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RESEARCH MEETING PRACTICE TO
PREVENT
MUSCULOSKELETAL DISORDERS

CRE-MSD
Centre of Research Expertise for the Prevention of Musculoskeletal Disorders

Exoskeletons: Reimagining Safety at Work – Working Smarter, Not Harder

A CRE-MSD Webinar

Seth Burt, Toyota Motor Manufacturing Canada (TMMC)

Clark Dickerson, University of Waterloo (UW)

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Agenda

- Introduction
- Gap Analysis – Why Exoskeletons?
- TMMC Exoskeleton History Recap
- Plan: Creating an Exoskeleton Standard/System
- Do: Detailed Implementation Plan
- Check: Measuring Exoskeleton Use
- Act: Results/Analysis
- UW Shoulder-Exoskeleton Evaluation
- Next Steps/Future Collaborations

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Introduction

Seth Burt

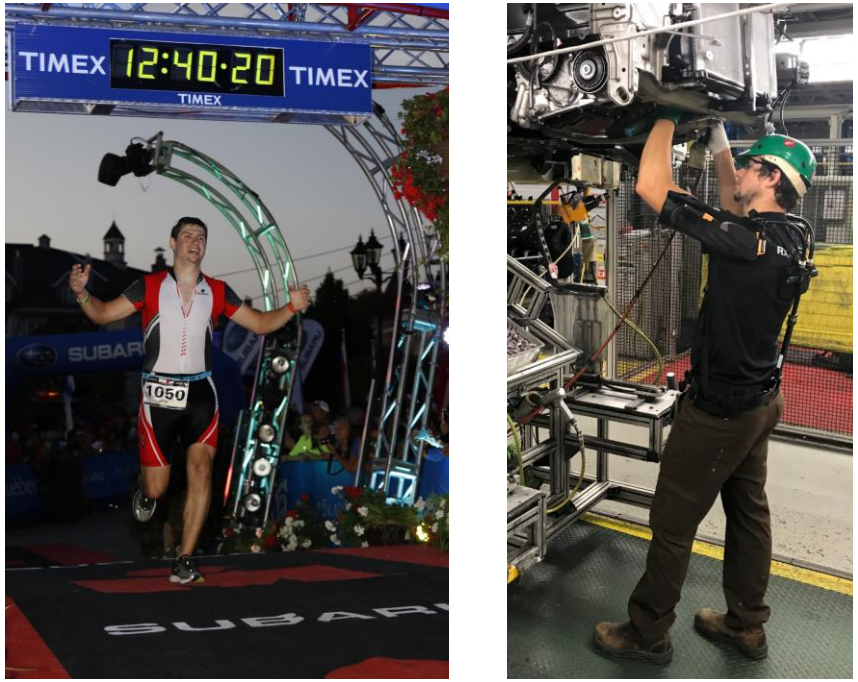
- Health and Safety Specialist, TMMC
- Bachelors in Kinesiology with a Specialization in Ergonomics at the University of Waterloo
- Canadian Certified Professional Ergonomist (CCPE)

Toyota Motor Manufacturing Canada (TMMC)

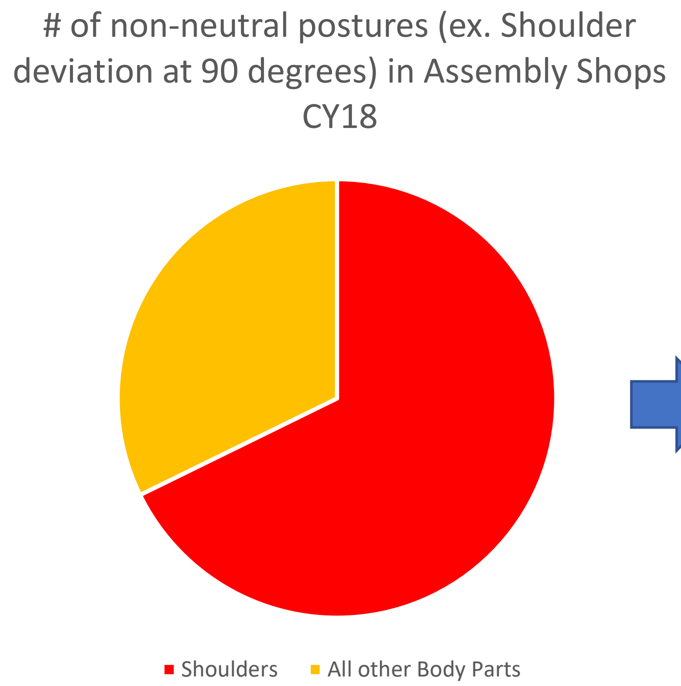
- Vehicle Assembly: Toyota Rav4, Lexus RX, Lexus NX (CS)
- 3 Plants at 2 Locations (Cambridge and Woodstock, Ontario, Canada)
- +10,000 Team Members (Employees)

