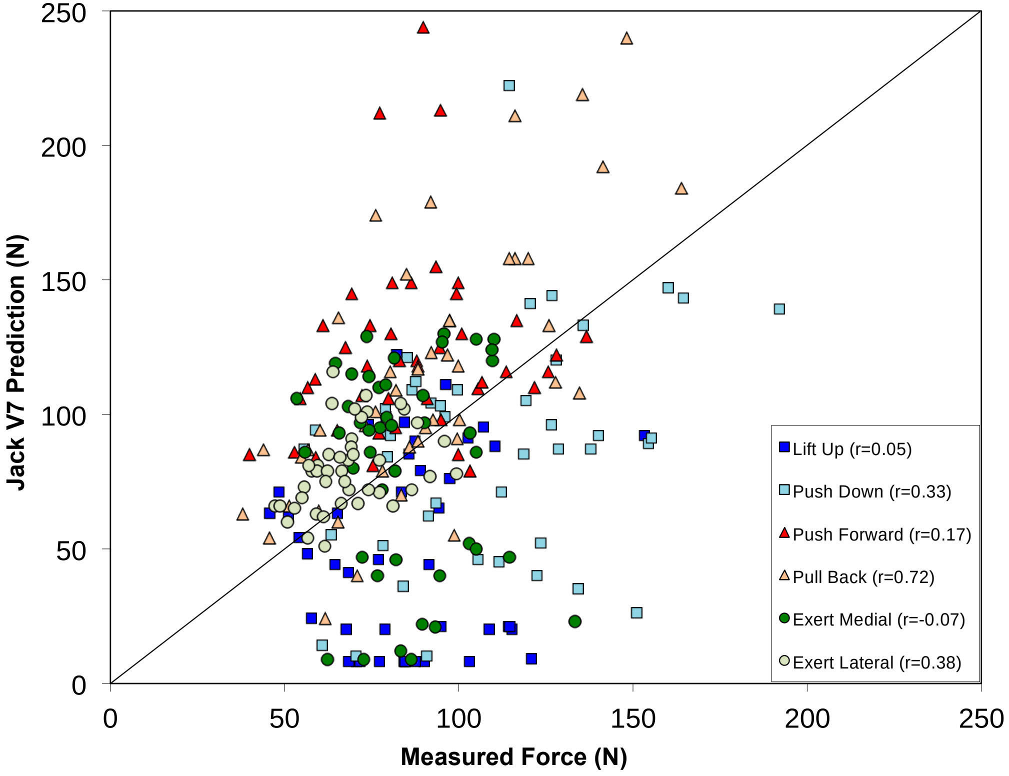


Testing Strength Prediction Approaches

3DSSPP vs. Empirical Data Means
n=264
r^2=9.3%
RMSD=39 N



Jack vs. Empirical Data Means
n=264
R^2=7.8%
RMSD=45 N



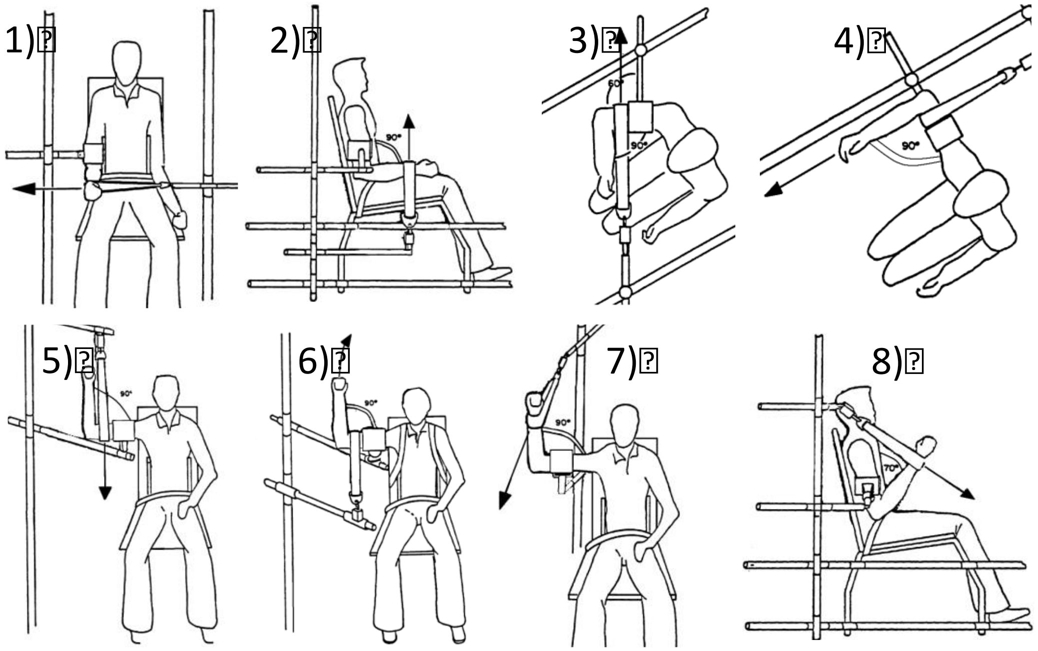
Testing Current MAS Predictions

CSB/SCB 2016

July 19-22, 2016
Hamilton, ON

ERGONOMICS SOFTWARE PACKAGES DO NOT ACCURATELY ESTIMATE MANUAL ARM STRENGTH FOR ERGONOMICS ASSESSMENTS

Andrew D. Hall[1], Nicholas J. La Delfa[2] & Jim R. Potvin[1]
[1]Department of Kinesiology, McMaster University, Hamilton, Ontario, Canada. Email: potvinj@mcmaster.ca



Stobbe, 1982

- Andrew Hall M.Sc. Thesis
  - 15 female participants
  - 4 hand locations x 6 directions
    - 24 conditions
    - Removed wrist from strength
  - Measure Stobbe strengths on individual participants
  - Used 3DSSPP method to predict strength
    - Correct for arm posture
  - Compare measured MAS to that estimated with 3DSSPP method
    - Using actual subject strength (not population mean)

- *Represented absolute best chance of this method to accurately predict MAS*

Testing Current MAS Predictions

Given absolute best chance (individual rather than population-based comparisons), this approach appears to still have significant limitations

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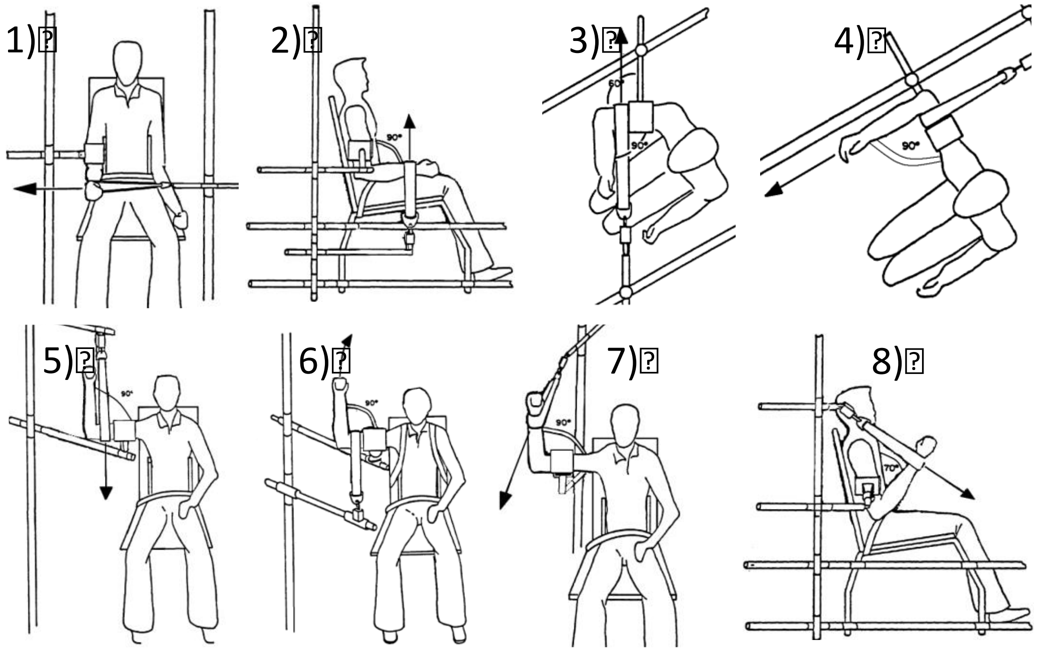
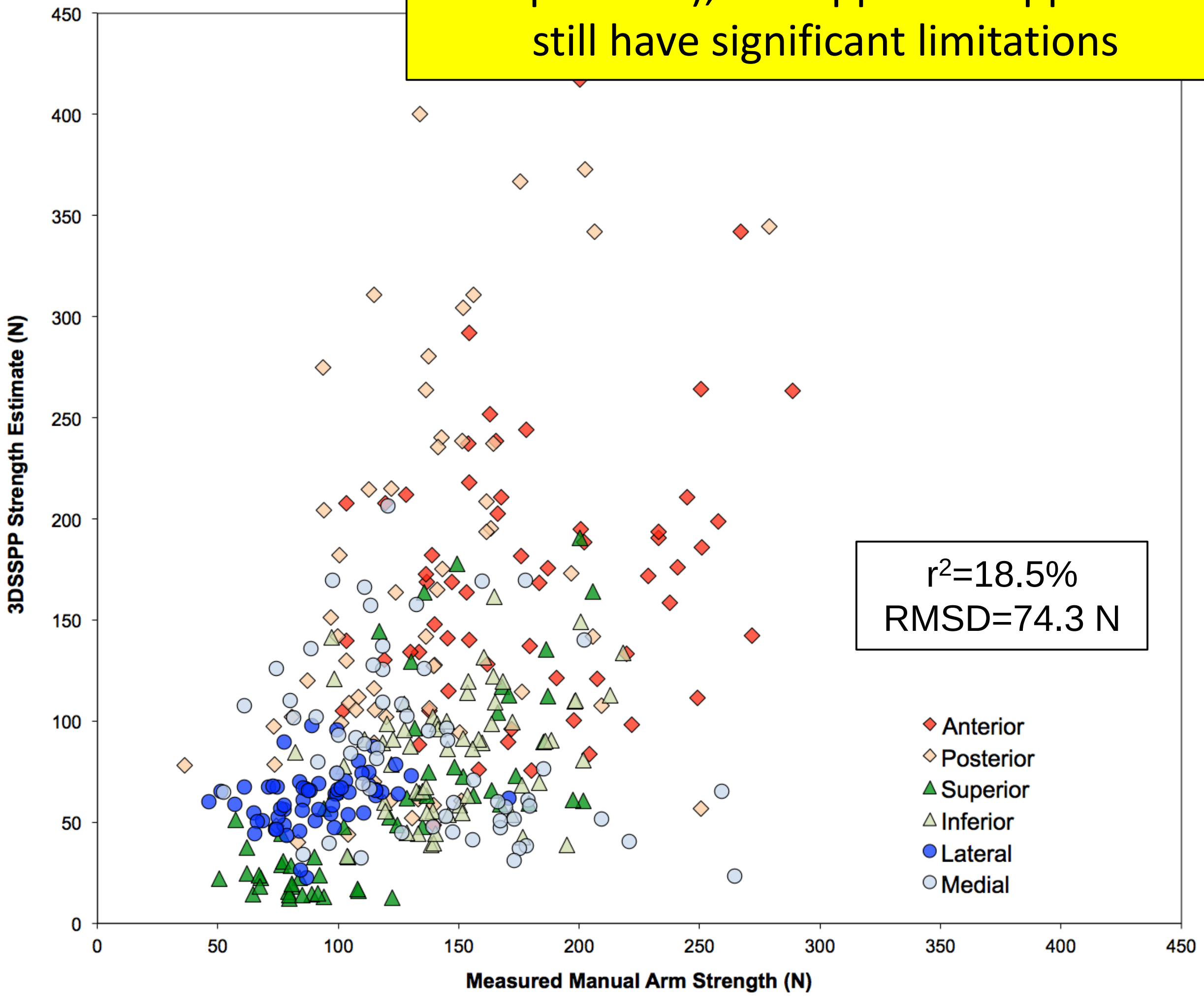


Stobbe, 1982



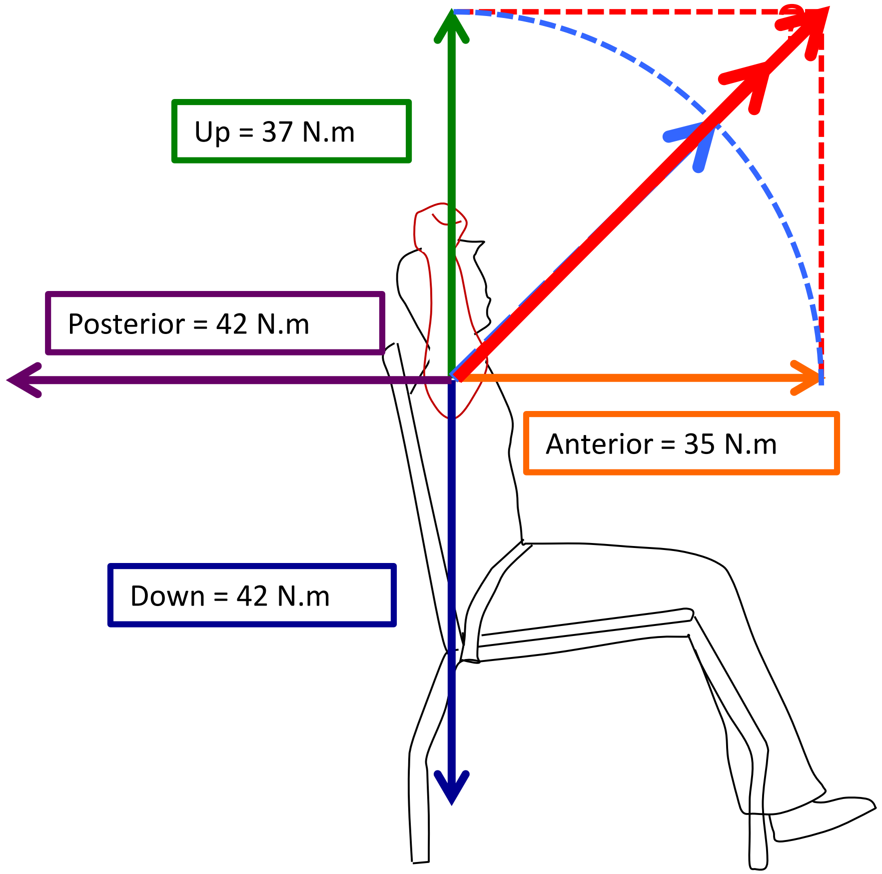
What are the issues?

1. Out-dated & limited strength data
   - Stobbe (1982)
     - ~37 years old
     - Changes in anthropometry/strength of population since?

2. Up to 7 joint strength predictions to estimate manual arm strength
   - Accumulation of errors?

3. Assumes independence of joint strength axes
   - Shoulder (Hodder et al., 2015),

Strength between orthopedic axes



What about Up & Anterior?

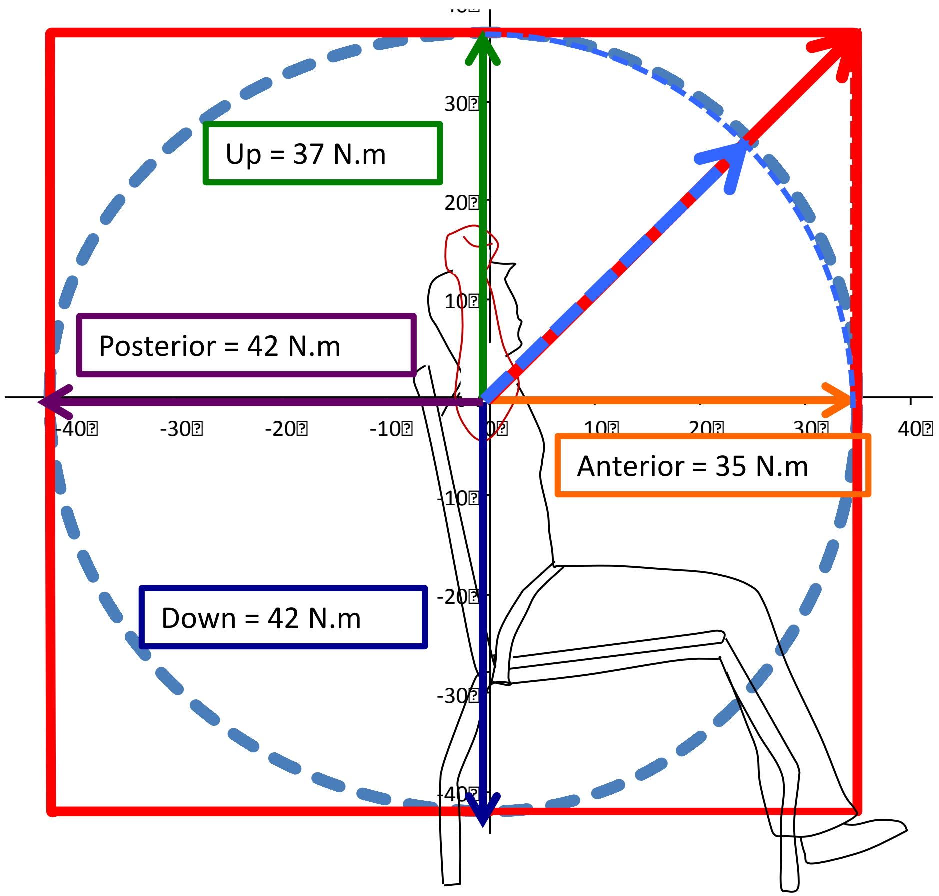
Independent Axis Approach (IAA)

- Currently used in DHMs

Weighted Average Approach (WAA)

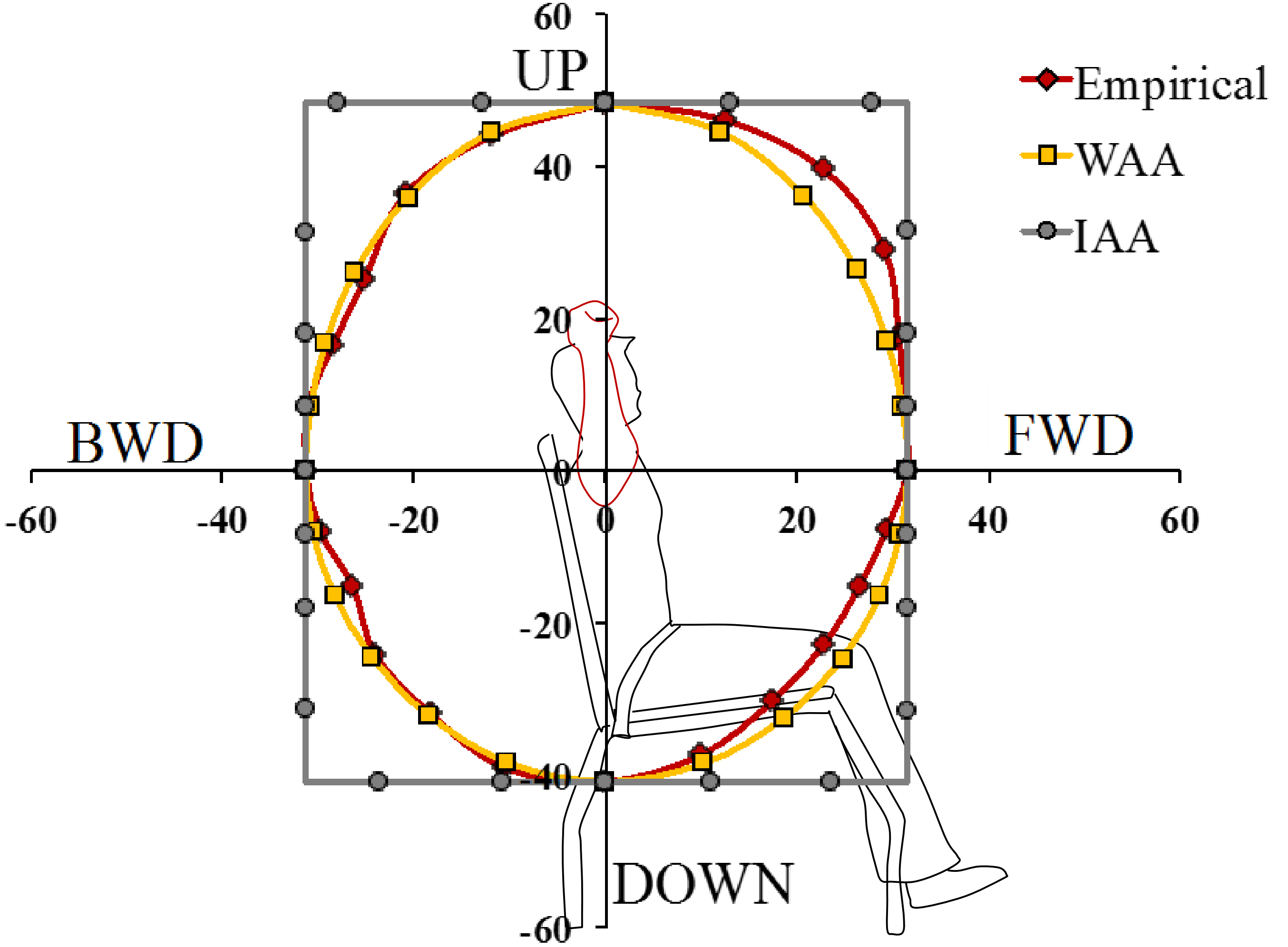
- Weighted average of two orthopedic axis strengths

Strength between orthopedic axes



- Hodder, La Delfa & Potvin (2015)
  - Is the WAA a better predictor of strength between orthopedic axes than the IAA?
  - 15 female subjects
  - dynamic strength about 360 deg

Strength between orthopedic axes



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What are the issues?

