New Risk Assessment Methods in Ergonomics

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Preview of Talk

- The Liberty Mutual Manual Materials Handling (LM-MMH) Equations
  - development
  - equations
  - app
- Evaluation of the Validity of DHM Software for Estimating Manual Arm Strength
  - study
  - results
  - implications
- The Arm Force Field (AFF) for Estimating Manual Arm Strength
  - studies
  - results
  - development of the "AFF"
  - implementation
- A New Tool to Assess Above-Shoulder Work
  - theory
  - tool (work in progress)

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The Liberty Mutual Manual Materials Handling Equations

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ERGONOMICS
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ARTICLE

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The liberty mutual manual materials handling (LM-MMH) equations

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ABSTRACT
We summarise more than 40 years of Liberty Mutual psychophysical research on lifting, lowering, pushing, pulling and carrying, including the 7 studies used to develop the Snook & Ciriello tables and 12 subsequent studies. Predictive equations were developed based on 612 mean maximum acceptable loads (MALs), representing 388 unique conditions from 123 female and 149 male participants, starting with a maximum reference load that is scaled based on frequency, height, distance (vertical for lift & lower, horizontal for push, pull and carry tasks) and horizontal reach (for lift & lower tasks). Representative coefficients of variation are provided to allow for the calculation of MALs for any percentile. Each equation performed well and, overall, they explained 90% of the variance in MAL values, with RMS differences of 6.7% and 4.8% of the full range for females and males, respectively. We propose that these equations replace the 1991 Liberty Mutual Tables.

Practitioner summary: We propose predictive equations to replace the 14 manual materials handling tables in Snook and Ciriello (1991). These equations are based on 12 more publications, matched the empirical data well, are easier to use and allow for both a wider range and more specific inputs than the tables.

Abbreviations: ANSUR: anthropometric survey of U.S. army personnel; C: Coupling; CV: coefficient of variation; DH: displacement horizontal; DV: displacement vertical; F: frequency; H: horizontal reach; LM: Liberty Mutual Insurance; MAL: maximum acceptable load; MMH: manual materials handling; RL: reference load; SF: scale factor; V: vertical height; VRM: vertical range middle

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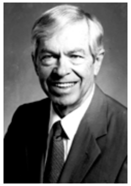
Liberty Mutual MMH Research: 1971 to 1991



Stover Snook

Task		1 Snook (1971)
Task	Particpants	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		1 Snook (1971)
Gender	Task	Particpants	28
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
		Frequencies (per min)	1 to 10
		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
		Frequencies (per min)	1 to 10
		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
		Frequencies (per min)	1 to 10
		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

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Liberty Mutual MMH Research: 1971 to 1991

n = 7

Gender	Task		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)
Gender	Task	Participants	28	16		15	10	10	6
Male	Lift	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
		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
	Lower	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	
		Distances per min (m)	0.51 to 5.1				0.001 to 6.1	0.51 to 2.2	
	Push	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	12
		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
Gender	Task	Participants			15		12	12	
Female	Lift	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	
		Distances per min (m)			0.51 to 3.4		0.001 to 6.1	0.51 to 2.2	
	Lower	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	
		Distances per min (m)			0.51 to 5.1		0.001 to 6.1	0.51 to 2.2	
	Push	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	

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Conditions: 7 Studies from 1971 to 1991

Task		Gender	Conditions with MAL Values: Conditions	Total n	Mean n	Unique Combinations: Combinations	Mean n	Liberty Mutual Tables: Combinations	% with Data
Lift		Female	70	858	12.3	41	20.9	216	19%
		Male	101	1,220	12.1	55	22.2	216	25%
Lower		Female	28	354	12.6	24	14.8	216	11%
		Male	31	472	15.2	27	17.5	216	13%
Push	Initial	Female	29	351	12.1	25	14.0	105	24%
		Male	42	706	16.8	32	22.1	105	30%
	Sustained	Female	36	456	12.7	29	15.7	105	28%
		Male	43	722	16.8	32	22.6	105	30%
Pull	Initial	Female	6	75	12.5	4	18.8	105	4%
		Male	10	164	16.4	8	20.5	105	8%
	Sustained	Female	7	90	12.9	5	18.0	105	5%
		Male	10	164	16.4	8	20.5	105	8%
Carry		Female	20	276	13.8	20	13.8	42	48%
		Male	39	672	17.2	28	24.0	42	67%
Total per Gender		Female	196	2,460	12.6	148	16.6	894	17%
		Male	276	4,120	14.9	190	21.7	894	21%
Totals per Task		Lift	171	2,078	12.2	96	21.6	432	22%
		Lower	59	826	14.0	51	16.2	432	12%
		Push	150	2,235	14.9	118	18.9	420	28%
		Pull	33	493	14.9	25	19.7	420	6%
		Carry	59	948	16.1	48	19.8	84	57%
7 Studies (1991 Tables)			472	6,580	13.9	338	19.5	1,788	18.9%

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Liberty Mutual MMH Research: 1971 to 2011

Gender	Task		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)
Gender	Task	Participants	28	16		15	10	10	6
Male	Lift	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
		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
	Lower	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	
		Distances per min (m)	0.51 to 5.1				0.001 to 6.1	0.51 to 2.2	
	Push	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	12
		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
Gender	Task	Participants			15		12	12	
Female	Lift	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	
		Distances per min (m)			0.51 to 3.4		0.001 to 6.1	0.51 to 2.2	
	Lower	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	
		Distances per min (m)			0.51 to 5.1		0.001 to 6.1	0.51 to 2.2	
	Push	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	