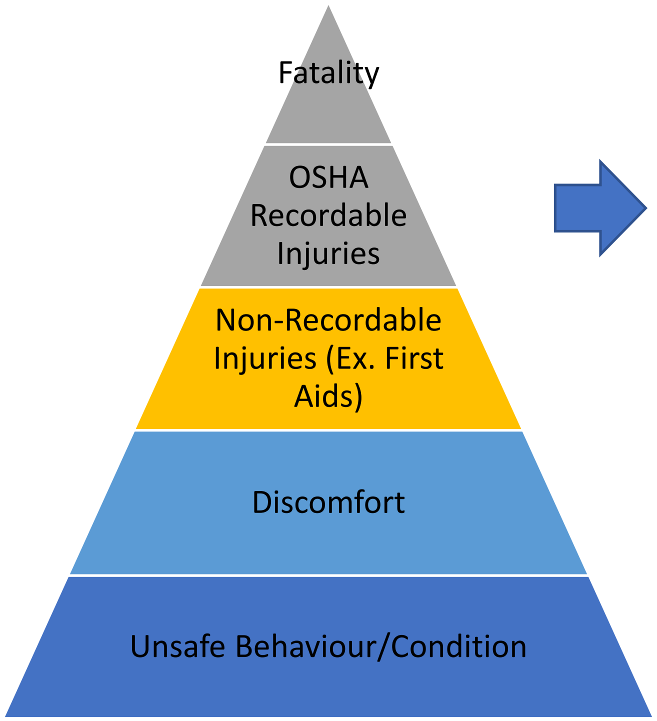
2014 – From Ironman

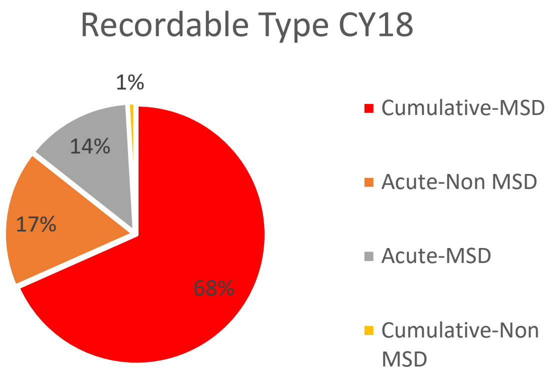
2018 – To Ironman

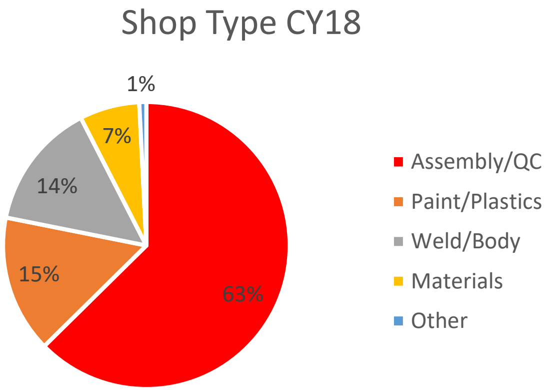


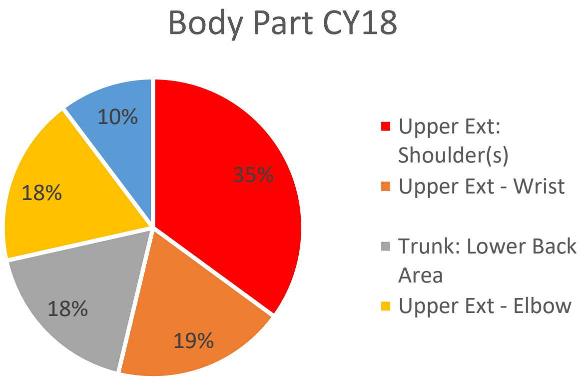
Gap Analysis – Heinrich's Accident Triangle