1. Out-dated & limited strength data
   - Stobbe (1982)
     - ~37 years old
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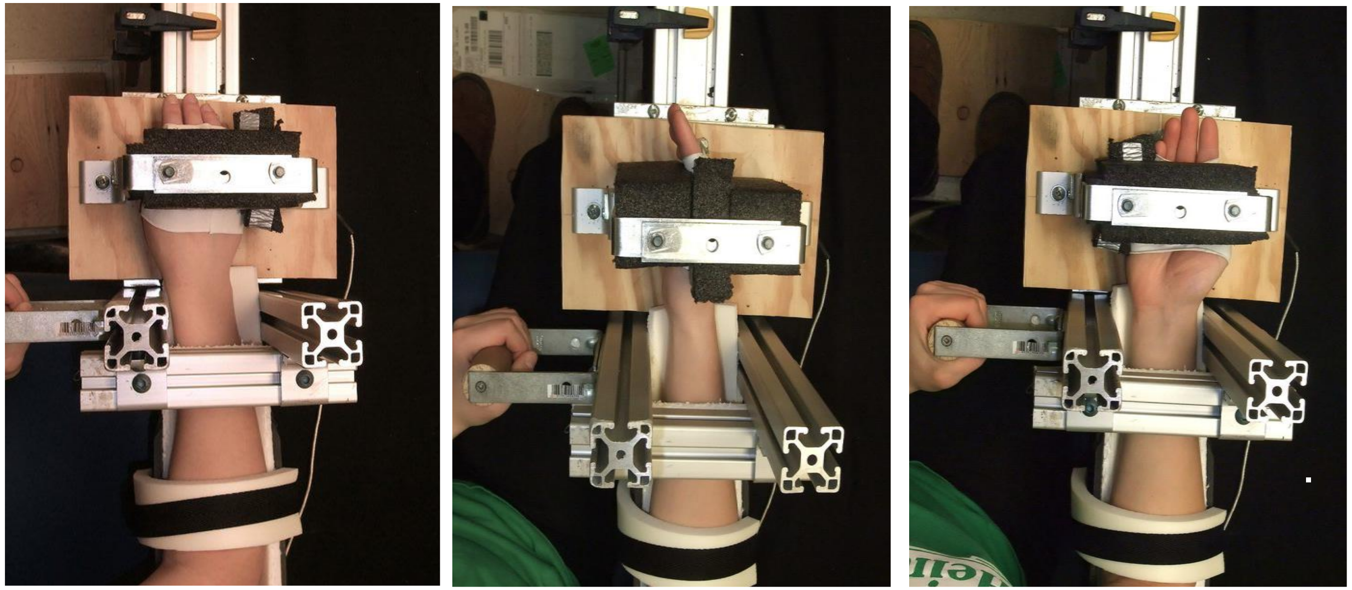
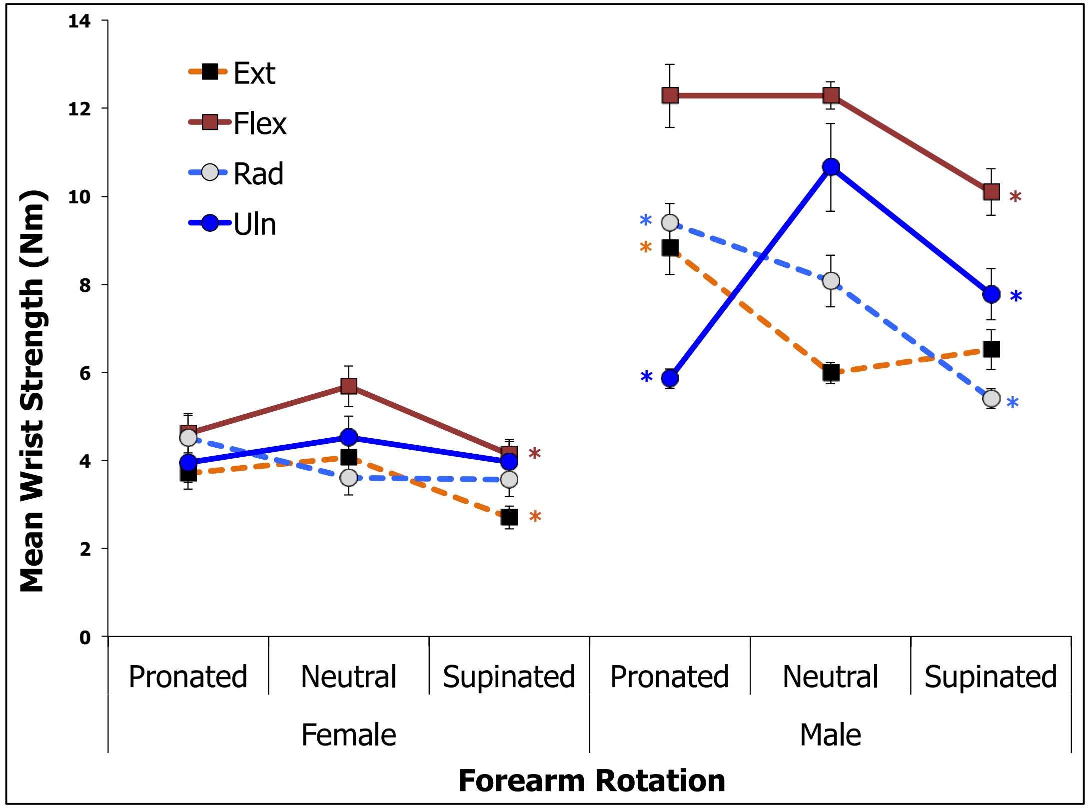
2. Up to 7 joint strength predictions to estimate manual arm strength
   - Accumulation of errors?
3. Assumes independence of joint strength axes
   - Shoulder (Hodder et al., 2015)
4. Assumes no interaction effects between joint strength axes
   - Wrist (Plewa et al., 2015; La Delfa et al., 2015; La Delfa & Potvin, 2017)
     - Wrist flexion strength does not depend on Radial/Ulnar deviation angle

Wrist strengths not accurately represented in current software…

Study 1: Empirical data collection

Pronation **Neutral** **Supination**

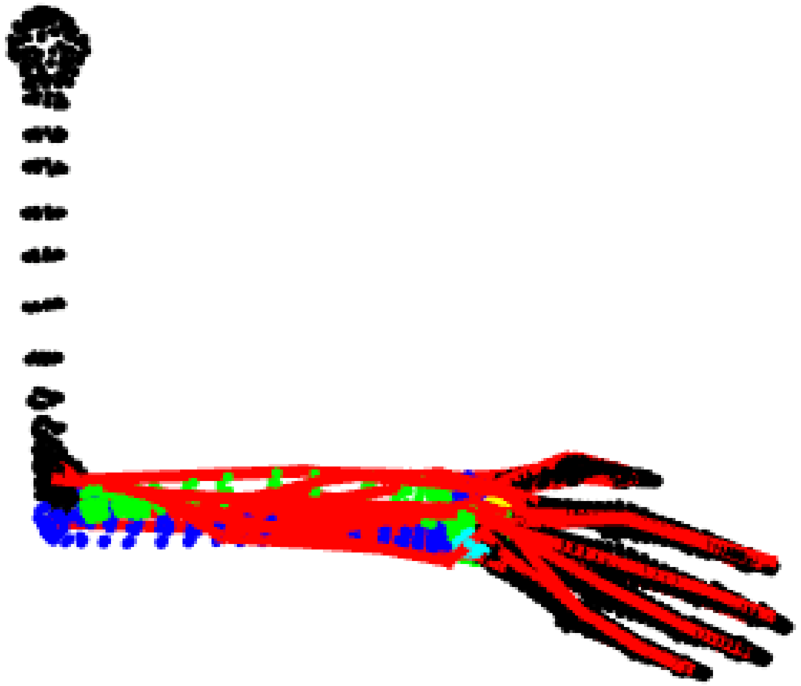


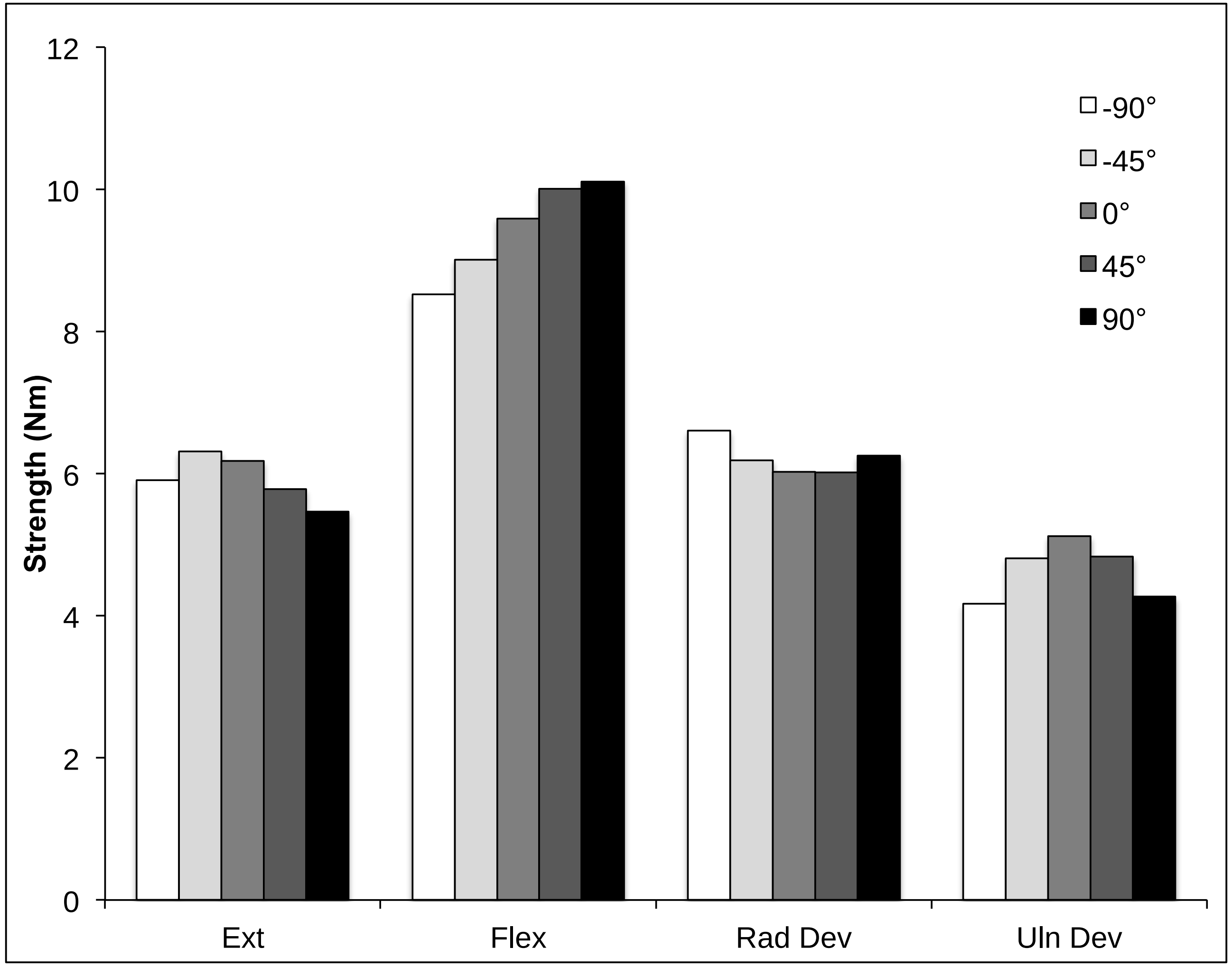


La Delfa et al., 2015. *Int.J.Indust.Ergo.*

Wrist strengths not accurately represented in current software…

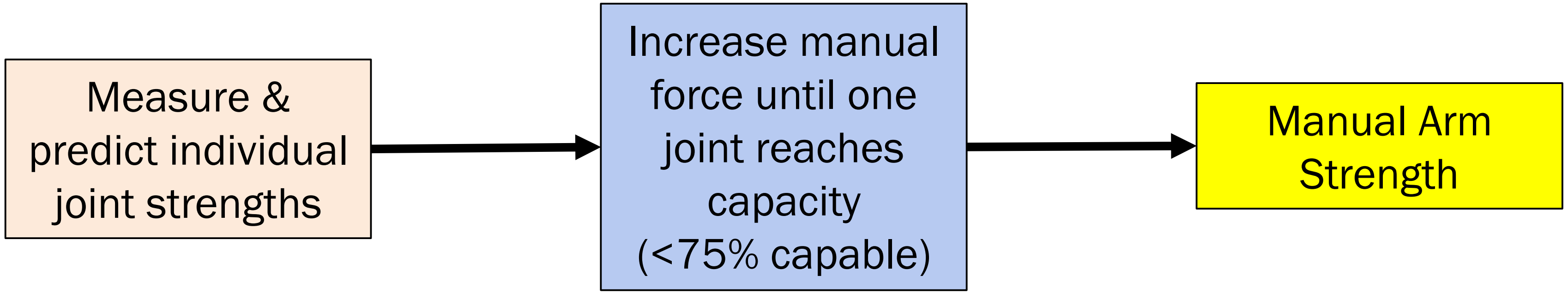
Study 2: Musculoskeletal Modeling



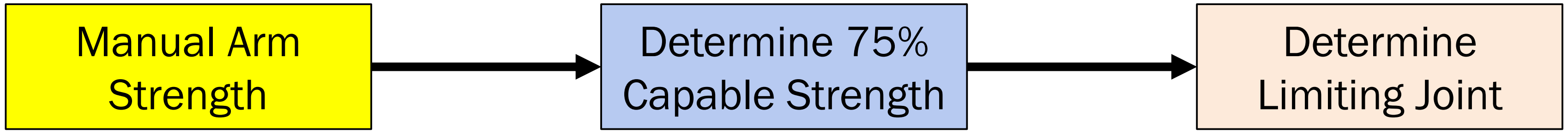


There's got to be a better way…

Traditional Approach:



Proposed Approach:



Proof in Principle

Ergonomics, 2014
http://dx.doi.org/10.1080/00140139.2014.885588
Taylor & Francis
Taylor & Francis Group

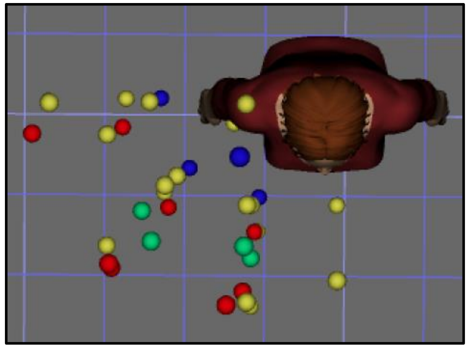
Equations to predict female manual arm strength based on hand location relative to the shoulder

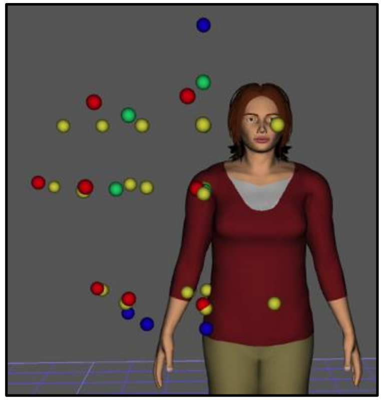
Nicholas J. La Delfa[a], Christopher C. Freeman[b], Cassandra Petruzzi[a] and Jim R. Potvin[a]*

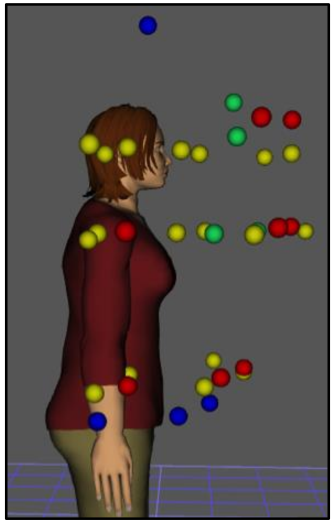
[a]*Department of Kinesiology, McMaster University, Hamilton, Ontario, L8S 4K1 Canada;* [b]*Department of Kinesiology, University of Windsor, Windsor, Canada*

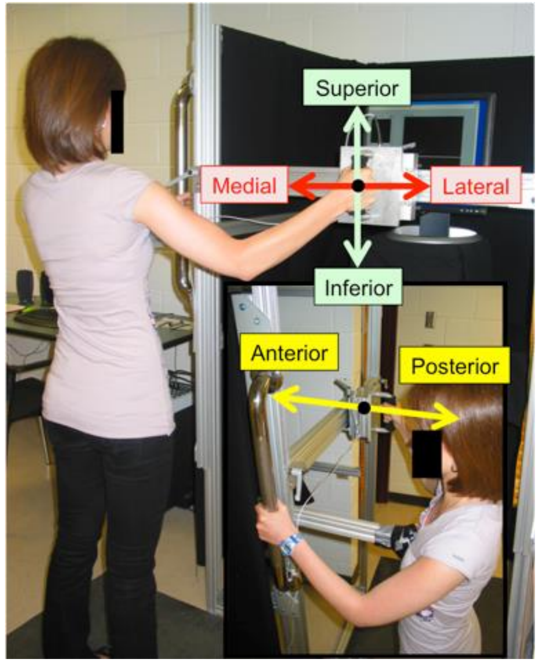
(*Received 10 April 2013; accepted 19 December 2013*)