Gender	Task		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)
Gender	Task	Participants	6	6	8	8					14	23		
Male	Lift	Conditions		4		15						6		
		Box Widths		L		S, XL						S		
		Ranges		FK		FK, KnE, KS						FK, KS		
		Distances per effort (m)		0.25 to 0.76		0.51						0.51		
		Frequencies (per min)		4.3		1/day to 20						1 to 12		
		Distances per min (m)		1.1 to 3.3		0.001 to 10.2						0.51 to 6.1		
	Lower	Conditions		12								6		
		Box Widths		S, L								S		
		Ranges		FK, KS								FK, KS		
		Distances per effort (m)		0.25 to 0.76								0.51		
		Frequencies (per min)		4.3								1 to 12		
		Distances per min (m)		1.1 to 3.3								0.51 to 6.1		
	Push	Conditions	2		2						2	2		
		Heights	KnE		KnE						KnE	KnE		
		Distances per effort (m)	7.6		7.6, 15.2						7.6	7.6		
		Frequencies (per min)	1		1						1	1, 4		
		Distances per min (m)	7.6		7.6, 15.2						7.6	7.6, 30.5		
	Pull	Conditions			2							2		
		Heights			KnE							KnE		
		Distances per effort (m)			7.6 to 15.2							7.6		
		Frequencies (per min)			1							1, 4		
		Distances per min (m)			7.6 to 15.2							7.6, 30.5		
	Carry	Conditions										2		
		Box Widths										S		
		Carry Heights										K		
		Distances per effort (m)										4.3		
		Frequencies (per min)										1, 4.3		
		Distances per min (m)										4.3, 18.3		
Gender	Task	Participants					10	11	10	10			19	24
Female	Lift	Conditions							4	15				6
		Box Widths							S, L	S, L, XL				S
		Ranges							FK	FK, KnE, KS				FK, KS
		Distances per effort (m)							0.25 to 0.76	0.51				0.51
		Frequencies (per min)							4.3	1/day to 20				1 to 12
		Distances per min (m)							1.1 to 3.3	0.001 to 10.2				0.51 to 6.1
	Lower	Conditions							12					6
		Box Widths							S, L					S
		Ranges							FK, KS					FK, KS
		Distances per effort (m)							0.25 to 0.76					0.51
		Frequencies (per min)							4.3					1 to 12
		Distances per min (m)							1.1 to 3.3					0.51 to 6.1
	Push	Conditions					2	2	2				2	2
		Heights					KnE	KnE	KnE				KnE	KnE
		Distances per effort (m)					7.6, 15.2	7.6	7.6				7.6	7.6
		Frequencies (per min)					1	1	0.2, 1				1	1, 4
		Distances per min (m)					7.6, 15.2	7.6	1.52, 7.6				7.6	7.6, 30.5
	Pull	Conditions					2		1					2
		Heights					KnE		KnE					KnE
		Distances per effort (m)					7.6 to 15.2		2.1					7.6
		Frequencies (per min)					1		1					1, 4
		Distances per min (m)					7.6 to 15.2		2.1					7.6, 30.5
	Carry	Conditions							2					2
		Box Widths							S					S
		Carry Heights							K					K
		Distances per effort (m)							2.1, 4.3					4.3
		Frequencies (per min)							1, 4.3					1, 4.3
		Distances per min (m)							4.3, 9.1					4.3, 18.3

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Conditions: 19 Studies from 1971 to 2011

Task		Gender	Conditions with MAL Values: Conditions	Total n	Mean n	Unique Combinations: Combinations	Mean n	Liberty Mutual Tables: Combinations	% with Data
Lift		Female	95	1,192	12.5	54	22.1	216	25%
		Male	126	1,510	12.0	58	26.0	216	27%
Lower		Female	46	618	13.4	34	18.2	216	16%
		Male	49	706	14.4	37	19.1	216	17%
Push	Initial	Female	39	499	12.8	26	19.2	105	25%
		Male	47	788	16.8	32	24.6	105	30%
	Sustained	Female	46	604	13.1	30	20.1	105	29%
		Male	48	804	16.8	32	25.1	105	30%
Pull	Initial	Female	11	153	13.9	6	25.5	105	6%
		Male	14	226	16.1	9	25.1	105	9%
	Sustained	Female	12	168	14.0	7	24.0	105	7%
		Male	14	226	16.1	9	25.1	105	9%
Carry		Female	24	344	14.3	22	15.6	42	52%
		Male	41	718	17.5	32	22.4	42	76%
Total per Gender		Female	273	3,578	13.1	179	20.0	894	20%
		Male	339	4,978	14.7	209	23.8	894	23%
Totals per Task		Lift	221	2,702	12.2	112	24.1	432	26%
		Lower	95	1,324	13.9	71	18.6	432	16%
		Push	180	2,695	15.0	120	22.5	420	29%
		Pull	51	773	15.2	31	24.9	420	7%
		Carry	65	1,062	16.3	54	19.7	84	64%
19 Studies (Equations)			612	8,556	14.0	388	22.1	1,788	21.7%
7 Studies (1991 Tables)			472	6,580	13.9	338	19.5	1,788	18.9%
			+30%			+15%			

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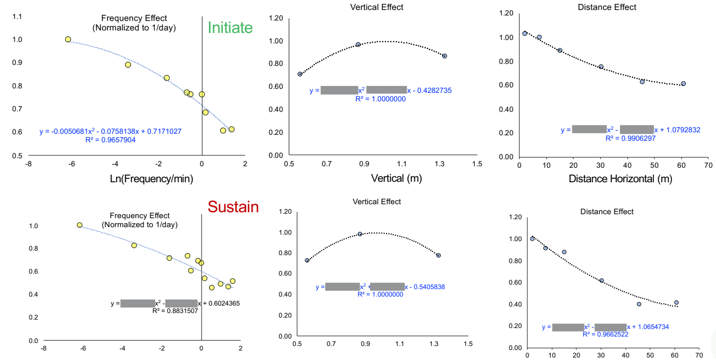
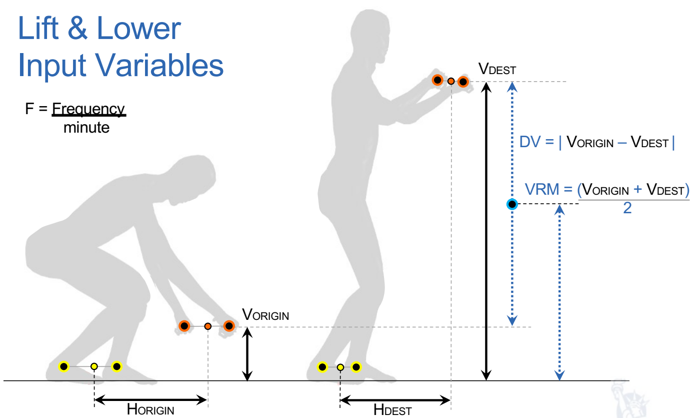
Procedures

- 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
- Anthropometry
  - estimated heights with ANSUR II database
    - knee, knuckle heigh, elbow, shoulder, stature, and arm reach
- Equation Development
  - input variables
    - H, D (horizontal or vertical), F, V (origin & destination for Lifts & Lowers)
    - determine the independent effects of changes in each variable on the MAL
    - normalize each relationship to have a maximum scale factor of 1.00
    - determine the maximum/reference load for best fit.