Top Site Wide Need:

Cumulative MSD of the Shoulder in Assembly

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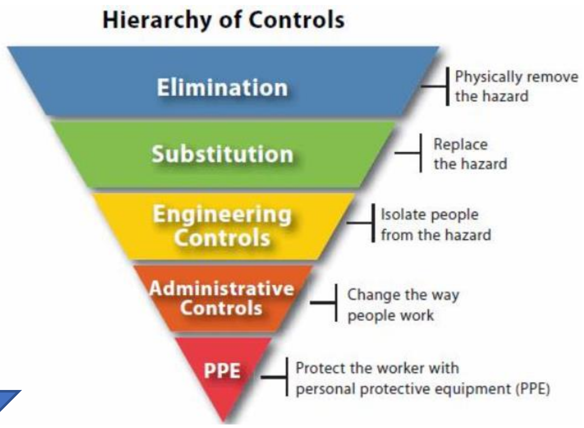
Gap Analysis – Hierarchy of Controls

	North 320B			Current South			West 320B			Overall Totals			
Complex Items	Trim	Chassis	Final	Trim	Chassis	Final	Trim	Chassis	Final	TMMC	All Trim	All Chassis	All Final
Vertical Outer Vehicle Reaching	213	82	153	91	45	63	6	8	232	893	310	135	448
Overhead Work	67	169	2	141	126	0	75	159	58	797	283	454	60
Engine Compartment Reaching	0	143	100	0	196	70	0	0	62	571	0	339	232
Centre Vehicle Reaching	34	21	154	76	70	57	19	6	78	515	129	97	289
Inner Panels & Dash	131	0	65	31	26	17	98	0	33	401	260	26	115
Under IP	132	32	48	8	21	29	46	48	12	376	186	101	89
Inner Hatch	52	0	66	12	17	51	43	0	119	360	107	17	236
Sub-line/Skillet	20	4	29	128	81	0	29	58	0	349	177	143	29
Tooling	31	29	41				32	22	37	192	63	51	78
Inner Luggage Area	43	2	34	9	28	0	62	0	4	182	114	30	38
Other (no specific category)	252	170	383	201	209	168	0	0	0	1383	453	379	551

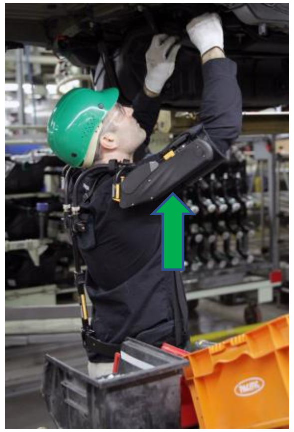


RISK MANAGEMENT OF OVERHEAD WORK ON CHASSIS 1 CONVEYOR

For the purpose of this evaluation, each control method was considered independently. Please note that a combination of control methods could also be considered and evaluated accordingly.