- 71 females
- 28 hand locations









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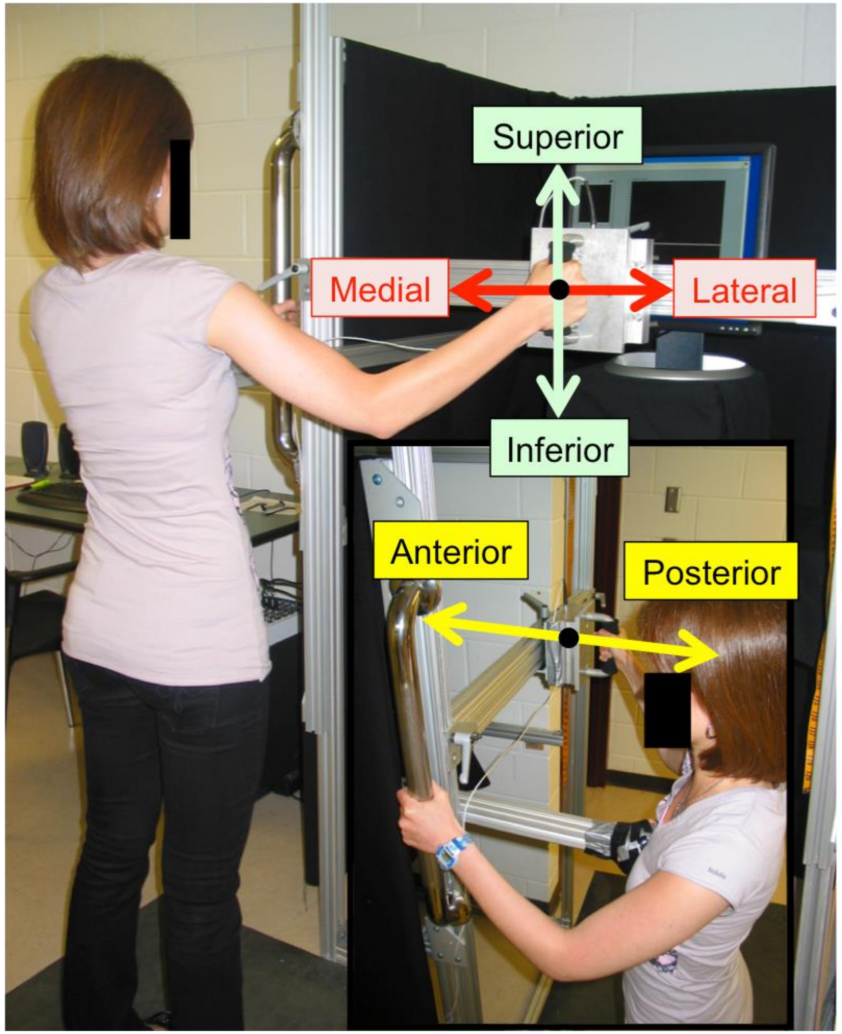
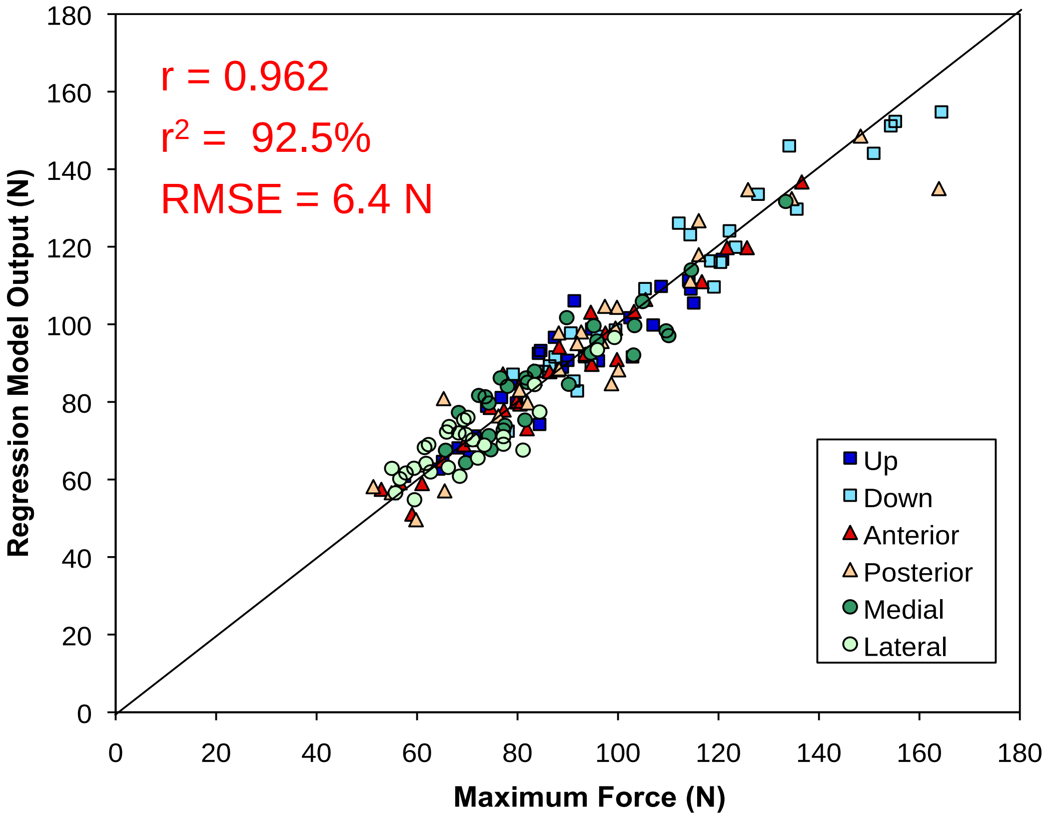




- However, still some limitations...
  - Only applicable to 6 directions
  - Limited by upright torso
  - Not validated with external data

Purpose of my PhD Dissertation

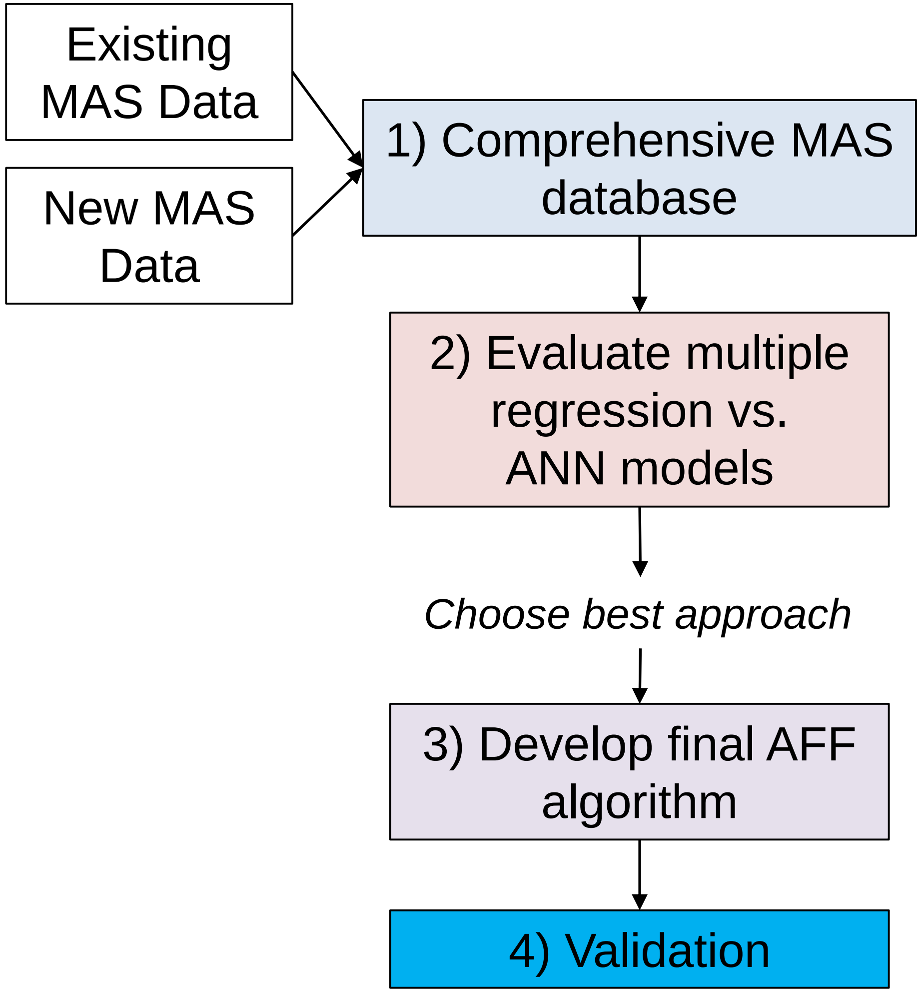
General Purpose:

- To improve the estimations of acceptable hand forces that are currently being made in digital human models.

Specific Purpose:

- To develop, validate and implement a novel ergonomics tool for manual arm strength prediction, given any combination of hand location, force direction and torso orientation.

Theoretical Development of Arm Force Field Method



4 phases of development

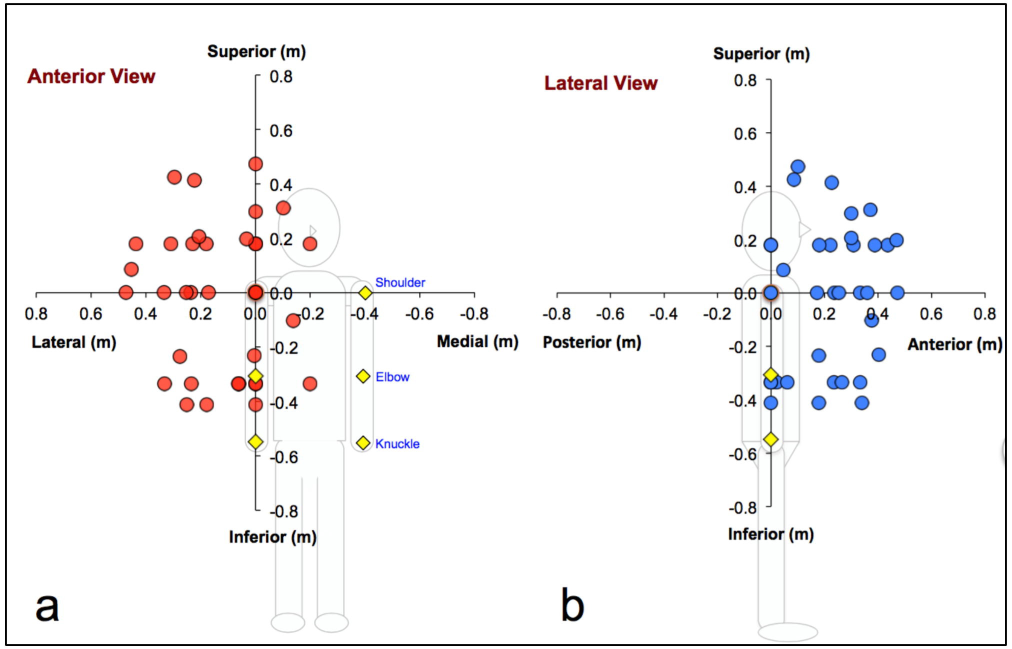
Theoretical Development of Arm Force Field Method

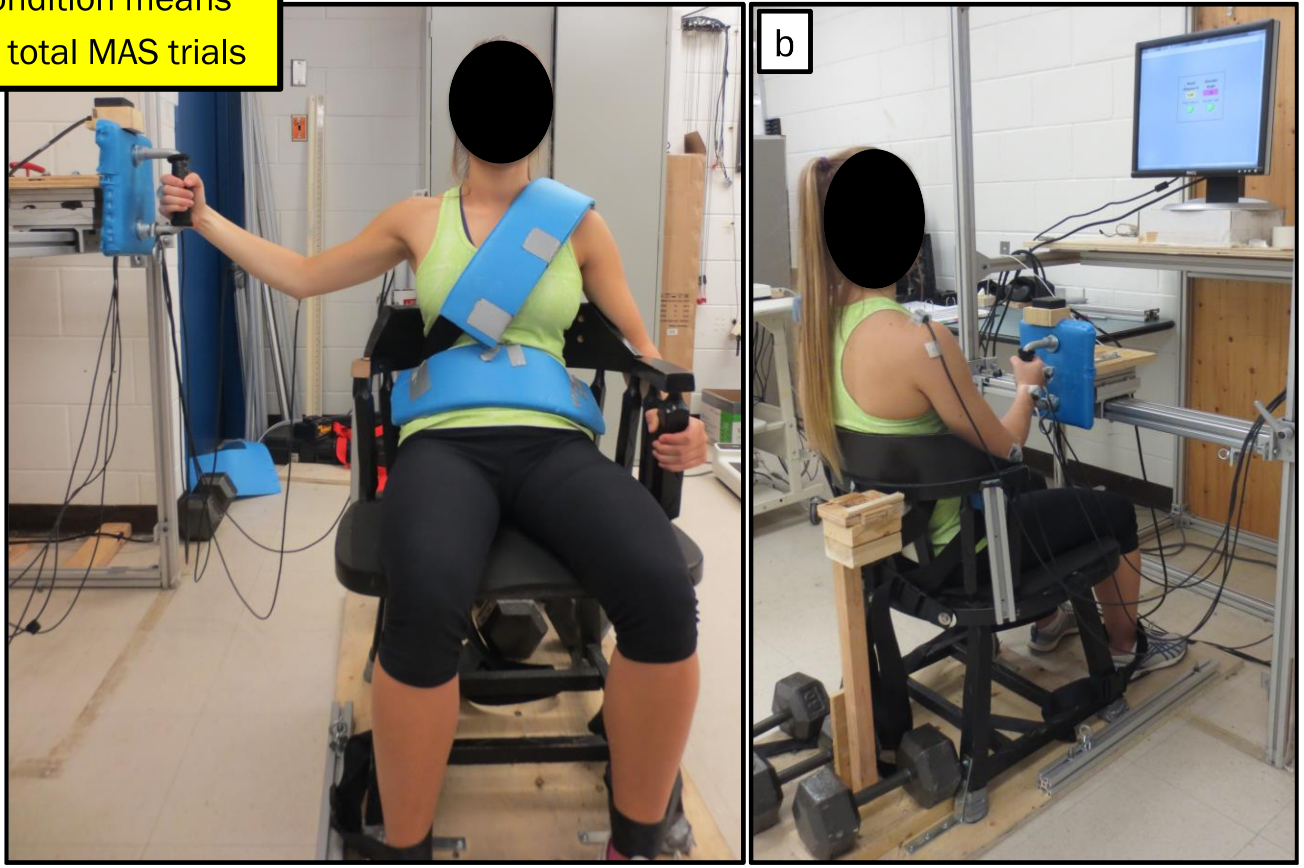
Existing MAS Data

New MAS Data

→ 1) Comprehensive MAS database

95 participants
36 hand locations
536 condition means
13,460 total MAS trials





Theoretical Development of Arm Force Field Method

	Hand Location Characteristics				Hand Coordinates (m)			Directions: 1D						2D												3D								
Study	Height	Angle	Reach	Posture	S/I	A/P	L/M	1 Sup	2 Inf	3 Ant	4 Post	5 Med	6 Lat	7 Sup Ant	8 Sup Post	9 Sup Med	10 Sup Lat	11 Inf Ant	12 Inf Post	13 Inf Med	14 Inf Lat	15 Ant Med	16 Ant Lat	17 Post Med	18 Post Lat	19 Sup Ant Med	20 Sup Ant Lat	21 Sup Post Med	22 Sup Post Lat	23 Inf Ant Med	24 Inf Ant Lat	25 Inf Post Med	26 Inf Post Lat	Mean
3	Overhead	0°	80%	Stand	0.473	0.100	0.000	122.8	153.2	55.4	71.4	69.7	61.8	139.7	74.4	100.7	103.6	91.9	161.5	136.9	96.1	67.0	78.2	86.9	82.5	129.4	126.4	81.7	77.1	106.6	80.4	172.3	135.4	102.4
4	Overhead	90°	80%	Sit	0.425	0.086	0.296	126.1	150.3	56.0	53.8	84.7	65.9	84.9	57.4	75.0	105.8	78.7	84.9	140.5	61.6	70.8	57.7	68.2	51.5	84.7	129.7	62.0	69.9	102.8	59.2	116.8	72.7	83.5
4	Overhead	45°	80%	Sit	0.414	0.226	0.222	131.4	178.2	69.2	74.8	84.9	62.8	135.9	63.2	86.0	87.0	75.5	149.1	136.1	85.3	71.5	70.1	83.9	66.2	100.1	135.9	64.4	68.8	88.5	73.6	142.8	89.8	95.2
4	Stature	-20°	80%	Sit	0.312	0.371	-0.102	83.6	161.6	143.4	128.3	85.0	80.2	166.7	71.0	96.3	65.1	89.9	217.0	79.1	119.3	119.4	69.3	87.2	102.8	176.2	83.1	76.9	74.7	89.8	87.2	120.0	185.9	110.0
2	Stature	0°	70%	Stand	0.297	0.299	0.000	99.9	123.1	82.5	110.5	77.2	69.7	145.7	76.4	94.6	76.4	74.6	164.2	107.6	86.1	80.8	77.5	98.8	90.9	135.9	141.3	88.9	77.7	79.3	80.9	181.0	159.9	103.1
2	Eye	45°	70%	Stand	0.207	0.300	0.207	90.8	98.1	74.4	94.8	86.0	66.6	128.0	74.0	85.2	98.2	61.2	138.6	124.2	72.7	74.4	89.8	121.7	73.4	100.5	152.9	94.0	72.2	80.8	75.6	180.8	106.3	96.7
4	Eye	0°	80%	Sit	0.198	0.470	0.033	84.3	123.4	166.4	177.0	87.1	57.4	156.9	78.3	88.1	66.5	91.6	215.2	97.7	77.5	102.5	78.6	117.1	85.7	121.6	102.6	85.0	73.6	99.0	78.9	161.0	129.9	107.8
1	Stature	90°	40%	Stand	0.180	0.000	0.229	103.9	137.8	69.3	70.9	96.4	56.3																					89.1
1	Stature	90°	80%	Stand	0.180	0.000	0.436	99.4	103.5	59.0	59.8	111.1	89.7																					87.1
1	Stature	45°	40%	Stand	0.180	0.180	0.180	100.6	134.5	72.3	88.6	86.2	58.2																					90.1
1	Stature	0°	40%	Stand	0.180	0.222	0.000	101.1	147.9	74.9	110.8	81.7	77.2																					98.9
1	Stature	45°	80%	Stand	0.180	0.308	0.308	86.5	104.1	70.2	86.4	78.0	57.9																					80.5
1	Stature	-20°	80%	Stand	0.180	0.388	-0.200	85.5	112.9	97.7	119.9	65.5	68.7																					91.7
1	Stature	0°	80%	Stand	0.180	0.436	0.000	83.2	108.4	115.5	122.3	65.7	59.4																					92.4
4	Shoulder	90°	80%	Sit	0.087	0.046	0.454	90.7	85.3	62.9	44.9	197.7	170.3	82.4	66.0	98.0	111.3	61.1	63.1	148.9	80.4	87.2	91.7	87.3	60.0	98.2	106.2	87.0	82.5	102.8	79.0	112.5	69.8	93.4
1	Shoulder	90°	40%	Stand	0.000	0.000	0.236	105.6	98.8	77.3	76.2	103.3	70.1																					88.6
1	Shoulder	90°	80%	Stand	0.000	0.000	0.472	72.3	64.3	52.9	51.3	133.4	99.3																					78.9
1	Shoulder	45°	40%	Stand	0.000	0.172	0.172	111.6	106.7	94.8	91.9	95.8	68.3																					94.9
1	Shoulder	0°	40%	Stand	0.000	0.237	0.000	118.5	120.0	105.5	116.1	103.1	81.1																					107.4
2	Shoulder	45°	60%	Stand	0.000	0.253	0.253	86.8	91.4	86.4	96.8	110.1	77.2	118.3	94.0	98.5	93.8	75.1	117.9	123.6	78.4	91.5	111.3	137.2	74.0	106.0	133.1	119.3	78.0	90.0	93.3	172.6	97.4	102.0
1	Shoulder	45°	80%	Stand	0.000	0.334	0.334	79.1	79.9	88.0	92.7	95.2	66.2																					83.5
2	Shoulder	0°	60%	Stand	0.000	0.360	0.000	93.8	106.4	128.5	163.9	90.2	72.1	126.0	108.9	103.9	72.6	86.4	168.4	98.8	93.0	101.9	94.9	135.7	102.4	133.4	118.6	124.9	100.4	98.8	88.6	183.3	145.5	113.1
1	Shoulder	0°	80%	Stand	0.000	0.472	0.000	79.9	84.7	136.6	148.3	74.3	59.5																					97.2
4	Sternum	-20°	80%	Sit	-0.102	0.377	-0.138	111.7	103.6	183.9	223.3	107.2	73.0	115.5	144.9	103.5	79.4	128.8	125.2	86.5	90.0	152.6	69.1	98.0	142.7	139.6	64.8	132.2	144.3	154.1	89.2	86.5	146.3	119.1
4	Umbilicus	0°	80%	Sit	-0.231	0.403	0.005	126.2	101.6	170.4	174.1	87.2	58.6	104.7	157.2	109.1	87.7	156.1	107.8	89.9	72.1	115.5	78.6	97.7	99.2	114.6	82.2	149.0	132.3	136.0	114.0	91.3	91.9	111.7
4	Umbilicus	60°	80%	Sit	-0.234	0.179	0.277	115.6	106.7	105.5	66.2	127.4	96.0	98.6	85.1	133.0	78.0	111.4	71.4	80.6	98.6	84.4	124.7	123.3	57.5	122.4	111.3	167.3	67.4	93.0	144.6	89.3	74.0	101.3
1	Waist	90°	40%	Stand	-0.335	0.000	0.062	112.9	86.6	77.1	65.3	90.8	59.7																					82.1
1	Waist	90°	80%	Stand	-0.335	0.000	0.333	82.7	74.1	56.6	54.9	110.5	87.5																					77.7
1	Waist	0°	40%	Stand	-0.335	0.021	0.000	113.4	87.1	88.7	109.8	72.3	55.7																					87.8
1	Waist	45°	40%	Stand	-0.335	0.061	0.061	106.7	89.4	78.0	88.6	81.7	49.9																					82.4
1	Waist	45°	80%	Stand	-0.335	0.235	0.235	98.2	79.9	82.7	85.3	86.9	64.4																					82.9
1	Waist	-20°	80%	Stand	-0.335	0.266	-0.200	106.4	87.2	100.7	96.6	77.1	60.3																					88.1
1	Waist	0°	80%	Stand	-0.335	0.333	0.000	111.0	89.4	120.8	121.8	74.3	57.8																					95.9
3	Waist	45°	80%	Stand	-0.411	0.178	0.179	116.7	94.4	83.5	98.5	93.0	75.0	93.8	127.8	123.7	86.2	84.0	82.7	83.6	90.1	84.1	92.0	116.8	65.8	120.5	106.1	161.7	98.1	98.8	116.5	107.0	84.5	99.4
3	Waist	90°	80%	Stand	-0.411	0.000	0.251	96.4	90.3	61.0	65.5	107.3	86.7	83.9	99.8	137.9	81.2	84.1	78.1	76.3	105.7	88.1	87.9	114.7	60.4	123.7	88.2	155.3	76.5	87.8	111.4	96.6	85.5	93.5
3	Waist	0°	80%	Stand	-0.411	0.339	0.000	95.4	86.5	99.6	129.6	77.5	56.6	99.9	171.4	107.7	82.3	114.0	89.4	87.7	76.4	88.5	85.7	124.7	80.1	110.8	94.5	158.6	132.4	109.8	114.6	92.8	77.7	101.7
							Mean	100.9	107.0	93.0	100.9	93.2	71.6	117.5	96.9	102.6	85.9	91.5	127.2	106.1	86.5	92.5	84.8	106.2	80.9	119.8	111.0	113.0	89.1	101.1	92.9	131.7	109.5	99.1