Analysis Example: Scale Factors (Push & Pull Female)



Lift & Lower Input Variables



Lift & Lower Equations: Females

The Lift and Lower equations have the form: $MAL = RL\,[H_{SF}]\,[VRM_{SF}]\,[DV_{SF}]\,[F_{SF}]$

Lift - Female

$$MAL = 34.9\left[\text{[redacted]} - \frac{H}{\text{[redacted]}}\right]\left[0.9877 + \frac{VRM}{13.69} - \frac{VRM^2}{9.221}\right]\left[\text{[redacted]} - \frac{\ln(DV)}{\text{[redacted]}}\right]\left[\text{[redacted]} - \frac{\ln(F)}{\text{[redacted]}} - \frac{\ln(F)^2}{\text{[redacted]}}\right]$$

$CV = 0.260$

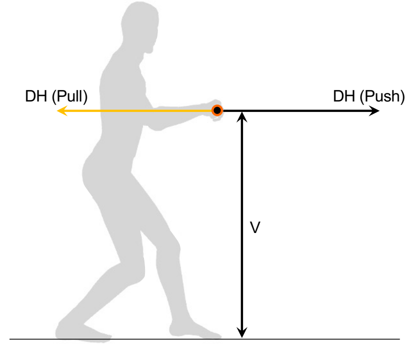
Horizontal Scale Factor | Vertical Range Middle Scale Factor | Vertical Displacement Scale Factor | Frequency Scale Factor

Lower - Female (note: only the RL and CV values are different from the Lift - Female equation)

$$MAL = 37.0\left[\text{[redacted]} - \frac{H}{\text{[redacted]}}\right]\left[\text{[redacted]} + \frac{VRM}{\text{[redacted]}} - \frac{VRM^2}{\text{[redacted]}}\right]\left[\text{[redacted]} - \frac{\ln(DV)}{\text{[redacted]}}\right]\left[\text{[redacted]} - \frac{\ln(F)}{\text{[redacted]}} - \frac{\ln(F)^2}{\text{[redacted]}}\right]$$

$CV = 0.307$

Push & Pull Input Variables



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Push & Pull: Female Equations

The Push and Pull equations have the form: $MAL = RL\,[V_{SF}]\,[DH_{SF}]\,[F_{SF}]$

Push or Pull - Initial - Female

$$MAL = 36.9\left[\square + \frac{V}{\square} - \frac{V^2}{\square}\right]\left[\square - \frac{DH}{\square} + \frac{DH^2}{\square}\right]\left[0.7251 - \frac{\ln(F)}{13.19} - \frac{\ln(F)^2}{197.3}\right]$$

$CV = \square$ for Push - Initial - Female, $CV = 0.234$ for Pull - Initial - Female

Push or Pull - Sustained - Female

$$MAL = 25.5\left[\square + \frac{V}{\square} - \frac{V^2}{\square}\right]\left[\square - \frac{DH}{\square} + \frac{DH^2}{\square}\right]\left[\square - \frac{\ln(F)}{\square} - \frac{\ln(F)^2}{\square}\right]$$

$CV = \square$ for Push - Sustained - Female, $CV = 0.298$ for Pull - Sustained - Female

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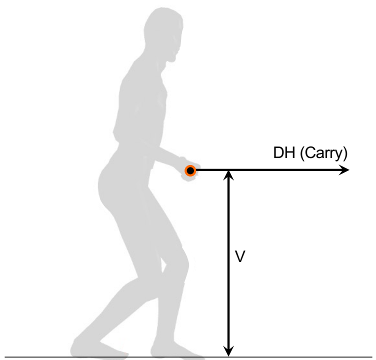
Carry Input Variables Variables



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Carry Equations

The Carry equations have the form: $MAL = RL\,[V_{SF}]\,[DH_{SF}]\,[F_{SF}]$

Carry - Female

$$MAL = 28.6\left[\square - \frac{V}{\square}\right]\left[\square - \frac{DH}{\square}\right]\left[\square - \frac{\ln(F)}{\square}\right]$$

$CV = \square$

Carry - Male

$$MAL = 74.9\left[\square - \frac{V}{\square}\right]\left[\square - \frac{\ln(DH)}{\square}\right]\left[\square - \frac{\ln(F)}{\square} - \frac{\ln(F)^2}{\square}\right]$$

$CV = \square$

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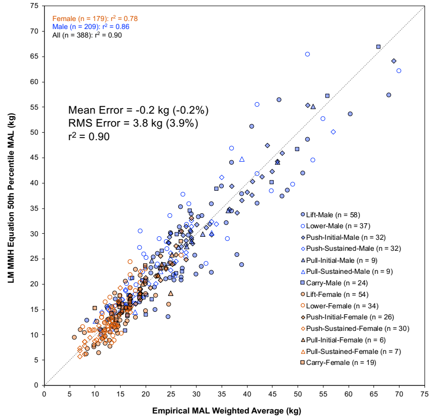
Equations Versus Empirical Data



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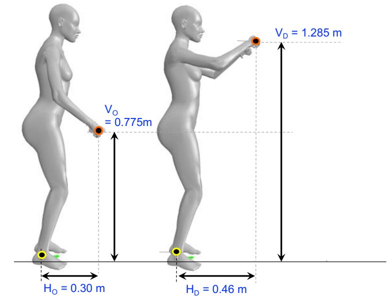
Example: Female Lift

- Frequency:
  - **F = 1.0/min**
- Heights
  - origin **V = 0.775 m**
  - destination **V = 1.285 m**
- Horizontal reach
  - **origin H = 0.30 m**
  - **destination H = 0.46 m**
- The total vertical displacement would be [1.0] [0.51] = 0.51 m/min.



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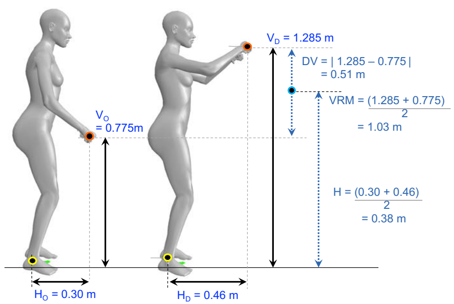
Example: Female Lift

- Frequency:
  - **F = 6.0/min**
- Heights
  - origin **V = 0.775 m**
  - destination **V = 1.285 m**
    - DV = 1.285 - 0.775 = 0.51 m
    - Vertical Range Middle (VRM) = [1.285 + 0.775] / 2 = 1.03 m
- Horizontal reach
  - **origin H = 0.30 m**
  - **destination H = 0.46 m**
    - H = [0.30 + 0.46] / 2 = 0.38 m
- The total vertical displacement would be [1.0] [0.51] = 0.51 m/min.