Desription of Control Method	Safety	Quality	Productivity	Implementation Time	Cost	Overall Evaluation	Score	Estimated Costs/Comments
ELIMINATE TASKS (Engineering Controls) - Automated machinery - Robotics	O	O	Δ	X	X	**X**	**5**	- Automated machinery: 350,000 - $650,000 - Collaborative robots: $300,000 - $450,000
ELIMINATE RISKS (Engineering Controls) - Rotating carrier with height adjustable platforms	O	O	O	X	X	**X**	**6**	- Rotating carriers (+/- 90 degrees): $70-80 million - Height adjustable platform (+/- 30cm): $35,000 - $100,000
REDUCE RISKS (Engineering Controls) - Height adjustable platforms - Hoists/lifts - Assist arms/tool balancers - Alternative tooling	Δ	Δ	Δ	Δ	Δ	Δ	**5**	- Height adjustable platform (+/- 30cm): $35,000 - $100,000 - Assist arms/tool balancers: $2,500 - $10,000 - Hoists/lifts to handle/position parts: $35,000 - $250,000 - Alternative tooling: $2,000 - $10,000 (If electric $30,000+)
MITIGATE RISKS (Administrative Controls) - Re-balance elements	X	-	-	-	-	-	-	- Moving elements into alternative processes could impact cumulative exposure within the process, but does not eliminate the risk factor
MITIGATE RISKS (PPE) - Exoskeleton	Δ	O	O	Δ	Δ	**O**	**8**	- Supporting the upper extremity in non-neutral shoulder postures may reduce muscular effort to perform tasks, but does not eliminate the risk factor
REDUCE EXPOSURE (Administrative Controls) - Job rotation	X	-	-	-	-	-	-	- Job rotation could impact cumulative exposure over the shift, but does not eliminate the risk associated with each process

Trial Upper Body Exoskeletons



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TMMC Exoskeleton Roadmap

2017-2020

3 Years Plan

2017

Q1 – Exoskeleton Introduction

Introduced to Esko-Bionics, Chairless Chair, and Levitate

Q2 – Initial Testing

Trialed 1 of each Exo in varies locations

Q3 – Mass 24 Levitate Exo Trial Prep

Developed mass trial based on scientific research and initial TM surveys

Q4 – Mass 24 Exo "Assembly" Trial

Conducted continuous surveys, strength testing, EMG (muscle activity) 3rd party scientific study

2018

Q1 – Trial Data Review

Compiled data and developed learning points for Kaizen

Q2 – Standard Development

Initialized TMNA Exo WG and Std and trialed TM product comfort feedback

Q3 – UPEST Development

Development of Exo Screening through external EMG study

Q4 – Mgt Sys Development + 24 Exo "Weld" Implementation

Developed production and safety management systems around Exo Use (Training, Storage, Communication) and wW QC process implementation

THE WALL STREET JOURNAL.

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THE FUTURE OF EVERYTHING

Industrial Exoskeletons Give Workers a Lift

Ford, Boeing, Toyota and others are equipping workers with wearable devices that enhance strength and endurance. "Iron Man"-style powered suits could be next

By Leigh Kamping-Carder

Jan. 17, 2019 8:00 am ET

SHARE TEXT 40

In the weld shop of Toyota Motor North America's 1.8-million-square-foot plant in Woodstock, Ontario, amid the clanking of robotic arms and the occasional spray of sparks, two workers inspect the steel frame of a future RAV4.

2019

Q1 – 72 Exo "Assembly" Implementation + 24 Exo "Weld" Implementation

WG meetings, PFS, Training, Medical screens, surveys, fit support teams for nA and nW

Q2 – 72 Exo "Assembly" review + New Exo "Assembly" Trials

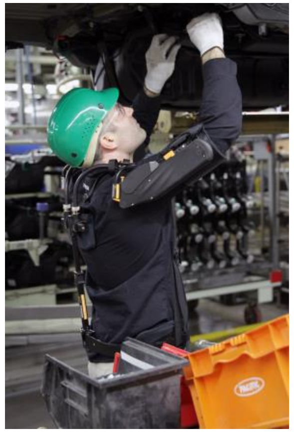
Reviewed 2 months of North Assembly Exo Use + Start Ottobock trial in South Assembly

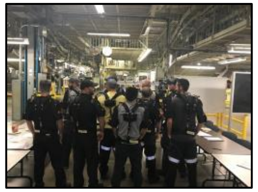
Q3 – "Assembly" Energy Expenditure Trials