Theoretical Development of Arm Force Field Method

Existing MAS Data

New MAS Data

1) Comprehensive MAS database

2) Evaluate multiple regression vs. ANN models

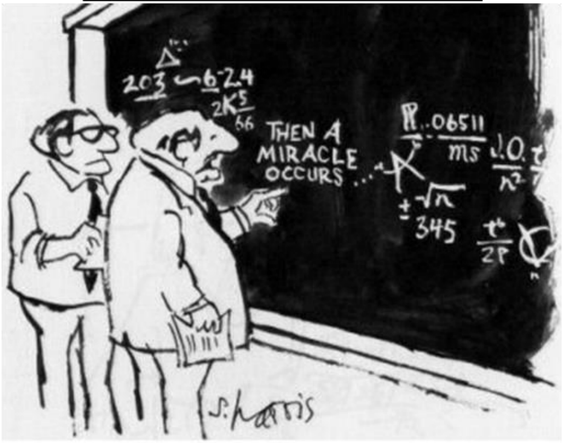
Inputs to Equation:

- Hand Location
- Force Direction
- Torso Orientation

Some statistical prediction tool

Output of Equation:

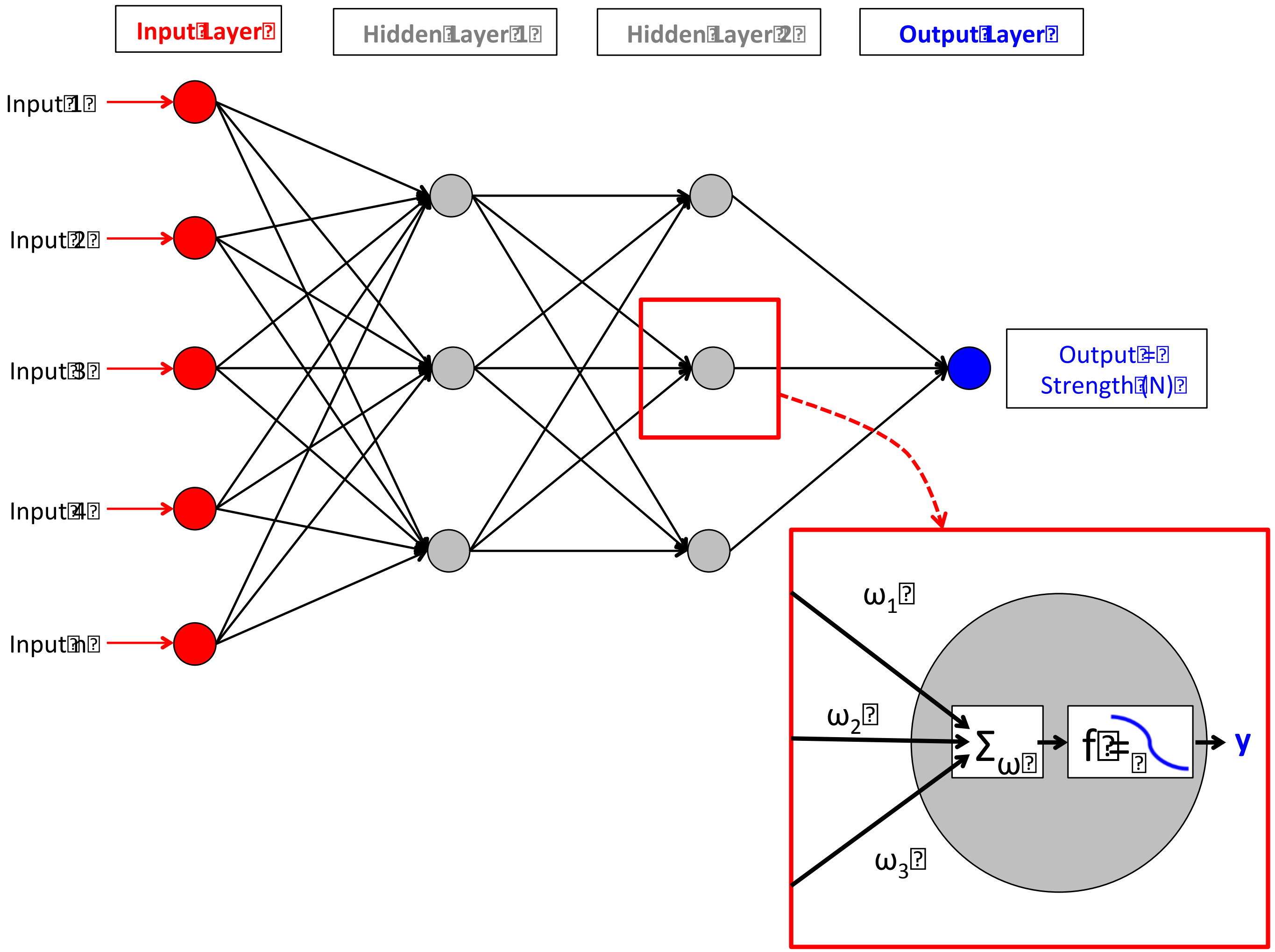
Predicted arm strength for the given inputs



"I think you should be more explicit here in step two."

Artificial Neural Network (ANN) Background

	Input Variables
Directions	Direction cosine (Up/Down)
	Direction cosine (Ant/Post)
	Direction cosine (Med/Lat)
Hand Locations	Horizontal (H, H^2, H^3)
	Vertical (V, V^2, V^3)
	Lateral (L, L^2, L^3)
	Interaction (H x V)
	Interaction (H x L)
	Interaction (V x L)
Kinematics	Shoulder 3D MA



- Multi-layered, feed-forward, fully-connected
- Trained using back-propagation algorithm
  - Equilibrates at global minimum for RMSE

Theoretical Development of Arm Force Field Method

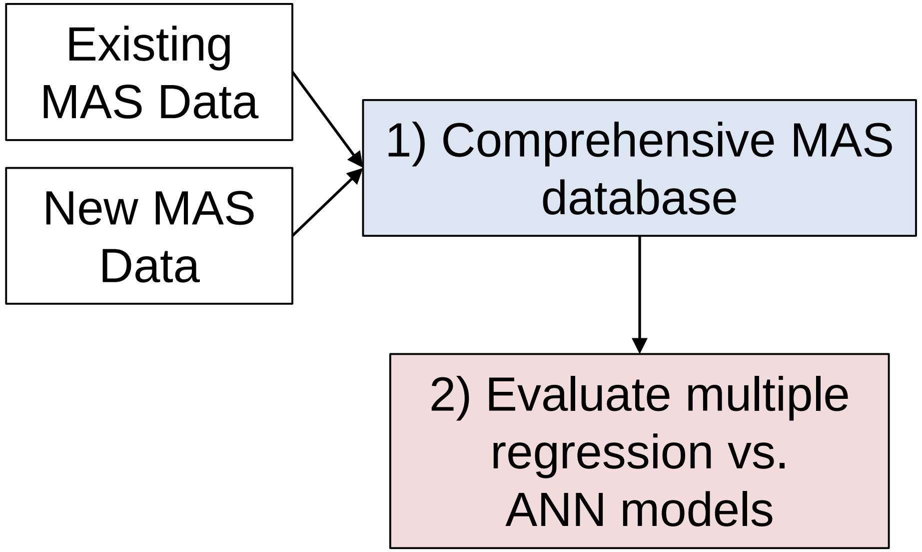


Table 3
Results of regression and ANN model performance.

Model	Data type	Correlation	Explained variance (%)	RMSD (N)
Regression	Development	0.815	66.5	17.24
	Validation	0.808	65.3	18.57
	All	**0.814**	**66.3**	**17.45**
ANN	Development	0.950	90.2	9.34
	Validation	0.886	78.6	15.12
	All	**0.938**	**88.1**	**10.40**

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www.JBiomech.com

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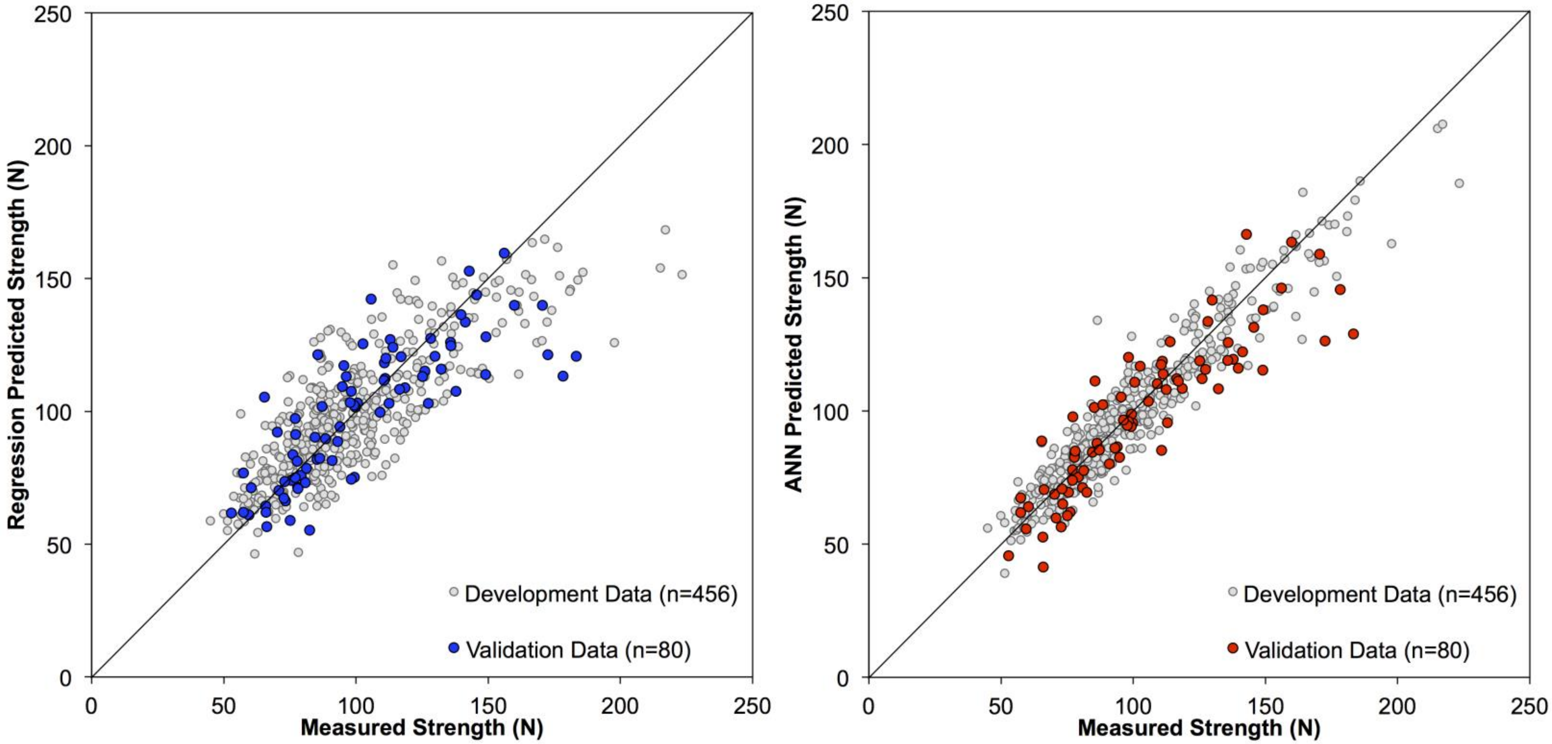
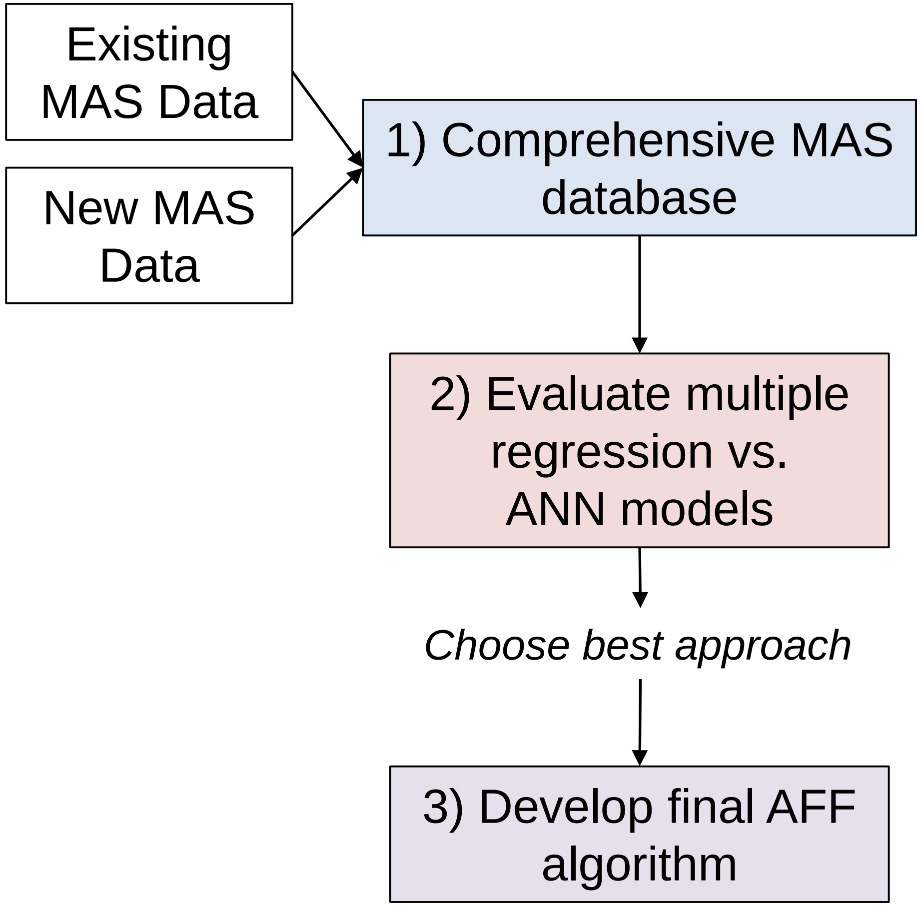
Short communication

Predicting manual arm strength: A direct comparison between artificial neural network and multiple regression approaches

Nicholas J. La Delfa [a,*], Jim R. Potvin [b]



Theoretical Development of Arm Force Field Method

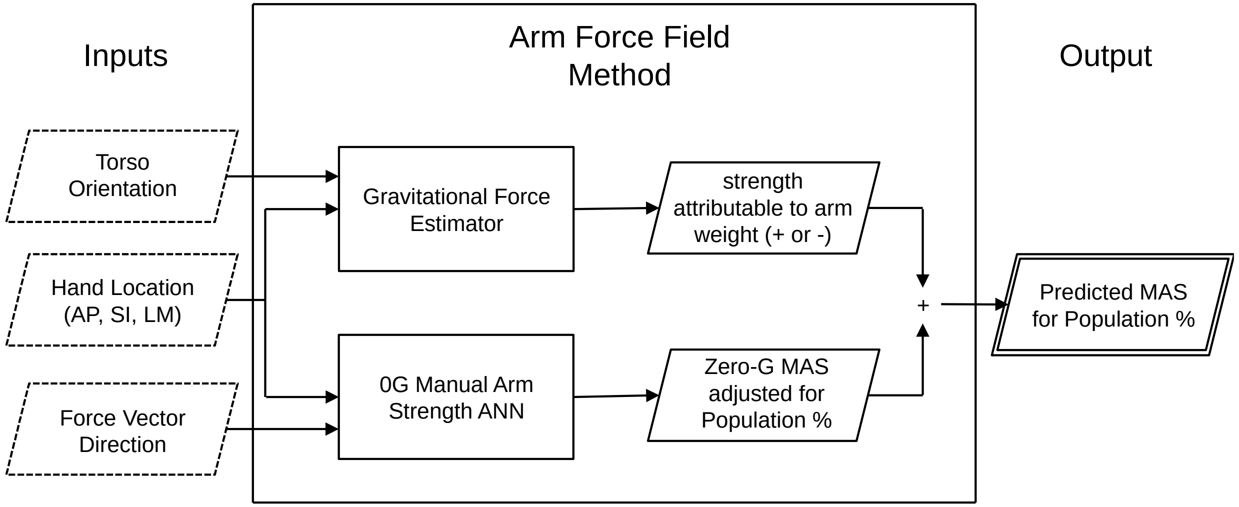


Applied Ergonomics 59 (2017) 410–421
Contents lists available at ScienceDirect
Applied Ergonomics
journal homepage: www.elsevier.com/locate/apergo