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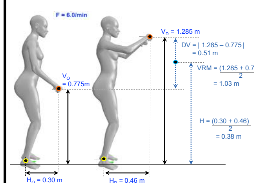
App Modules: Lift & Lower



	Inputs	
H	0.380	m
V_{TOP}	1.285	m
V_{BOTTOM}	0.775	m
F	6	/min
Actual Load	10.00	kg
%Capable	0.75	
VRM	1.030	m
DV	0.510	m
DV/min	3.06	m/min

	Lift	Lower
MAL (at 75% capable)	9.9 kg	10.1 kg
%Capable (of Actual Load)	73.6%	75.4%

Scale Factors (SF)		Lift	Lower
	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
	$\%Cap_{SF}$	0.825	0.793
	$Total_{SF}$	0.283	0.272

Potvin[1,2], Ciriello[1], Snook[1], Maynard[1], Brogmus[1] (2021)
[1]Liberty Mutual Insurance, [2]Potvin Biomechanics Inc.

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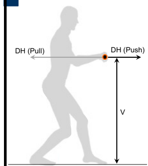
App Modules: Push & Pull



Inputs		
V	1.00	m
DH	5.00	m
F	6	/min
Initial Load	17.0	kg
Sustained Load	8.70	kg
%Capable	0.75	
DH/min	30.00	m/min

		Push		Pull	
		Initiate	Sustain	Initiate	Sustain
MAL (at 75% capable)		17.38 kg	8.73 kg	17.11 kg	8.64 kg
%Capable (of Actual Load)		77.7%	75.3%	75.7%	74.4%
	RL	36.9 kg	25.5 kg	36.9 kg	25.5 kg
Scale Factors (SF)	V_{SF}	0.999	0.999	0.999	0.999
	DH_{SF}	0.962	0.948	0.962	0.948
	F_{SF}	0.573	0.448	0.573	0.448
	Net_{SF}	0.550	0.424	0.550	0.424
	$\%Cap_{SF}$	0.856	0.807	0.842	0.799
	$Total_{SF}$	0.471	0.342	0.464	0.339

Potvin[1,2], Ciriello[1], Snook[1], Maynard[1], Brogmus[1] (2021)
[1]Liberty Mutual Insurance, [2]Potvin Biomechanics Inc.

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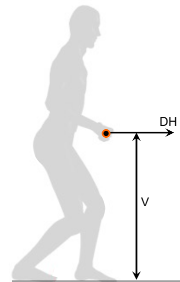
App Modules: Carry



Inputs		
V	0.770	m
DH	4.300	m
F	1.2	/min
Actual Load	15.0	kg
%Capable	0.75	
DH/min	5.16	m/min

		Initiate
MAL (at 75% capable)		14.5 kg
Capable (of Actual Load)		70.5%
	RL	28.6 kg
Scale Factors (SF)	V_{SF}	0.991
	DH_{SF}	0.989
	F_{SF}	0.611
	Net_{SF}	0.599
	$\%Cap_{SF}$	0.845
	$Total_{SF}$	0.506

Potvin[1,2], Ciriello[1], Snook[1], Maynard[1], Brogmus[1] (2021)
[1]Liberty Mutual Insurance, [2]Potvin Biomechanics Inc.

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Evaluation of the Accuracy of 3DSSPP to Estimate Manual Arm Strength

Andrew D. Hall, Nicholas J. La Delfa, Chris Loma, Jim R. Potvin

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A Comparison Between Measured Female Linear Arm Strengths and Estimates from the 3D Static Strength Prediction Program (3DSSPP)

Andrew D. Hall[1], Nicholas J. La Delfa[2], Chris Loma[3], Jim R. Potvin[1]*,
[1]Department of Kinesiology, McMaster University, Hamilton, ON
[2]Faculty of Health Sciences, Ontario Tech University, Oshawa, ON
[3]Advanced Ergonomics Studies Program, Fanshawe College, London, ON

in review: Applied Ergonomics

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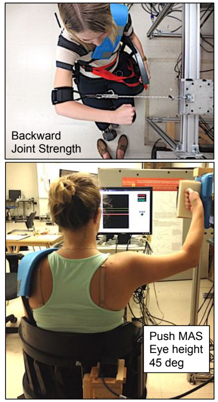
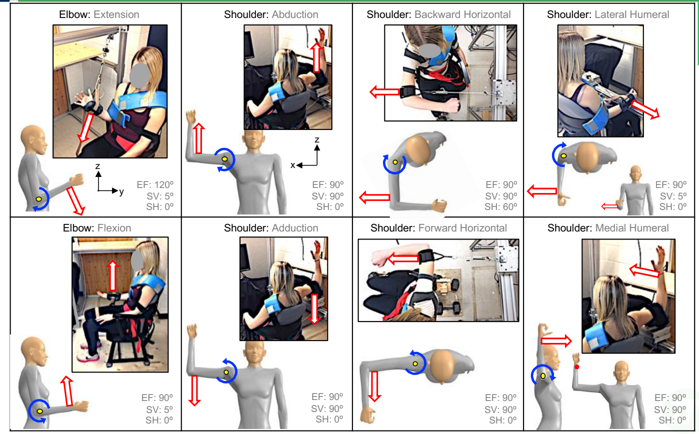
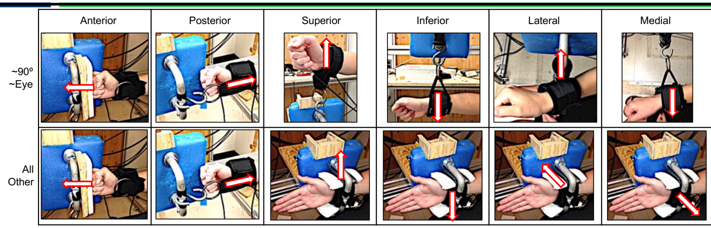
Data Collection