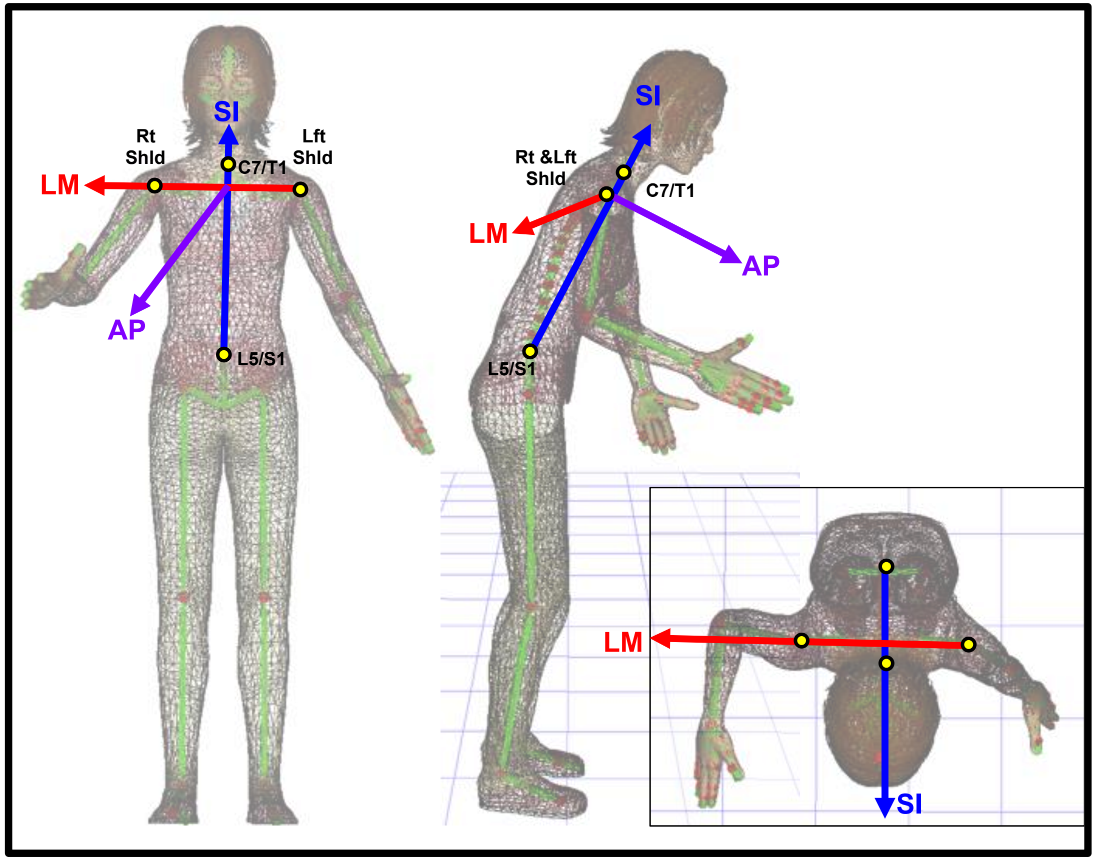
The 'Arm Force Field' method to predict manual arm strength based on only hand location and force direction

Nicholas J. La Delfa [a], Jim R. Potvin [b,*]

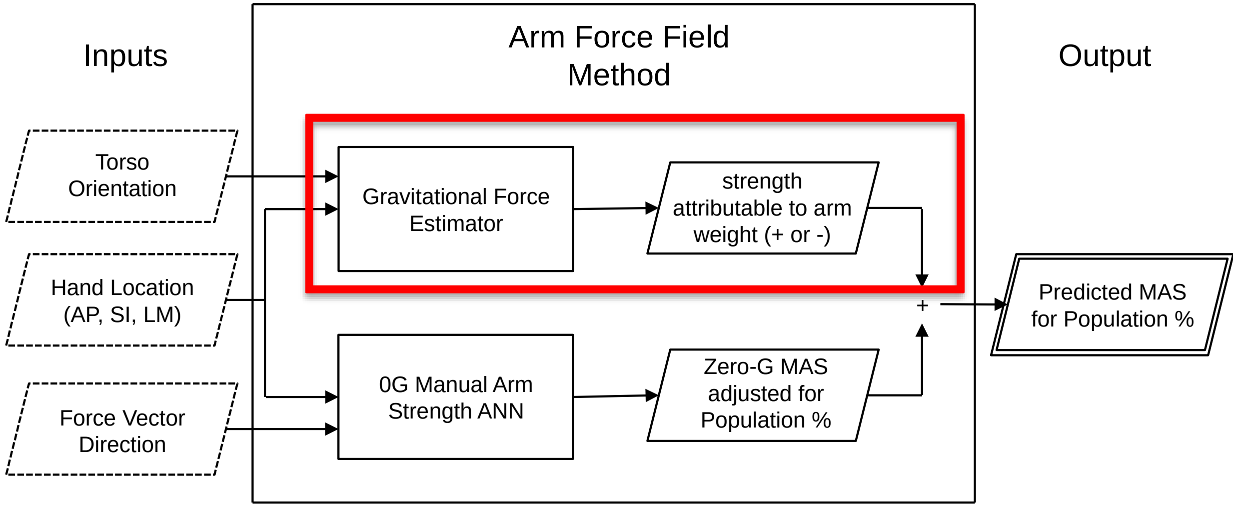
[a] Department of Kinesiology, University of Waterloo, Waterloo, Ontario, Canada
[b] Department of Kinesiology, McMaster University, Hamilton, Ontario, Canada



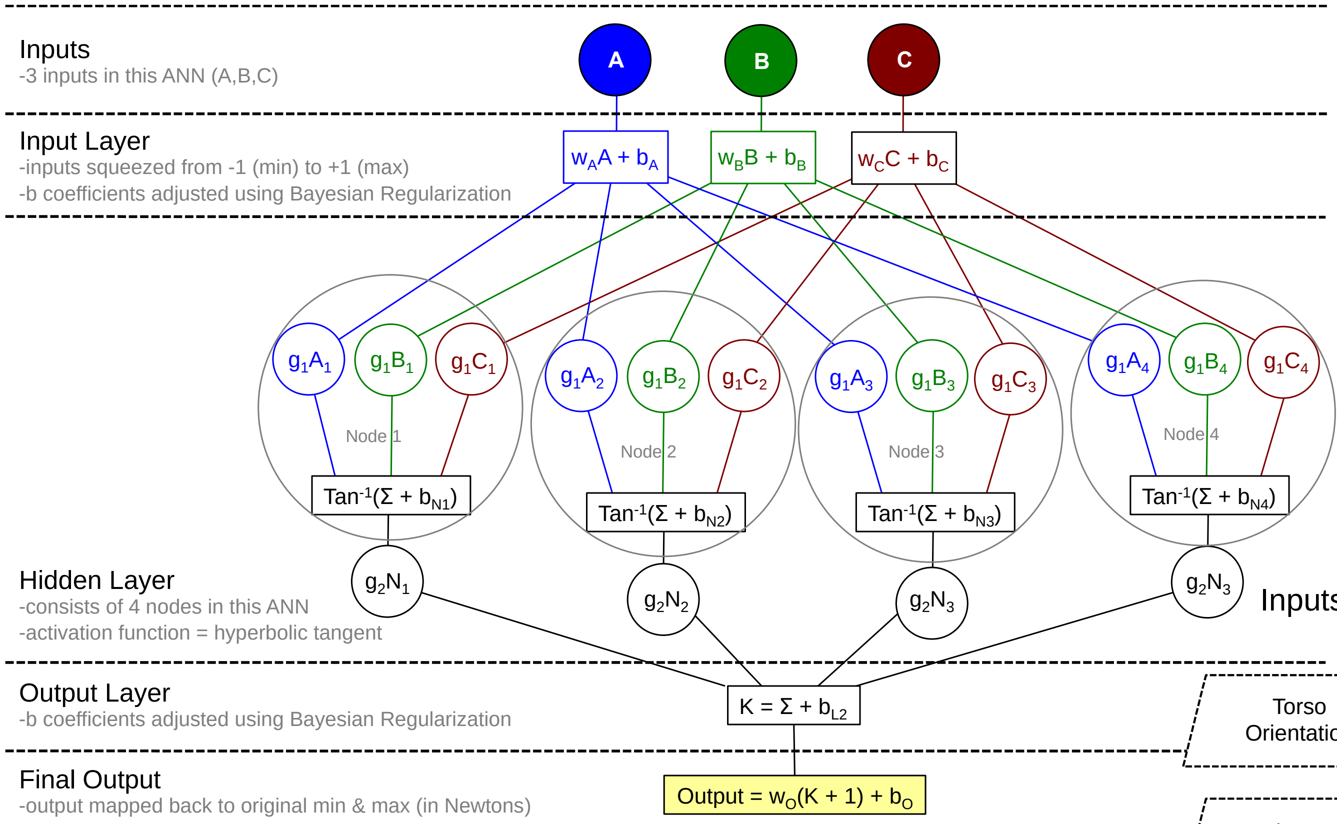
The Arm Force Field Method



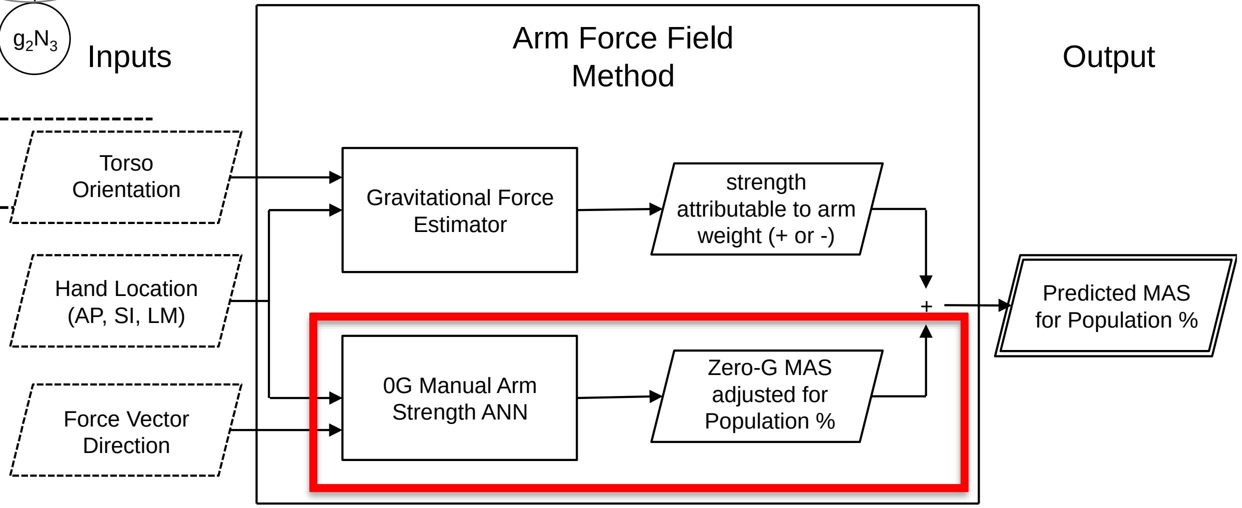
- All data collected with upright torso
- Solution:
  - estimate strength attributable to arm weight in intended direction (+ or -)
    - Shoulder Joint Coordinate System
    - Based on standard anthropometrics



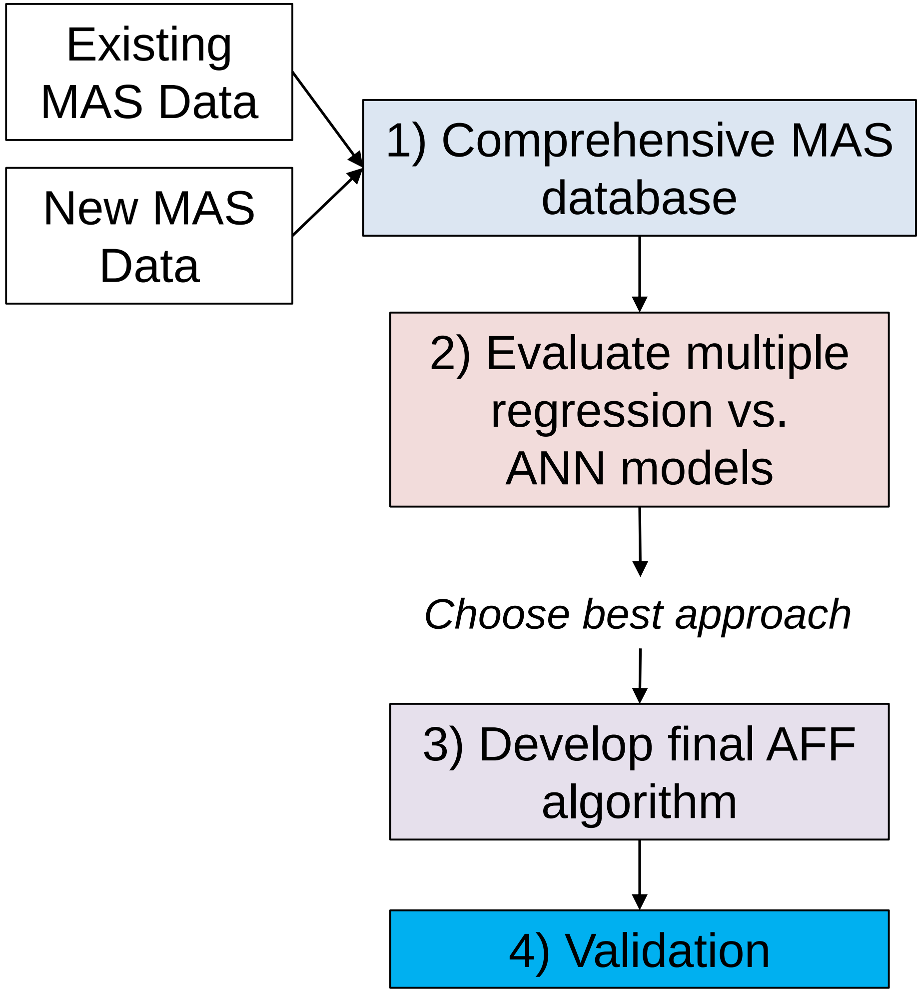
The Arm Force Field Method

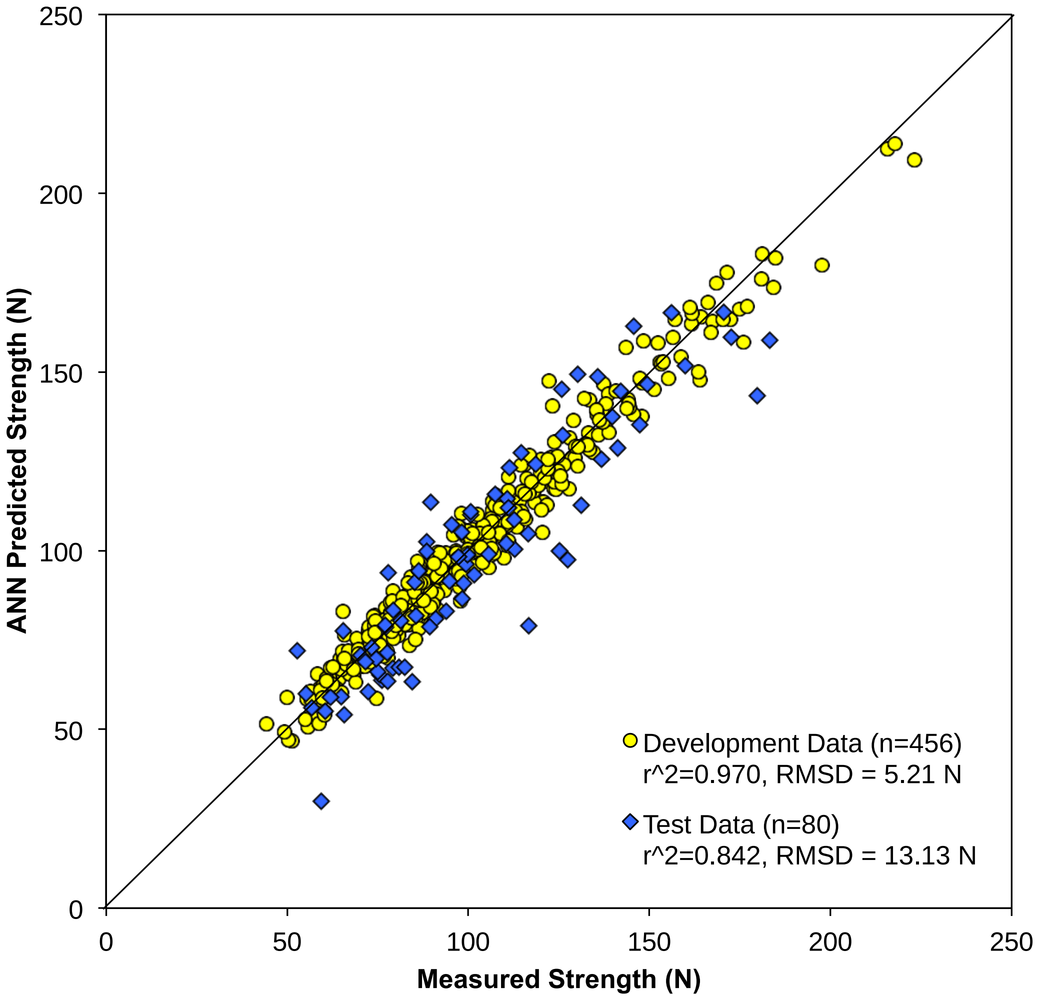


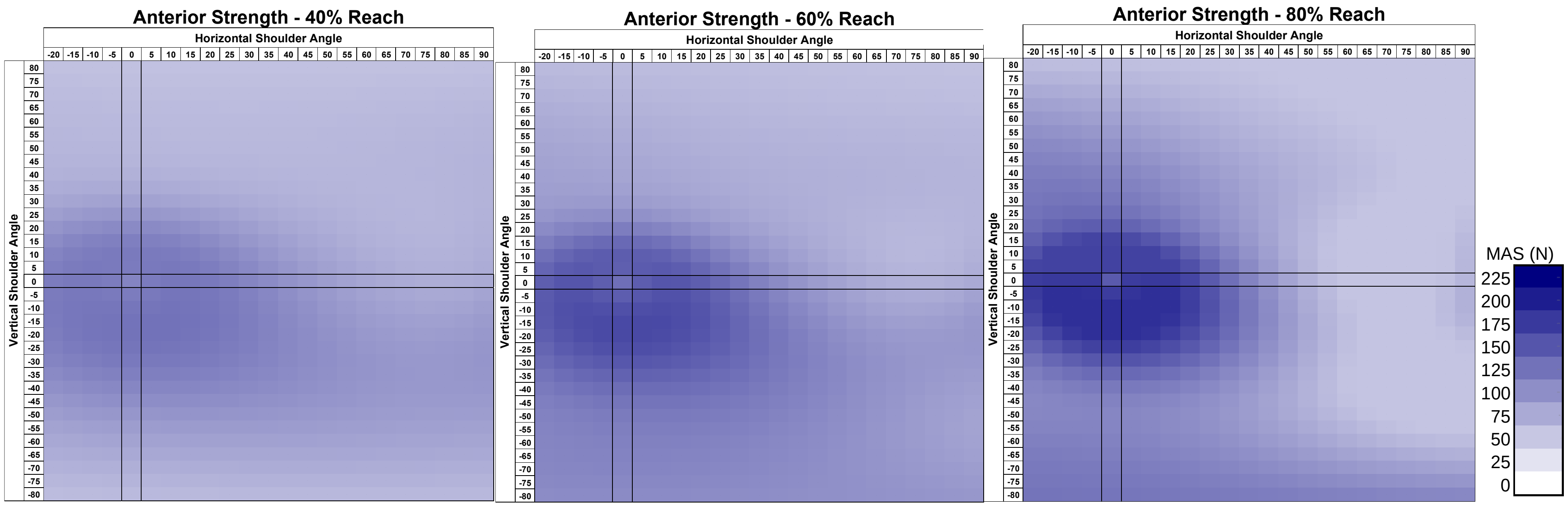
- Underwent rigorous process to determine optimal architecture
  - Decided upon model with 13 nodes and 18 inputs related to hand location and force direction

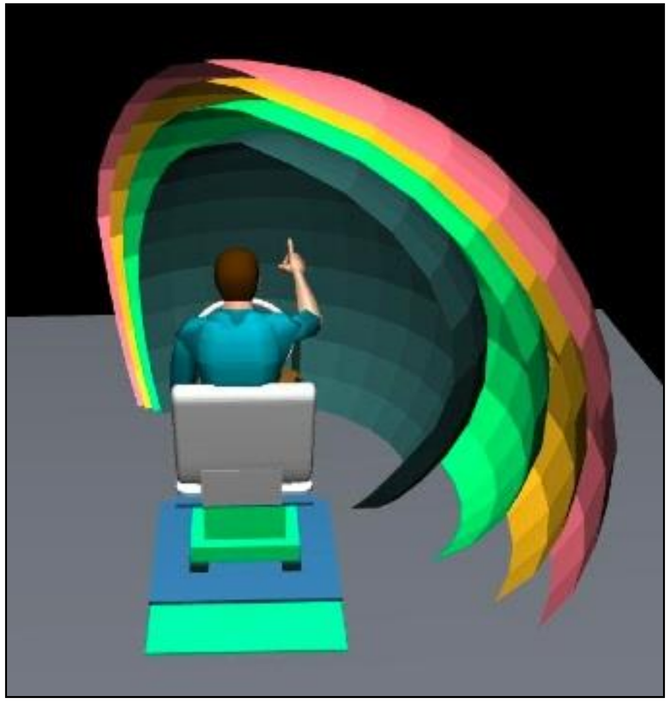


The Arm Force Field Method: Validation

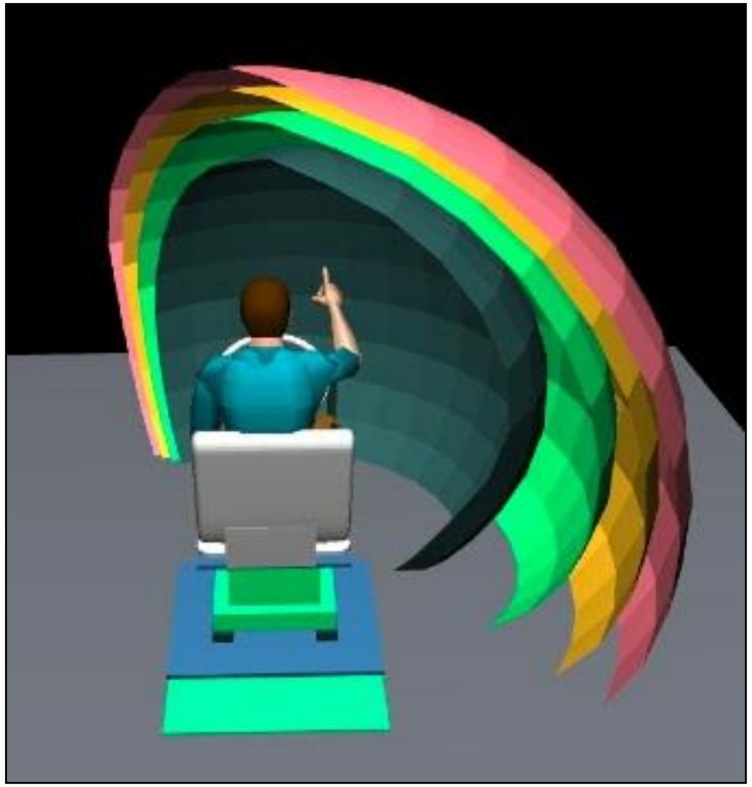


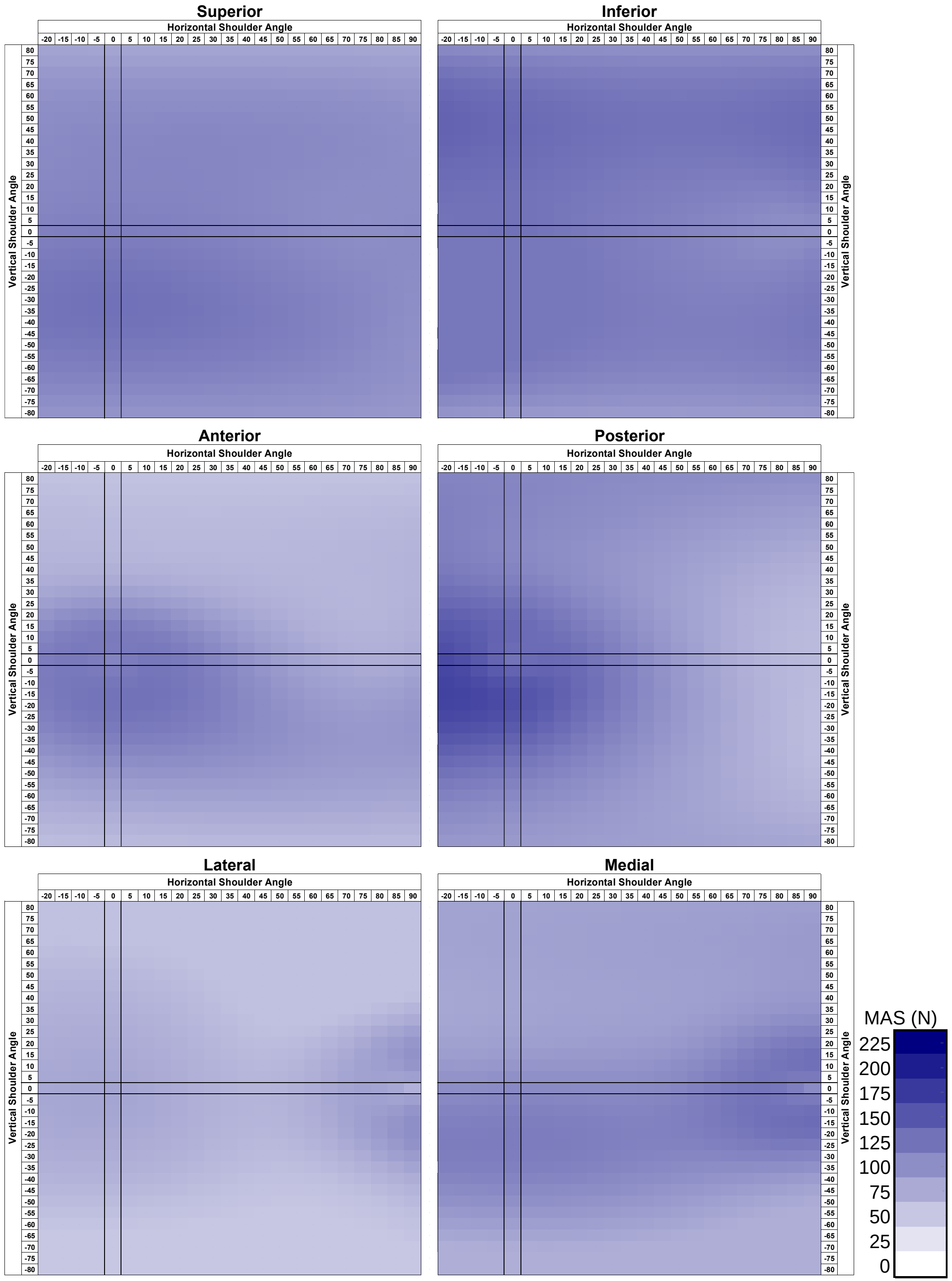



Anterior Strength - 40% Reach
Anterior Strength - 60% Reach
Anterior Strength - 80% Reach
Horizontal Shoulder Angle
Vertical Shoulder Angle
-20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 -5 -10 -15 -20 -25 -30 -35 -40 -45 -50 -55 -60 -65 -70 -75 -80
MAS (N)
225
200
175
150
125
100
75
50
25
0

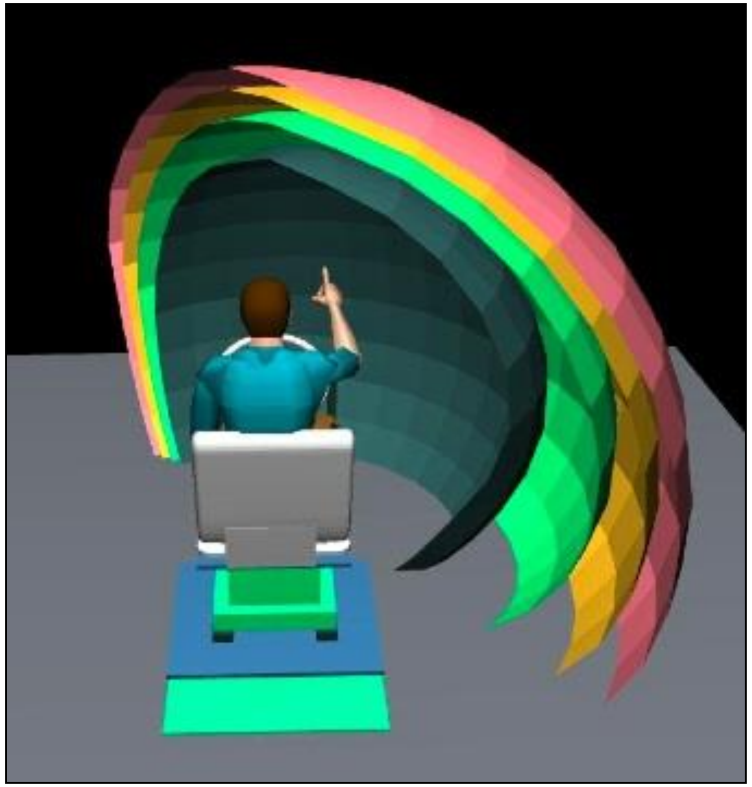


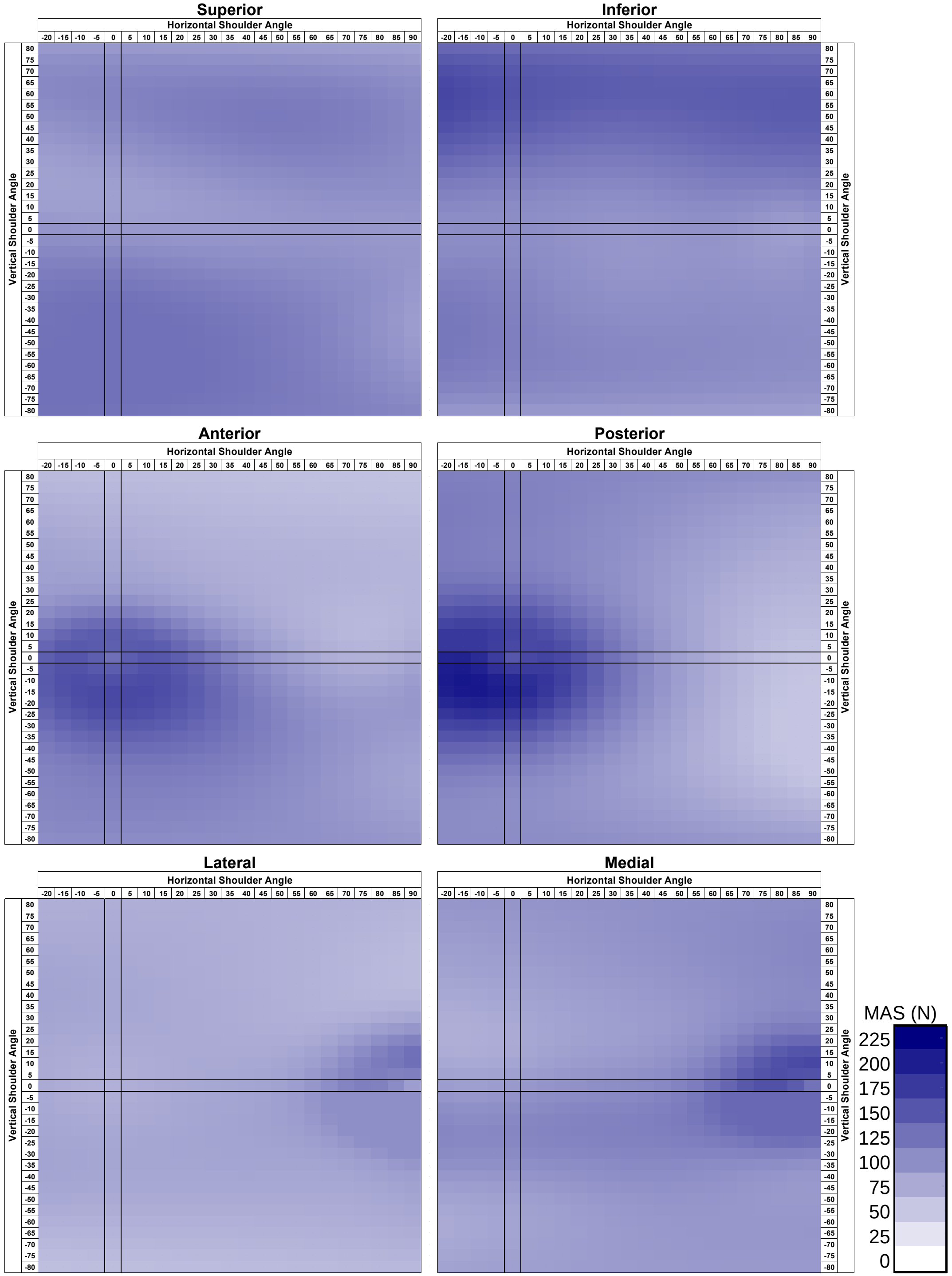
40% reach



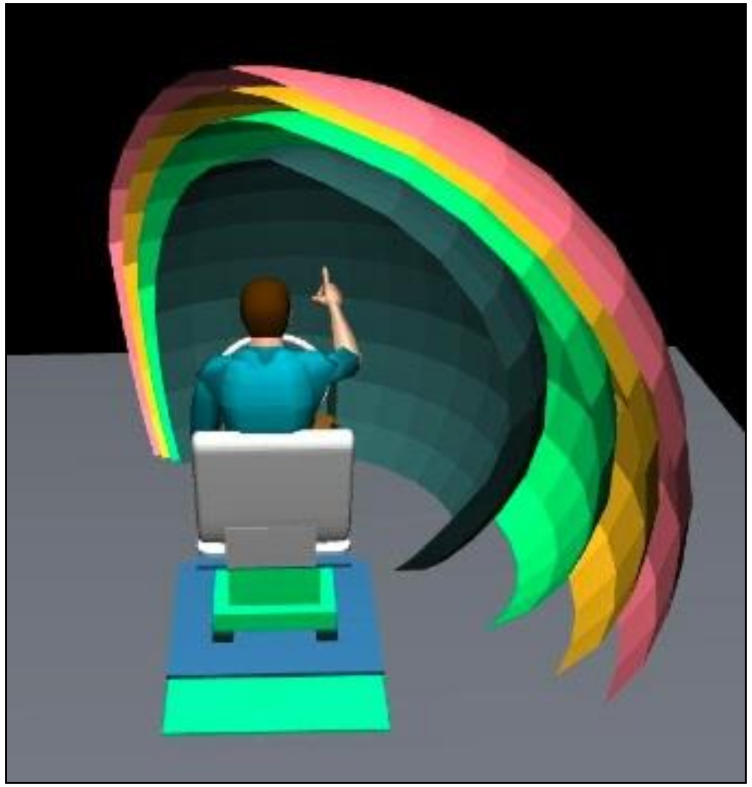

Superior
Inferior
Anterior
Posterior
Lateral
Medial
Horizontal Shoulder Angle
-20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
Vertical Shoulder Angle
80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 -5 -10 -15 -20 -25 -30 -35 -40 -45 -50 -55 -60 -65 -70 -75 -80
MAS (N)
225
200
175
150
125
100
75
50
25
0

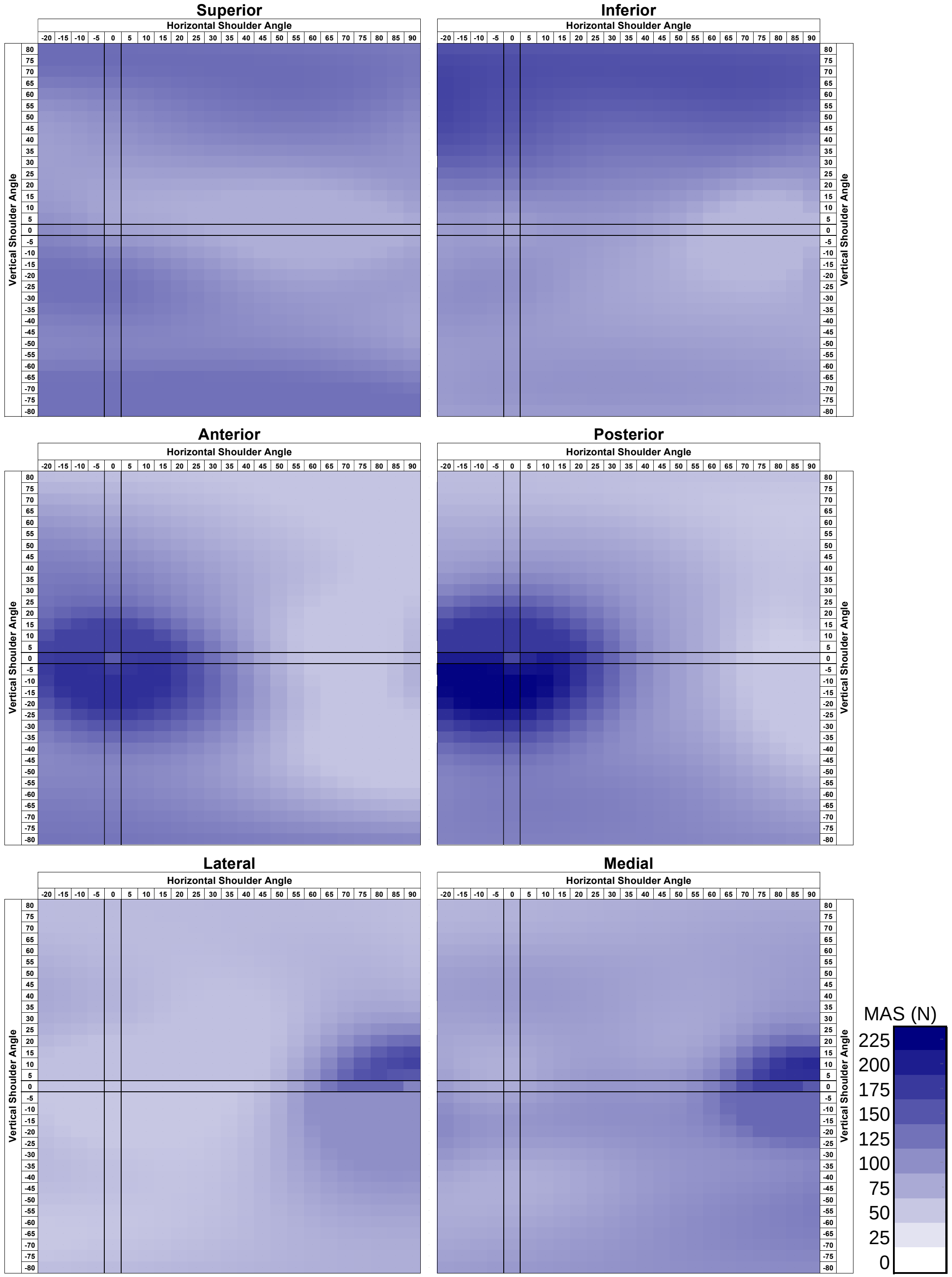
60% reach




Superior
Inferior
Anterior
Posterior
Lateral
Medial
Horizontal Shoulder Angle
-20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
Vertical Shoulder Angle
80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 -5 -10 -15 -20 -25 -30 -35 -40 -45 -50 -55 -60 -65 -70 -75 -80
MAS (N)
225
200
175
150
125
100
75
50
25
0

80% reach




Superior
Inferior
Anterior
Posterior
Lateral
Medial
Horizontal Shoulder Angle
Vertical Shoulder Angle
MAS (N)
225
200
175
150
125
100
75
50
25
0

Summary of Arm Force Field Method

AFF Development & Validation

Set Hand Location, Force Direction & Trunk Orientation

↓

Measure Manual Arm Strength (MAS)

↓

Estimate & Remove Gravity Effect

↓

Develop & Test Artificial Neural Network (ANN) to Predict 0G MAS

→ (to DHM Implementation: Use ANN to Predict 0G MAS)

DHM Implementation

Determine Hand Location, Force Direction & Trunk Orientation

↓

Calculate Hand Location & Force Direction in Shoulder Axis System

↓

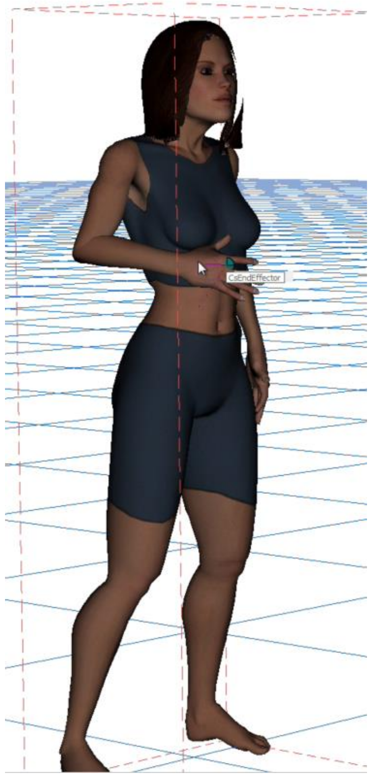
Use ANN to Predict 0G MAS

↓

Estimate & Add Gravity Effect

↓

Cap at Min and Max MAS Values for Quadrant → Correct for Percentile → Correct if Male



Summary of Arm Force Field Method

- 8+ researchers
  - Potvin, La Delfa, Hodder, Hall, Ibrahim, Evans, Petruzzi, Freeman
  - Primary focus of: 1 PhD thesis, 2 MSc theses, 3 UG theses

- 6-8 peer-reviewed publications related to AFF
  - 2 in prep

- 12+ conference presentations
  - ACE, PREMUS, CSB, ISB, Applied Ergo

- Integration within DHMs:
  - SantosHuman, Jack, HumanCAD

Current Limitations of AFF Method

- Only considers arm strength capability
  - Does not consider some other biomechanical limiters of MAS:
    - Balance
    - Torso/lower extremity strength
    - Hand strength
    - Grip orientation
      - La Delfa, Evans & Potvin (2019) *Applied Ergo*
  - Most DHM software can handle these analyses

Using the Arm Force Field Method

Inputs:

- Hand Location
- Force Direction
- Arm Posture

Arm Force Field Method

Is a lifting force of **45 N** acceptable to 75% of the population?