- 15 university age females
- 2 data collections
  - JAS: joint axis strengths
    - 8 axes, replicate Stobbe (1982)
  - MAS: right manual arm strength
    - 4 hand locations
      - 80% reach distance
      - heights: eye & umbilicus
      - rotations: 0 & 45/60 deg
- 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

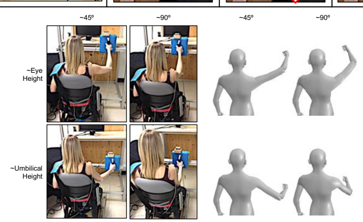


Joint Axis Strength



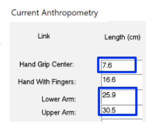


Manual Arm Strength

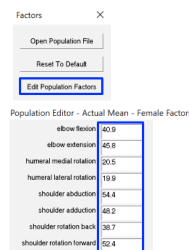


Data Analysis

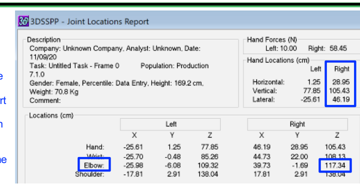
(1) enter subject mass and edit segment lengths



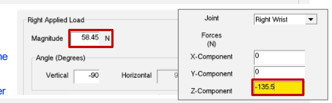
(2) modify arm strength values

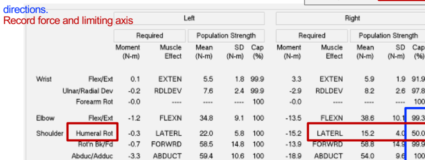


(3) move the right hand to the H, V & L location, wrt shoulder, recorded in the trials.
Move the elbow to the vertical location



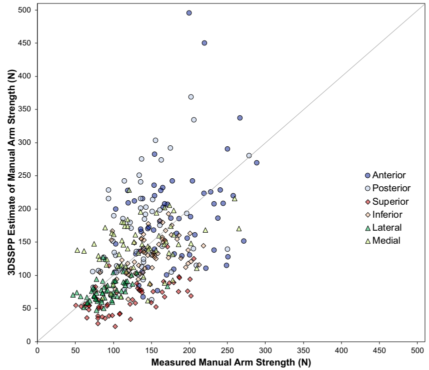
(4) Find the force, in the condition's direction, that results in 50% capable for the elbow or shoulder axes.
Applied at the knuckle for anterior and wrist for all other directions.
Record force and limiting axis





		Left					Right				
		Required		Population Strength			Required		Population Strength		
		Moment (N-m)	Muscle Effect	Mean (N-m)	SD (N-m)	Cap (%)	Moment (N-m)	Muscle Effect	Mean (N-m)	SD (N-m)	Cap (%)
Wrist	Flex/Ext	0.1	EXTEN	5.5	1.8	99.9	3.3	EXTEN	5.9	1.9	91.9
	Ulnar/Radial Dev	-0.2	RDLDEV	7.6	2.4	99.9	-2.9	RDLDEV	8.2	2.6	97.8
	Forearm Rot	-0.0	----	----	----	100	-0.0	----	----	----	100
Elbow	Flex/Ext	-1.2	FLEXN	34.8	9.1	100	-13.5	FLEXN	38.6	10.1	99.3
Shoulder	Humeral Rot	-0.3	LATERL	22.0	5.8	100	-15.2	LATERL	15.2	4.0	50.0
	Rot'n Bk/Fd	-0.7	FORWRD	58.5	14.8	100	-13.9	FORWRD	58.8	14.9	99.9
	Abduc/Adduc	-3.3	ABDUCT	59.4	10.6	100	-18.9	ABDUCT	54.0	9.6	100

Measured vs 3DSSPP Manual Arm Strength



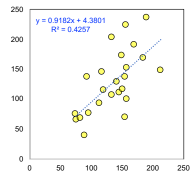
Average Error = **-6.7 N** (-1.5 lbs) & **-2.5%**

RMS Error = **56.0 N** (12.6 lbs) & **40.4%**

Overall explained variance = **29.2%**

The explained variance within participants, across the 24 conditions, ranged from 10.4% to 54.1%

Even when using the means pooled across the 15 participants for each of the 24 conditions, the RMS error = 39.5 N & 28.6%, and the explained variance is only 42.6%



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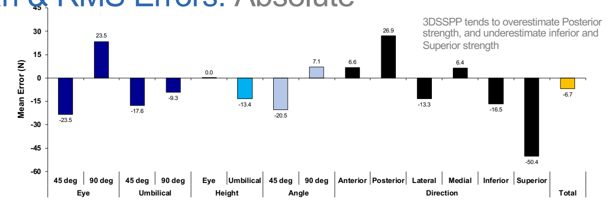
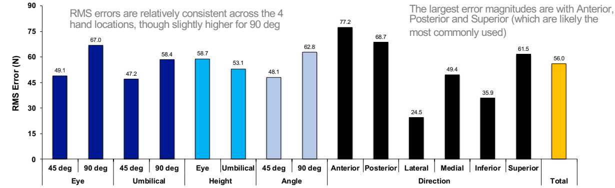
Mean & RMS Errors: Absolute



3DSSPP tends to overestimate Posterior strength, and underestimate inferior and Superior strength

RMS errors are relatively consistent across the 4 hand locations, though slightly higher for 90 deg

The largest error magnitudes are with Anterior, Posterior and Superior (which are likely the most commonly used)



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The Arm Force Field (AFF) Method to Predict Manual Arm Strength

Nick La Delfa & Jim Potvin

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

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Dr. Nick La Delfa
Assistant Professor
Ontario Tech

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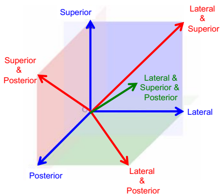
Manual Arm Strength Studies

- 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



6: 1D axes
12: 2D planes
8: 3D quadrants
26 directions

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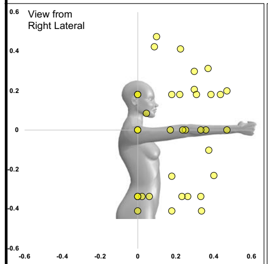
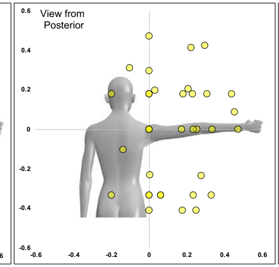
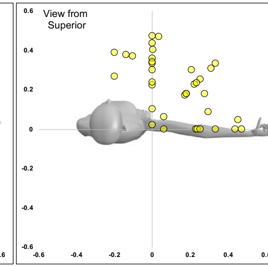
Hand Locations







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Results: Manual Arm Strength

La Delfa & Potvin (2017)

Study*	Hand Coordinates (m) S/I	A/P	L/M	Directions, 1 Axis: 1 Sup	2 Inf	3 Ant	4 Post	5 Med	6 Lat	2 Axes: 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	3 Axes: 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
C	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	78.2	86.9	**82.5**	129.4	126.4	81.7	**77.1**	106.6	80.4	172.3	135.4	102.4
B	0.425	0.086	0.296	126.1	150.3	56	53.8	84.7	65.9	84.9	**57.4**	75	105.8	78.7	84.9	140.5	61.6	**70.8**	57.7	68.2	51.5	84.7	129.7	62	69.9	102.8	59.2	116.8	**72.7**	83.5
B	0.414	0.226	0.222	131.4	**178.2**	69.2	74.8	84.9	62.8	**135.9**	63.2	86	87	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
B	0.312	0.371	-0.102	83.6	161.6	143.4	**128.3**	85	80.2	166.7	71	**96.3**	65.1	89.9	217	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	185.9	110.0
C	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	**159.9**	103.1
C	0.207	0.300	0.207	90.8	98.1	74.4	94.8	86	66.6	128	74	**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	72.2	80.8	**75.6**	180.8	106.3	96.7
B	0.198	0.470	0.033	84.3	123.4	166.4	177	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	73.6	99	78.9	161	**129.9**	107.8
A	0.180	0.436	0.000	83.2	108.4	115.5	122.3	65.7	59.4																					92.4
A	0.180	0.388	-0.200	85.5	112.9	97.7	119.9	**65.5**	68.7																					91.7
A	0.180	0.308	0.308	86.5	104.1	**70.2**	86.4	78	57.9																					80.5
A	0.180	0.222	0.000	101.1	147.9	74.9	**110.8**	81.7	77.2																					98.9
A	0.180	0.180	0.180	**100.6**	134.5	72.3	88.6	86.2	58.2																					90.1
A	0.180	0.000	0.436	**99.4**	103.5	59	59.8	111.1	89.7																					87.1
A	0.180	0.000	0.229	**103.9**	137.8	69.3	70.9	96.4	56.3																					89.1
B	0.087	0.046	0.454	90.7	85.3	62.9	44.9	197.7	170.3	82.4	**66**	98	111.3	61.1	63.1	**148.9**	80.4	87.2	91.7	87.3	60	**98.2**	106.2	87	82.5	102.8	79	**112.5**	69.8	93.4
A	0.000	0.472	0.000	79.9	84.7	136.6	148.3	74.3	**59.5**																					97.2
C	0.000	0.360	0.000	93.8	106.4	128.5	163.9	90.2	72.1	**126**	108.9	103.9	72.6	86.4	168.4	98.8	93	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
A	0.000	0.334	0.334	**79.1**	79.9	88	92.7	95.2	66.2																					83.5
C	0.000	0.253	0.253	86.8	91.4	86.4	96.8	110.1	77.2	118.3	**94**	98.5	93.8	75.1	117.9	123.6	78.4	91.5	**111.3**	137.2	74	106	133.1	119.3	78	90	93.3	**172.6**	97.4	102.0
A	0.000	0.237	0.000	118.5	120	105.5	116.1	103.1	81.1																					107.4
A	0.000	0.172	0.172	111.6	106.7	**94.8**	91.9	95.8	68.3																					94.9
A	0.000	0.000	0.472	72.3	64.3	**52.9**	51.3	133.4	99.3																					78.9
A	0.000	0.000	0.236	105.6	98.8	77.3	**76.2**	103.3	70.1																					88.6
B	-0.102	0.377	-0.138	111.7	103.6	183.9	223.3	107.2	**73**	115.5	144.9	103.5	79.4	128.8	**125.2**	86.5	90	152.6	69.1	98	142.7	139.6	64.8	**132.2**	144.3	154.1	89.2	86.5	146.3	119.1
B	-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	132.3	136	**114**	91.3	91.9	111.7
B	-0.234	0.179	0.277	115.6	106.7	105.5	66.2	**127.4**	96	98.6	85.1	133	**78**	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**	144.6	89.3	74	101.3
A	-0.335	0.333	0.000	**111**	89.4	120.8	121.8	74.3	57.8																					95.9
A	-0.335	0.266	-0.200	106.4	87.2	100.7	96.6	**77.1**	60.3																					88.1
A	-0.335	0.235	0.235	**98.2**	79.9	82.7	85.3	86.9	64.4																					82.9
A	-0.335	0.061	0.061	106.7	89.4	**78**	88.6	81.7	49.9																					82.4
A	-0.335	0.021	0.000	113.4	87.1	88.7	109.8	72.3	55.7																					87.8
A	-0.335	0.000	0.333	82.7	74.1	56.6	54.9	110.5	87.5																					77.7
A	-0.335	0.000	0.062	**112.9**	86.6	77.1	65.3	90.8	59.7																					82.1
C	-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	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
C	-0.411	0.178	0.179	116.7	94.4	83.5	98.5	93	**75**	93.8	127.8	123.7	**86.2**	84	82.7	83.6	90.1	84.1	92	116.8	**65.8**	120.5	106.1	161.7	98.1	98.8	**116.5**	107	**84.5**	99.4
C	-0.411	0.000	0.251	96.4	90.3	61	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
Mean				100.9	107	93	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	113	89.1	101.1	92.9	131.7	109.5	99.1

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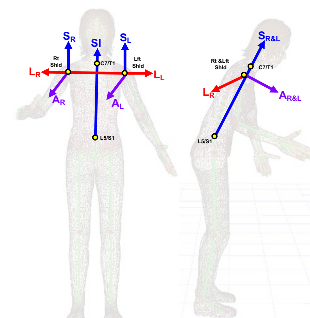
The Arm Force Field: Predicting MAS