Outputs:

Acceptable Hand Load **= 89 N**

Task is acceptable!

Using the Arm Force Field Method

Inputs:

Hand Location

Force Direction

Arm Posture

Arm Force Field Method

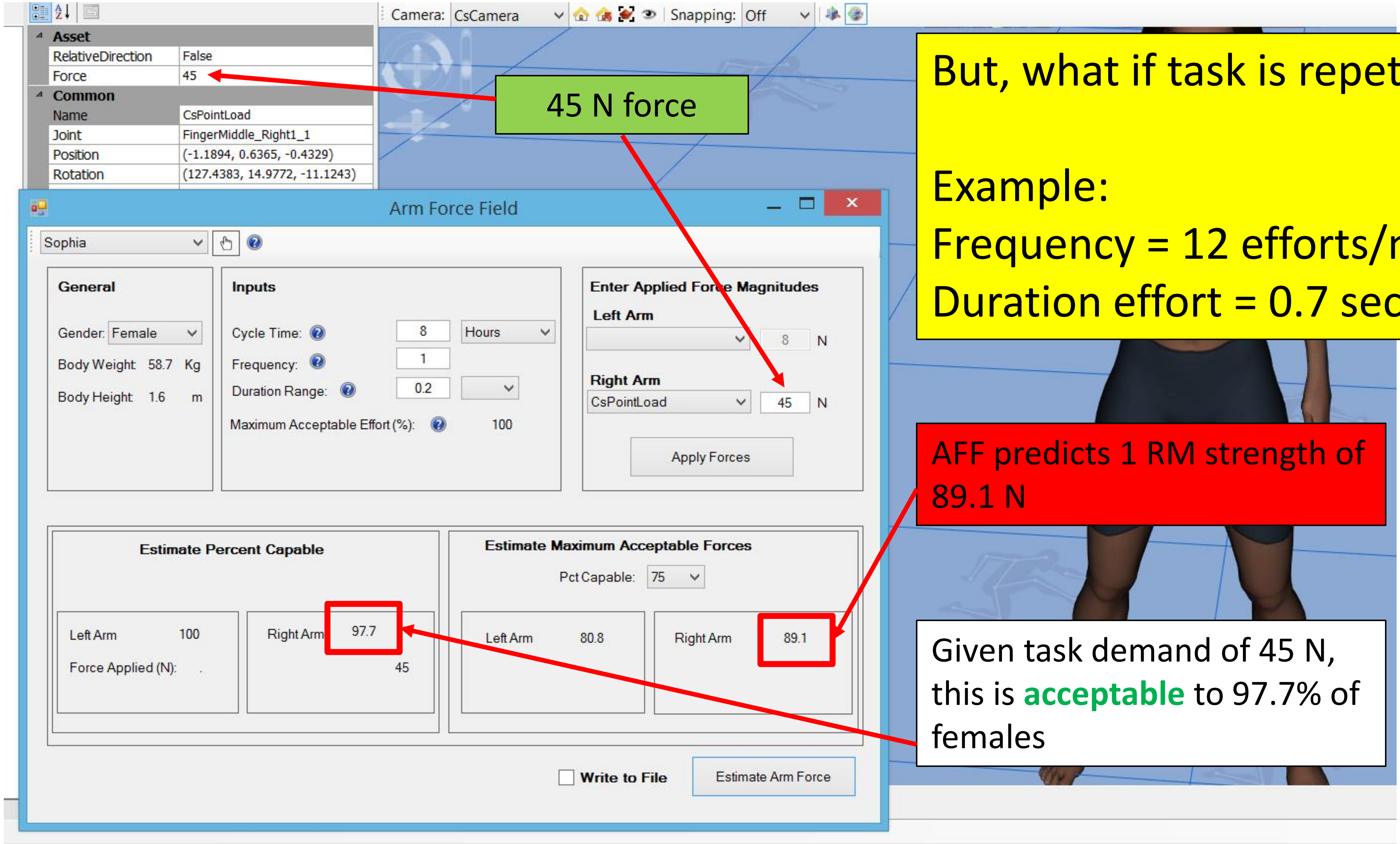
Is a lifting force of **45 N** acceptable to 75% of the population?

Outputs:

Acceptable Hand Load **= 40 N**

Task is not acceptable!

Arm Force Field in DHM software (e.g. SantosHuman)



45 N force

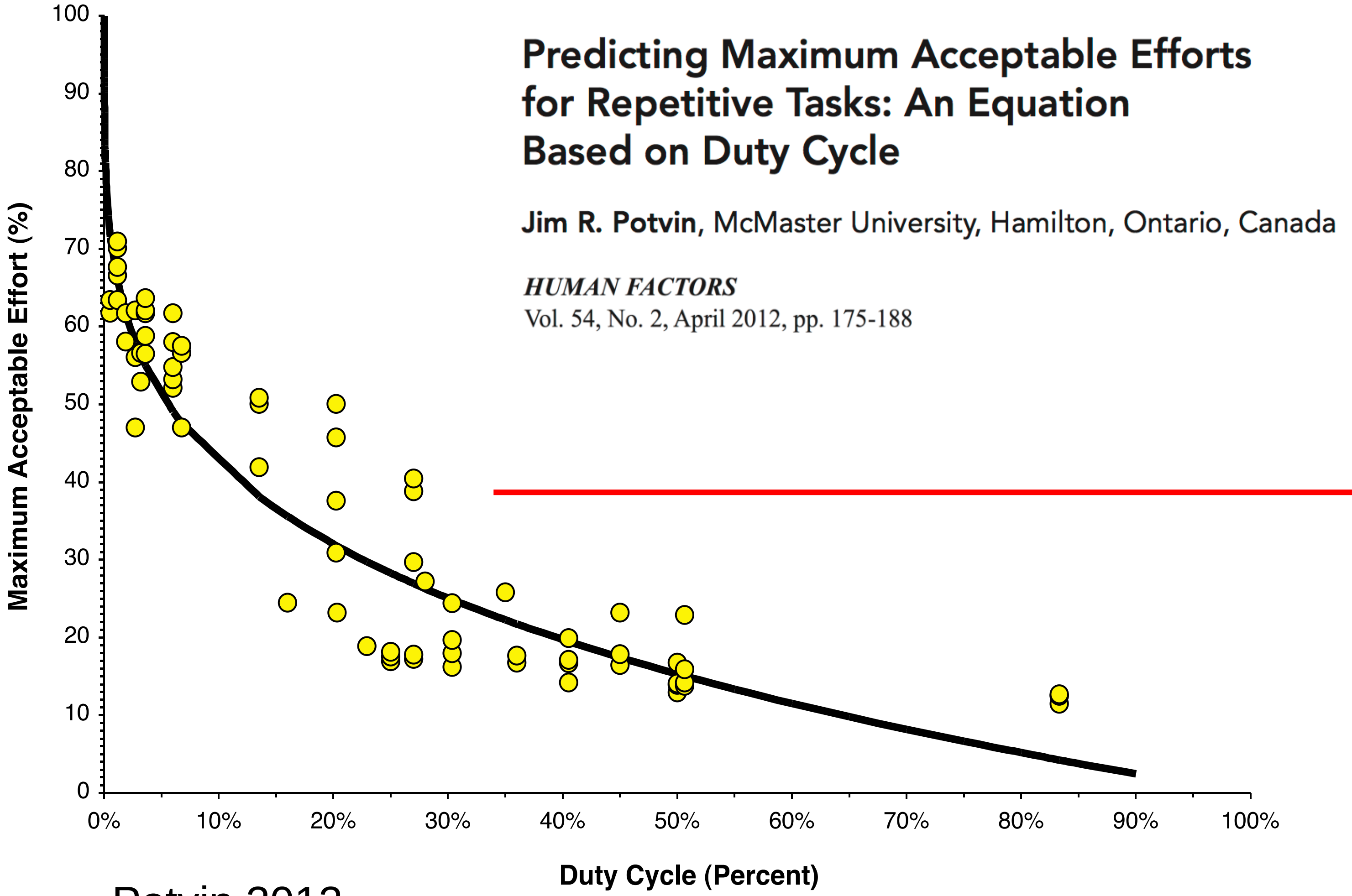
But, what if task is repetitive?

Example:
Frequency = 12 efforts/min
Duration effort = 0.7 seconds

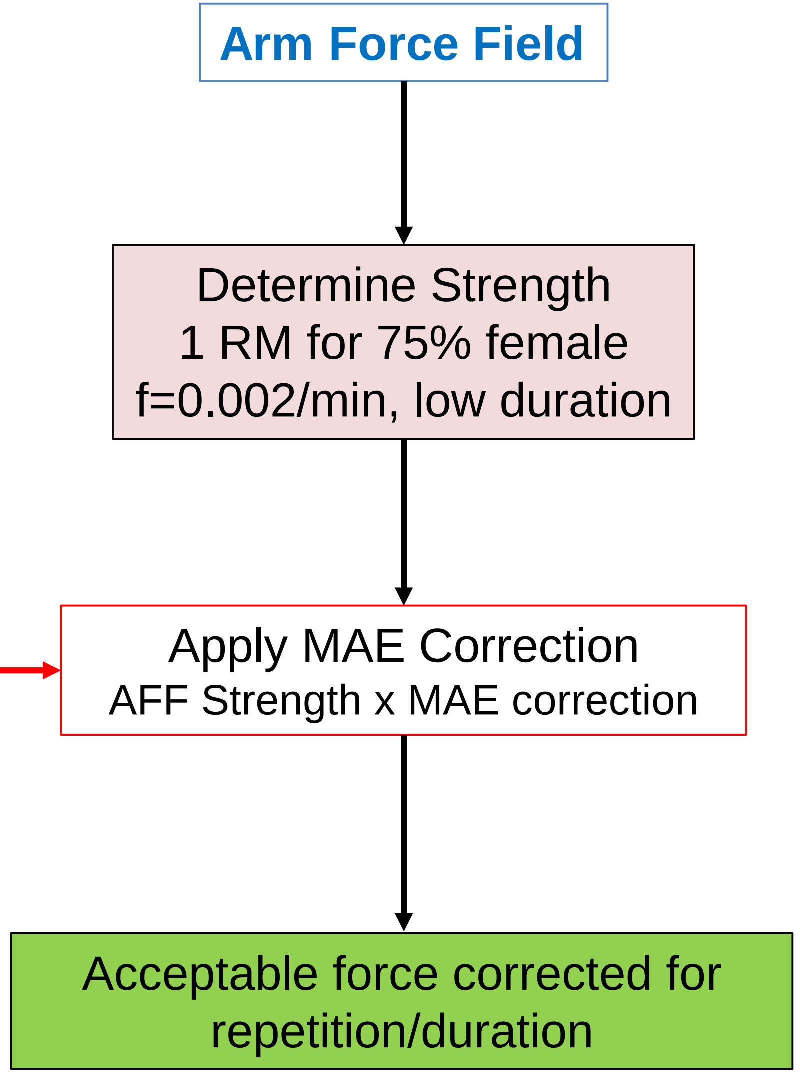
AFF predicts 1 RM strength of 89.1 N

Given task demand of 45 N, this is **acceptable** to 97.7% of females

Accounting for duty cycle



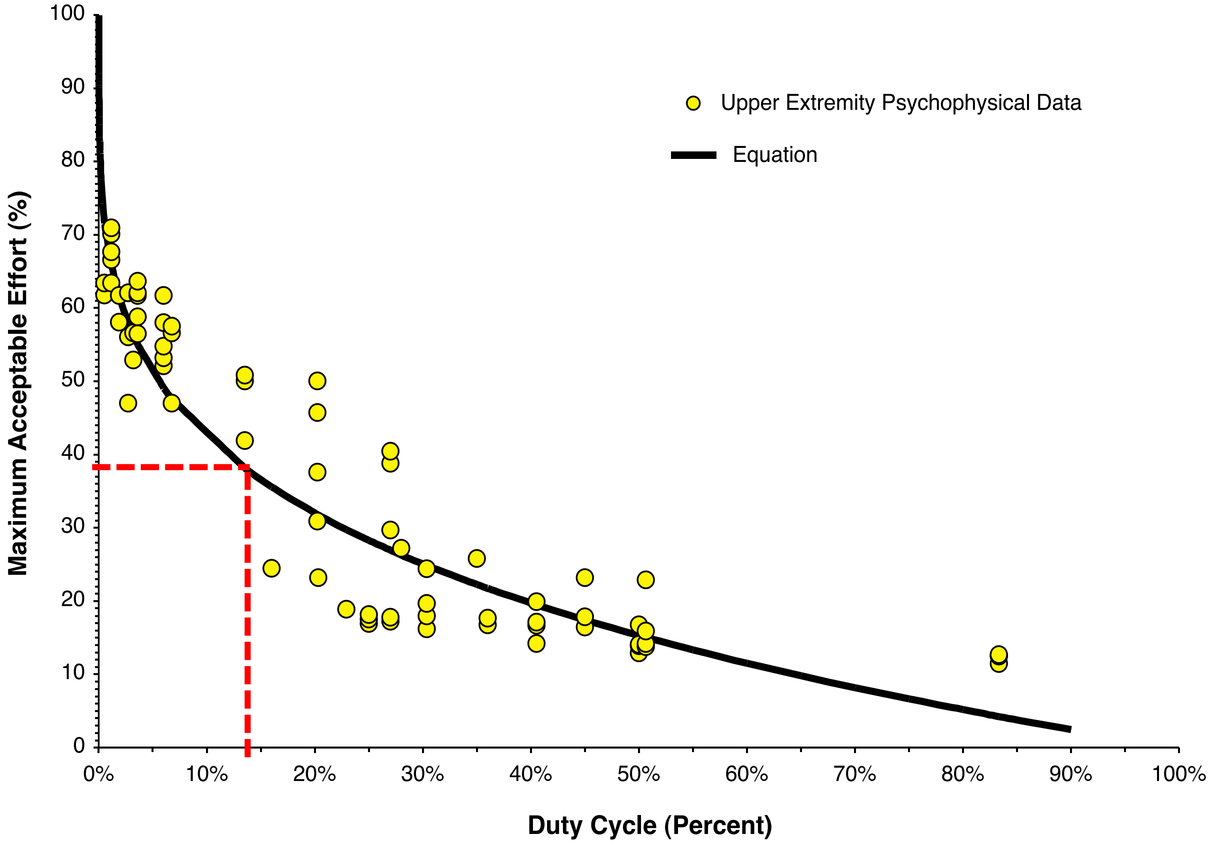
Potvin 2012



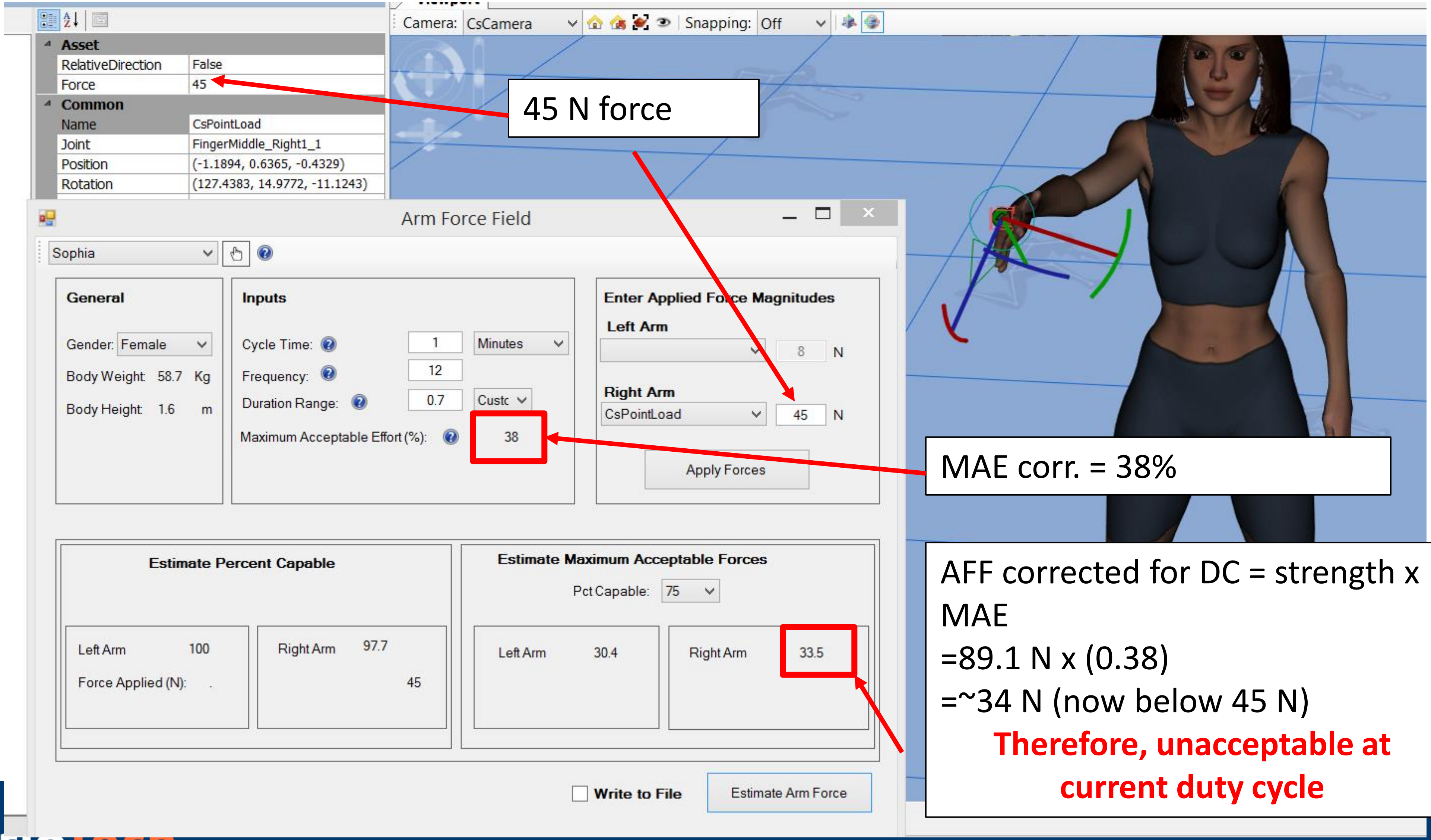
Accounting for duty cycle

- What if task has following parameters:
  - Frequency = 12 efforts/min
  - Duration effort = 0.7 s