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



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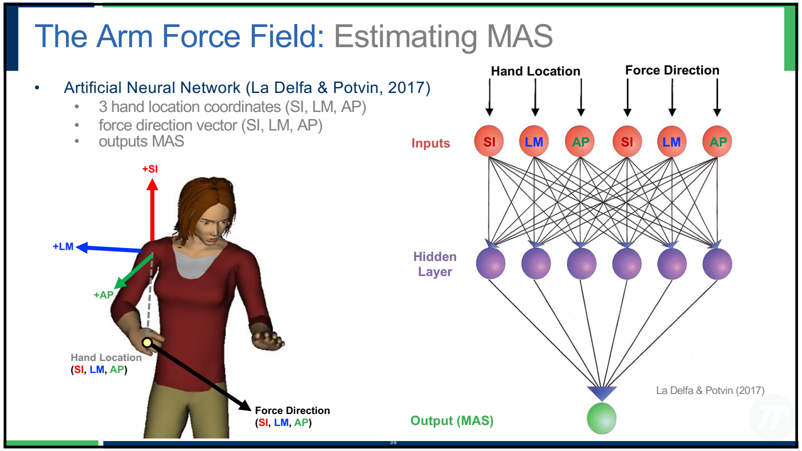
The Arm Force Field: Estimating MAS
Artificial Neural Network (La Delfa & Potvin, 2017)
3 hand location coordinates (SI, LM, AP)
force direction vector (SI, LM, AP)
outputs MAS
Hand Location
Force Direction
Inputs
SI
LM
AP
SI
LM
AP
Hidden Layer
Output (MAS)
La Delfa & Potvin (2017)
+SI
+LM
+AP
Hand Location
(SI, LM, AP)
Force Direction
(SI, LM, AP)

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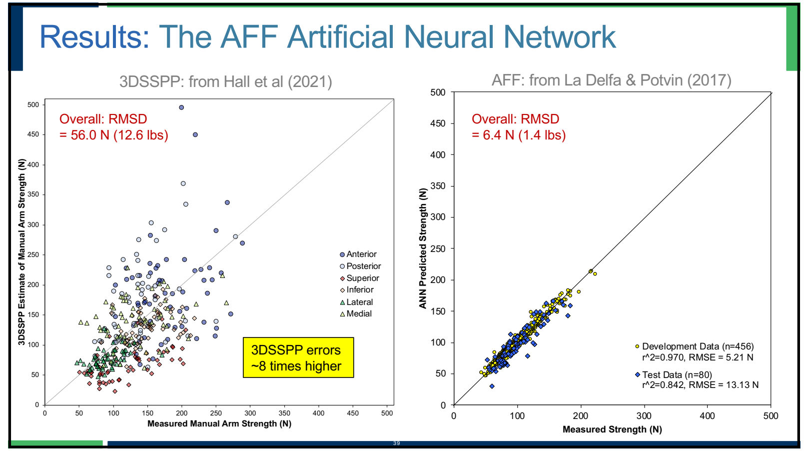
Results: The AFF Artificial Neural Network
3DSSPP: from Hall et al (2021)
Overall: RMSD
= 56.0 N (12.6 lbs)
3DSSPP Estimate of Manual Arm Strength (N)
Measured Manual Arm Strength (N)
Anterior
Posterior
Superior
Inferior
Lateral
Medial
3DSSPP errors
~8 times higher
AFF: from La Delfa & Potvin (2017)
Overall: RMSD
= 6.4 N (1.4 lbs)
ANN Predicted Strength (N)
Measured Strength (N)
Development Data (n=456)
r^2=0.970, RMSE = 5.21 N
Test Data (n=80)
r^2=0.842, RMSE = 13.13 N

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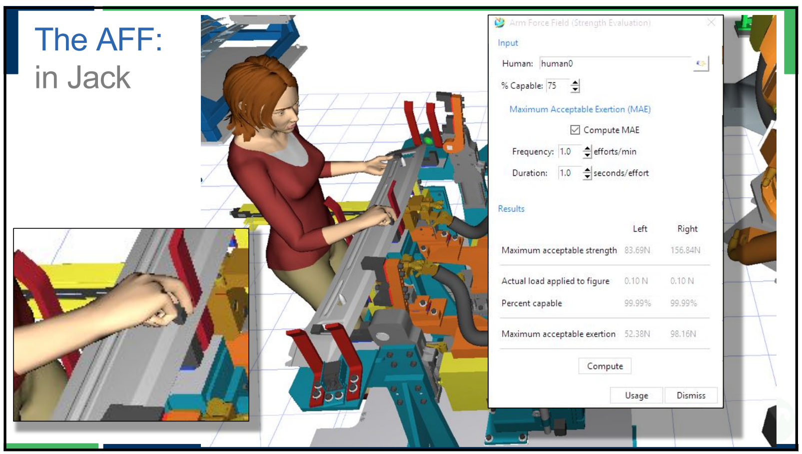
The AFF:
in Jack
Arm Force Field (Strength Evaluation)
Input
Human: human0
% Capable: 75
Maximum Acceptable Exertion (MAE)
Compute MAE
Frequency: 1.0 efforts/min
Duration: 1.0 seconds/effort
Results
Left
Right
Maximum acceptable strength 83.69N 156.84N
Actual load applied to figure 0.10 N 0.10 N
Percent capable 99.99% 99.99%
Maximum acceptable exertion 52.38N 98.16N
Compute
Usage
Dismiss

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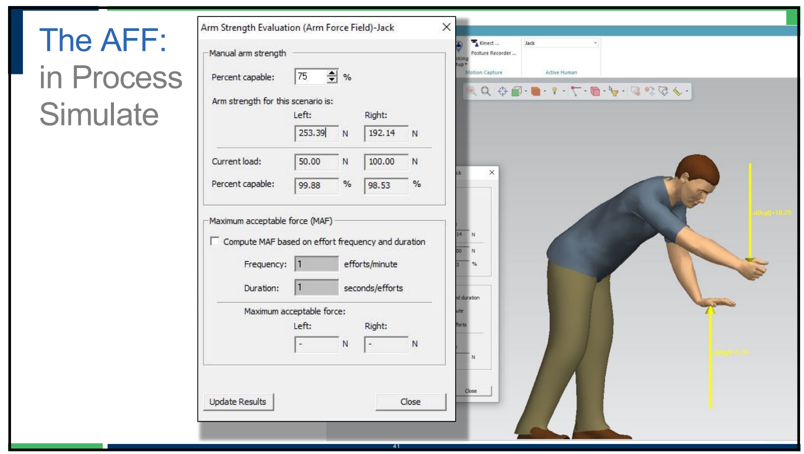
The AFF:
in Process
Simulate
Arm Strength Evaluation (Arm Force Field)-Jack
Manual arm strength
Percent capable: 75 %
Arm strength for this scenario is:
Left:
Right:
253.39 N
192.14 N
Current load: 50.00 N 100.00 N
Percent capable: 99.88 % 98.53 %
Maximum acceptable force (MAF)
Compute MAF based on effort frequency and duration
Frequency: 1 efforts/minute
Duration: 1 seconds/efforts
Maximum acceptable force:
Left:
Right:
Update Results
Close