- DC = (12 x 0.7)/60 = 0.14 (14%)
- MAE = 1 - $(0.14 - 0.000035)^{0.24}$ = 0.38 (38%)



Arm Force Field in DHM software (e.g. SantosHuman)



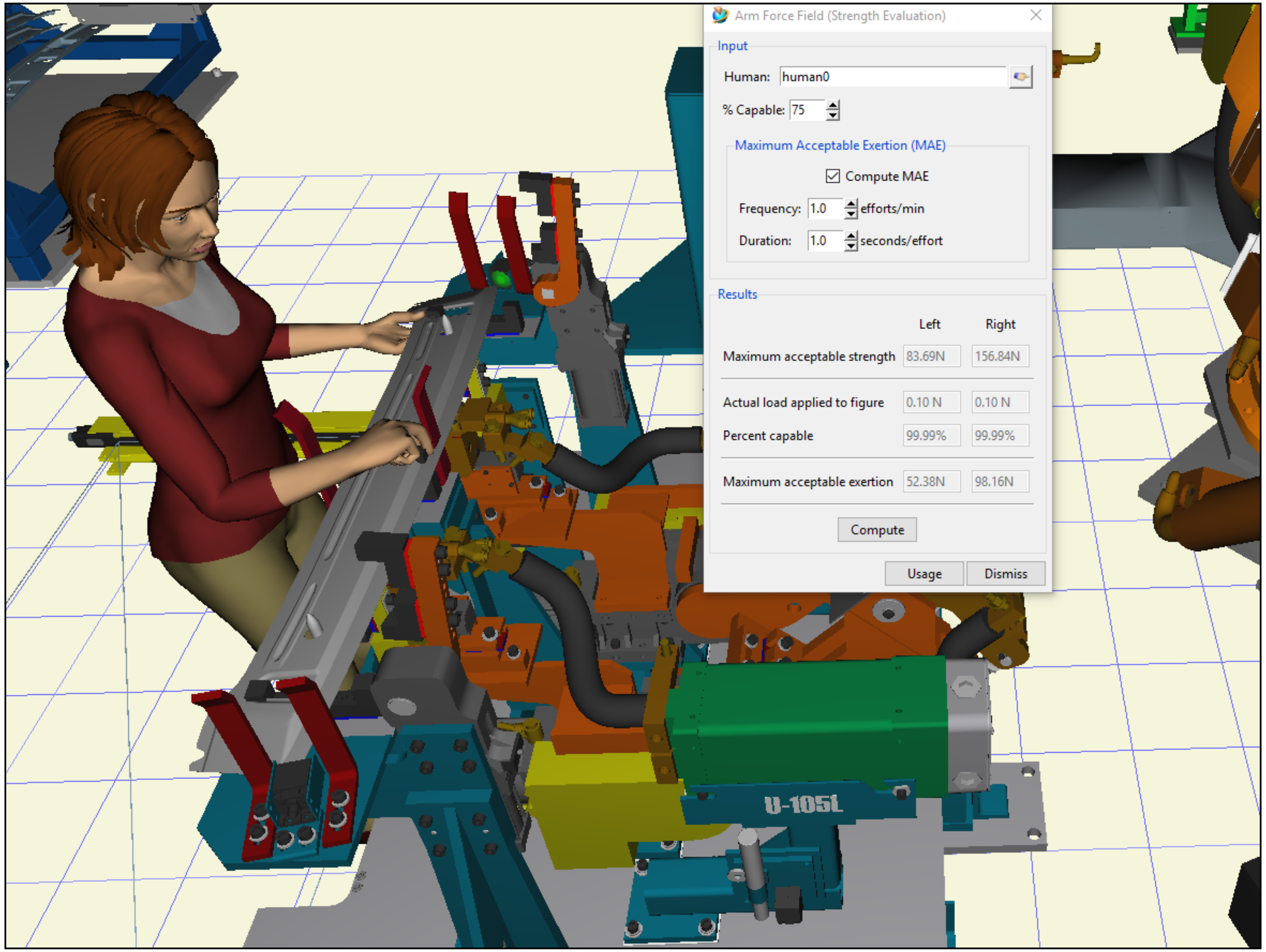
45 N force

MAE corr. = 38%

AFF corrected for DC = strength x MAE
=89.1 N x (0.38)
=~34 N (now below 45 N)

Therefore, unacceptable at current duty cycle

Arm Force Field in Jack



Others ways to utilize the AFF: Lookup Tables

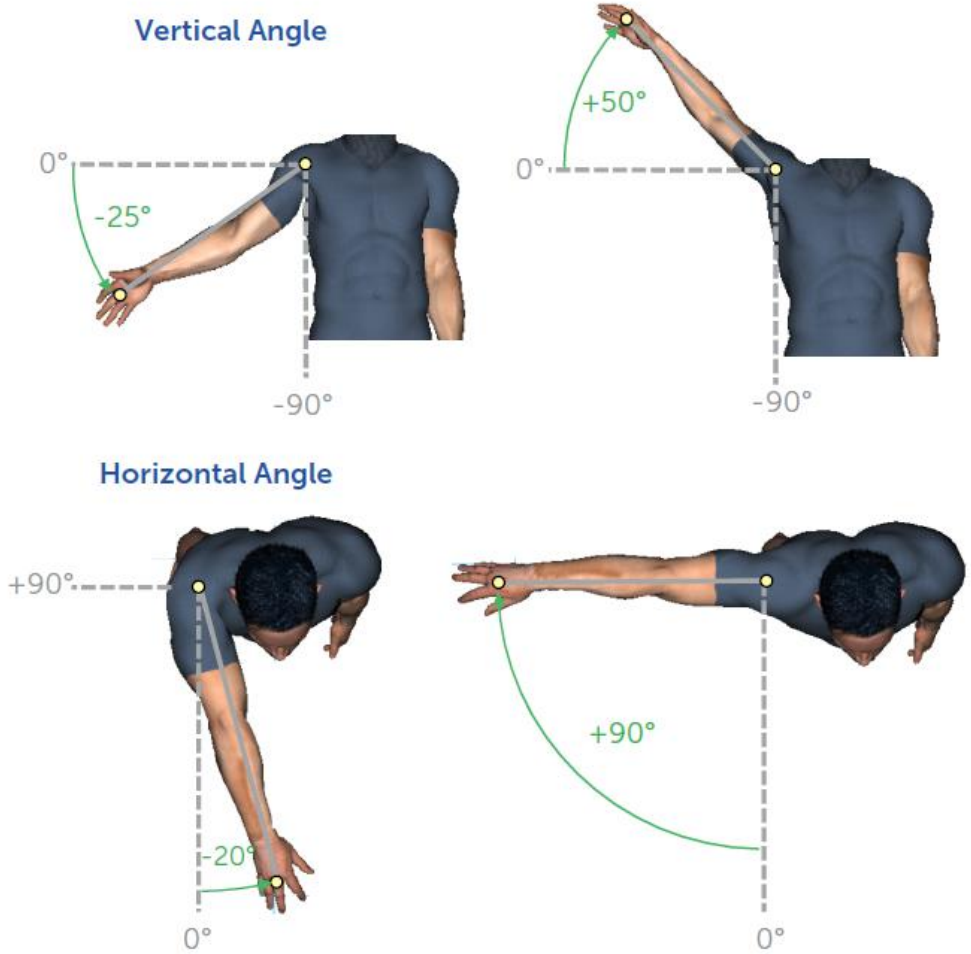
PREMUS 2016 Abstract

Lookup Tables for Manual Arm Strength

Nicholas La Delfa, PhD
nladelfa@gmail.com

Jim Potvin, PhD
jim.potvin@gmail.com
PotvinBiomechanics.com

July 1, 2016



Others ways to utilize the AFF: Lookup Tables

Female - 25th Percentile Manual Arm Strength (N)

25 cm Reach

Superior

Vertical Angle	Horizontal Angle -20	0	30	60	90
75	69	69	69	69	67
50	82	83	84	83	79
25	84	86	86	83	81
0	90	92	89	83	83
-25	98	100	96	88	81
-50	96	97	95	89	79
-75	81	81	80	79	75

Anterior

Vertical Angle	Horizontal Angle -20	0	30	60	90
75	47	46	46	47	47
50	53	52	51	52	54
25	70	76	64	54	56
0	94	89	88	65	62
-25	92	100	92	76	76
-50	71	76	76	72	71
-75	52	54	56	56	55

Lateral

Vertical Angle	Horizontal Angle -20	0	30	60	90
75	46	46	46	46	46
50	52	52	46	46	46
25	59	60	51	48	69
0	63	65	56	59	56
-25	60	61	54	54	78
-50	49	49	45	42	50
-75	41	41	41	41	41

Inferior

Vertical Angle	Horizontal Angle -20	0	30	60	90
75	96	93	89	89	91
50	114	109	103	102	107
25	107	105	100	96	100
0	102	104	96	88	81
-25	99	99	97	92	97
-50	99	99	96	94	98
-70	87	84	80	80	82

Posterior

Vertical Angle	Horizontal Angle -20	0	30	60	90
75	90	88	84	80	77
50	92	86	78	69	62
25	109	101	81	63	52
0	130	101	94	65	50
-25	132	124	94	66	48
-50	102	95	80	64	51
-75	78	76	71	66	61

Medial

Vertical Angle	Horizontal Angle -20	0	30	60	90
75	67	67	68	70	72
50	65	66	68	70	73
25	66	67	69	76	89
0	82	85	83	93	84
-25	94	95	92	91	96
-50	79	80	77	69	61
-75	59	59	59	59	59

37.5 cm Reach

Superior

Vertical Angle	Horizontal Angle -20	0	30	60	90
75	78	78	78	76	71
50	79	84	92	93	83
25	66	69	77	83	80
0	74	72	72	73	72
-25	95	96	90	83	72
-50	99	100	98	89	70
-75	100	100	98	91	82

Anterior

Vertical Angle	Horizontal Angle -20	0	30	60	90
75	53	51	49	47	46
50	65	62	57	54	53
25	76	80	65	55	54
0	116	104	99	63	61
-25	111	127	109	81	75
-50	90	95	93	80	67
-75	85	86	84	79	73

Lateral

Vertical Angle	Horizontal Angle -20	0	30	60	90
75	59	60	59	56	53
50	65	63	60	55	50
25	64	63	61	59	76
0	61	57	63	76	70
-25	65	64	65	69	81
-50	62	61	61	61	65
-75	49	50	51	52	54

Inferior

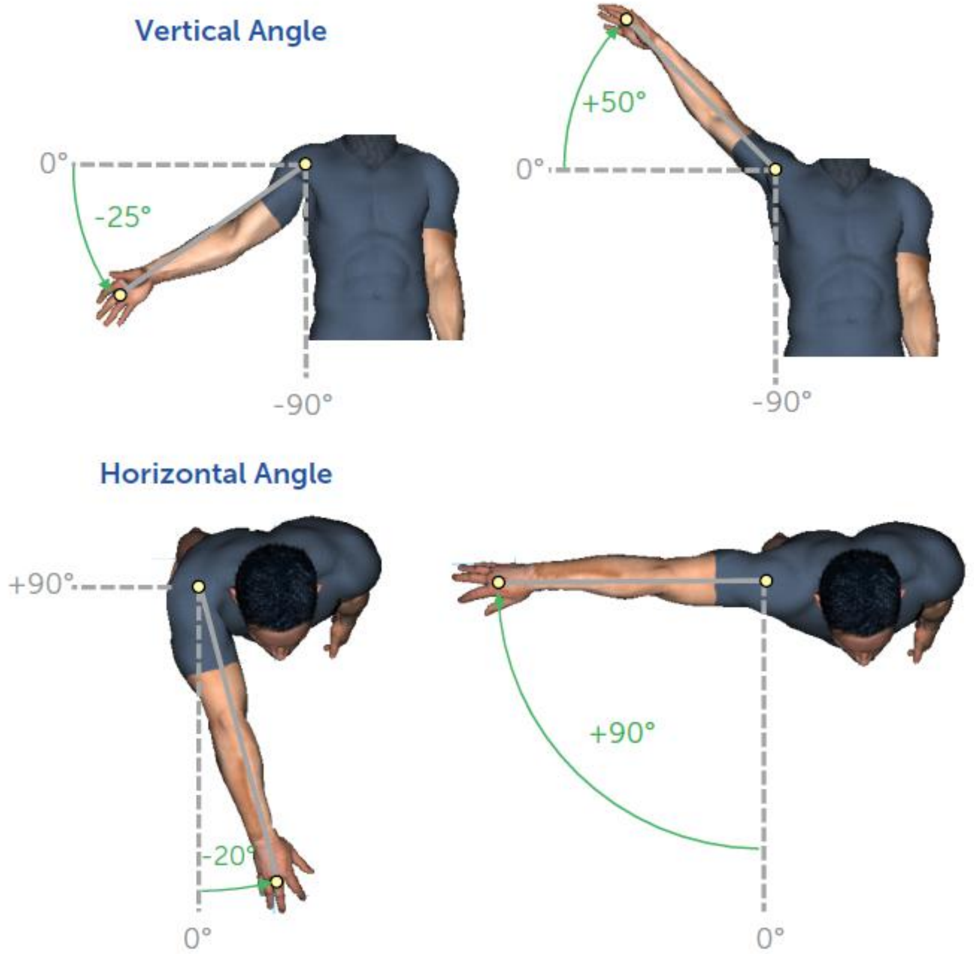
Vertical Angle	Horizontal Angle -20	0	30	60	90
75	122	118	113	111	110
50	133	123	115	117	120
25	104	99	93	99	101
0	85	86	79	81	73
-25	95	91	82	82	83
-50	100	95	89	88	85
-70	86	85	82	80	78

Posterior

Vertical Angle	Horizontal Angle -20	0	30	60	90
75	94	91	86	79	74
50	94	90	81	69	60
25	113	112	84	62	52
0	158	121	103	60	44
-25	146	144	94	58	42
-50	95	91	74	57	42
-75	84	82	78	71	64

Medial

Vertical Angle	Horizontal Angle -20	0	30	60	90
75	74	76	78	82	85
50	66	69	74	80	86
25	59	62	69	79	95
0	71	74	81	102	102
-25	87	87	90	94	102
-50	66	69	75	76	74
-75	64	68	72	74	74



Others ways to utilize the AFF: Matlab

```
% Arm Force Field Method
% code copyright to Jim Potvin (2016)
% last updated 2016-05-29

clear
clc
%clf('reset')                    % clears all graphics
format short

CV = 0.277;                      % coefficient of variation for strength
bm = 65.0;                       % body mass (kg)
ht = 1.600;                      % stature (m)
pc = 75;                         % percent capable
Antro = [bm, ht, pc]
GravityG = [0, -1, 0];           % gravity in Global Axis System


UAcogR = 0.436;                  % CofG distance ratios (from Chaffin, Andersson, Martin, 1999)
FAcogR = 0.430;
HcogR = 0.740;

UAmassR = 0.028;                 % Body mass ratios (from Chaffin, Andersson, Martin, 1999)
FAmassR = 0.017;
HmassR = 0.006;
```

Others ways to utilize the AFF: Excel Spreadsheet

Body Mass (kg)	72.1	note: skeleton is
Stature (m)	1.628	50th female
% Capable	75	
Sex	Female	

		Hand		
Axis Directions		**Left**	**Right**	
Right/Left	+ Right / - Left	0	0	Hand locations wrt Shoulder
Anterior/Posterior	+ Ant / - Post	0	45	
Up/Down	+ Up / - Down	-50	-30	

all in cm

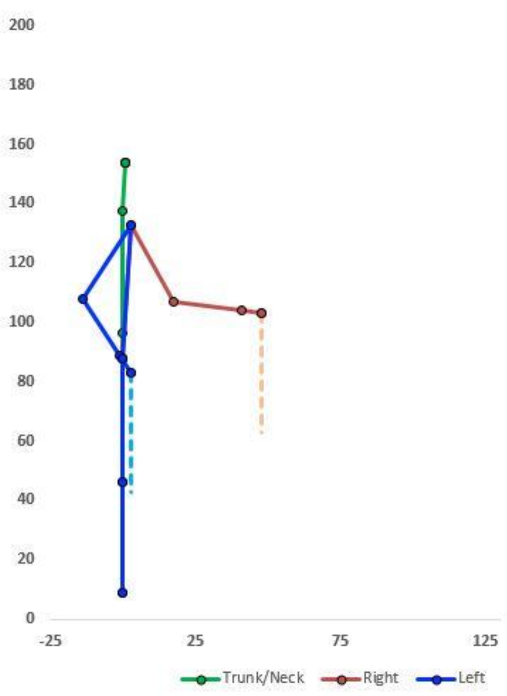
Arm Force Field

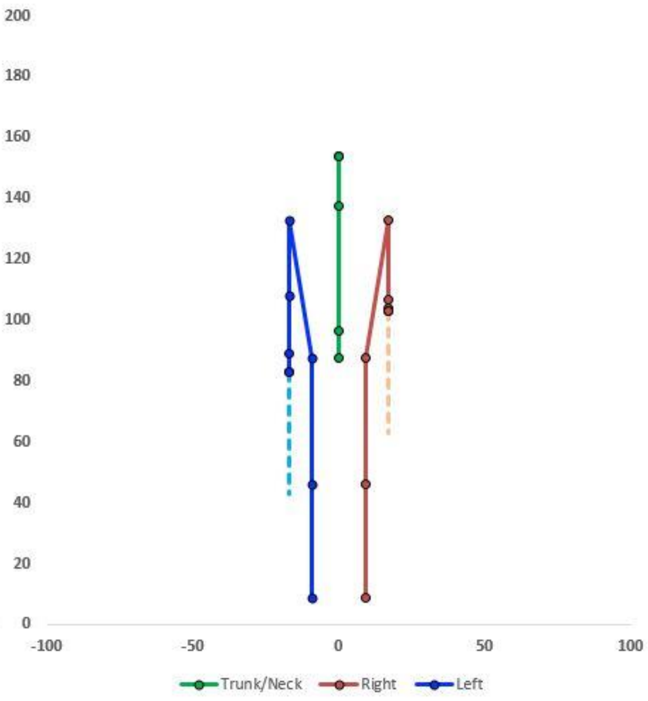
La Delfa & Potvin (2017)

Enter the Direction of the Force acting on the hand (from -1.000 to +1.000)	Left Force Vector (in Global)		
	X	Y	Z
	0	0	-1
Direction polarity	+ is Right	+ is Ant	+is Sup
Hand Effort Direction			Up

Right Force Vector (in Global)		
X	Y	Z
0	0	-1
+ is Right	+ is Ant	+is Sup
		Up

	Left		Right
Hand Force (N)	0		58
Manual Arm Strength	59.7 N	75 %Cap	90.9 N
%Capable	100 %Capable		97 %Capable





Available upon request: nicholas.ladelfa@uoit.ca

Conclusions

- The traditional way of estimating manual strength and acceptable forces were problematic
- The Arm Force Field method represents an approach to estimate strength capability for the population at the hand
- DHM software provide most complete utilization, but other methods to access AFF outputs are still possible

Establishing Acceptable Manual Forces in the Proactive Ergonomics Process:

Development and Implementation of the Arm Force Field Method

Automotive Partnership Canada
www.apc-pac.ca

USCAR UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH LLC

Ford CHRYSLER GM

Nick La Delfa, PhD
Assistant Professor
Faculty of Health Sciences
University of Ontario Institute of Technology
(now Ontario Tech University)
nicholas.ladelfa@uoit.ca

McMaster University

OntarioTech UNIVERSITY