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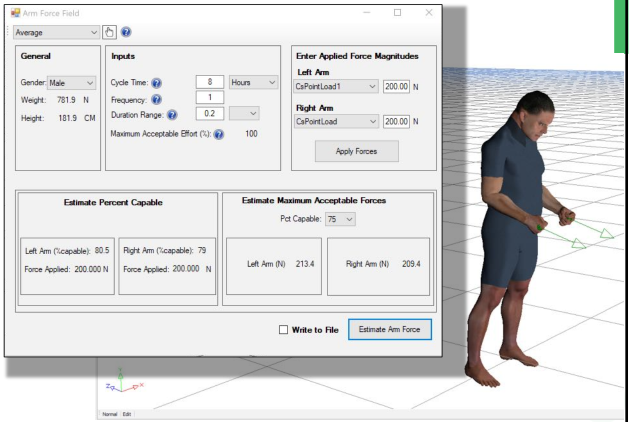
The AFF: in Santos



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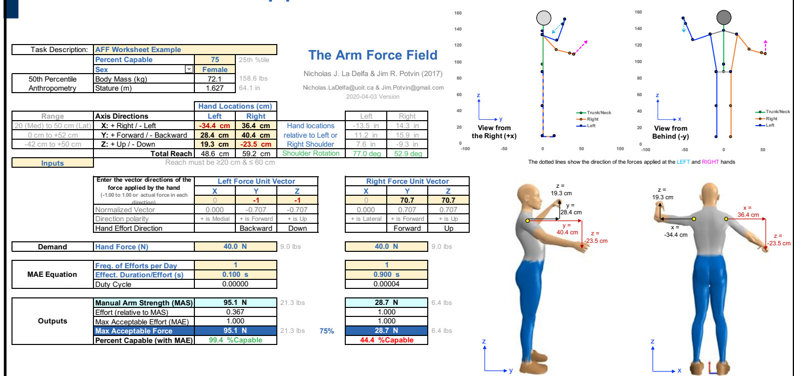
The AFF Excel App



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Ergonomics Assessment Tool for Above-Shoulder Work

David Rempel, Jim R. Potvin

Work in Progress

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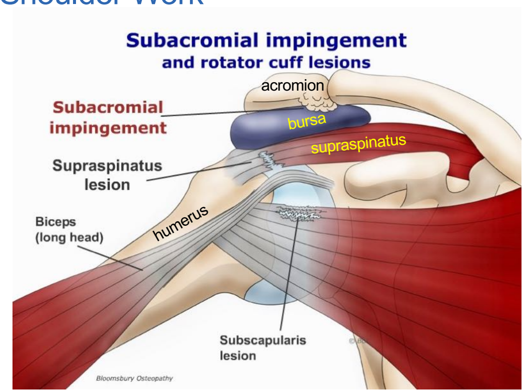
Above-Shoulder Work



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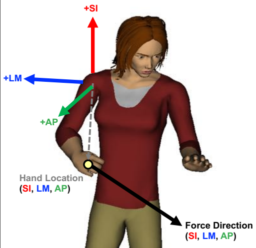
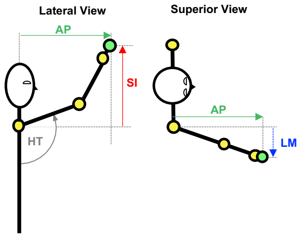
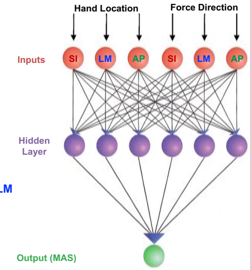
Above Shoulder Tool: Manual Arm Strength

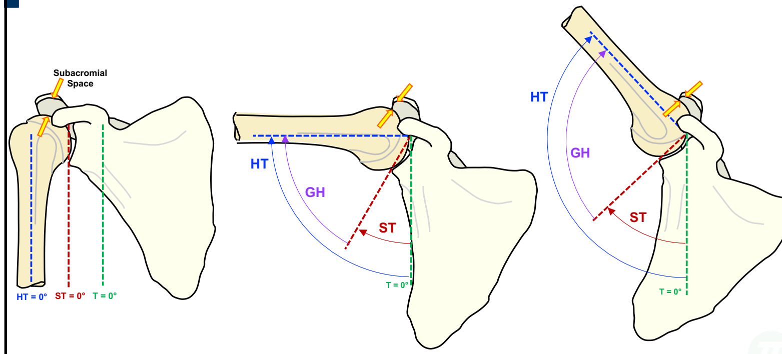
- Artificial Neural Network (ANN)
  - 3 hand location coordinates (SI, LM, AP)
  - force direction vector (SI, LM, AP)
    - Superior & Anterior
  - 25th percentile MAS





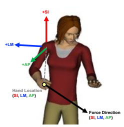


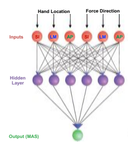
Above-Shoulder Tool: Shoulder Rhythm

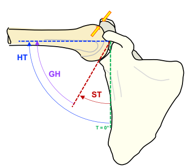


Above-Shoulder Assessment Tool

- Manual Arm Strength
  - The Arm Force Field
    - Superior (Up)
    - Anterior (Forward)
    - 25th percentile
- Estimate Glenohumeral Rotation from total shoulder rotation (HT)
- Estimate Sub-acromial impingement force
- Establish Sub-acromial impingement force scale factor







Summary

- The Liberty Mutual Manual Materials Handling (LM-MMH) Equations
  - available soon!
- Evaluation of the Validity of DHM Software for Estimating Manual Arm Strength
  - serious concerns
- The Arm Force Field for Estimating Manual Arm Strength
  - accurate alternative
- A New Tool to Assess Above-Shoulder Work
  - a work in progress

Thank You!

Jim.Potvin@gmail.com

Link to Cloud Folder of Potvin Ergonomics Tools:
https://bit.ly/3pYRJwn