Objectively review Exo using new tech provided by GoX and review Chassis 2

Q4 – New "Assembly" process and Exo Trials

Trial Chassis 2 changes and West Assembly SuitX





2020

Exo Comparison Study + University of Waterloo Study Protocol Development

UNIVERSITY OF WATERLOO

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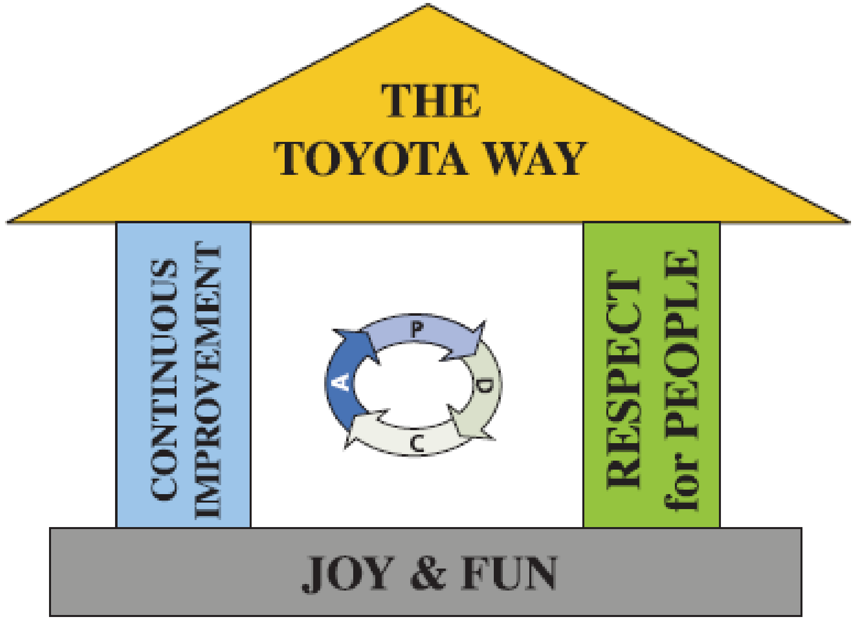
The Toyota Way = PDCA

The Toyota Way, supported by the two main pillars of **“Continuous Improvement” (Kaizen)** and **“Respect for People”**, defines Toyota’s mission as a corporation, as well as the values the company delivers to customers, shareholders, fellow Team Members, business partners and the global community.



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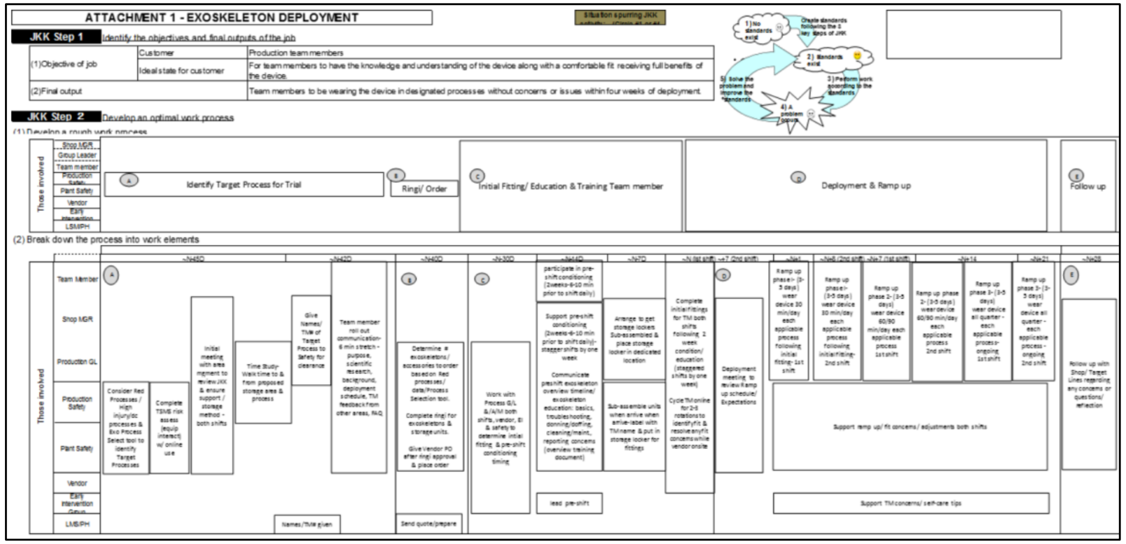
Plan: Establishing a Standard

Toyota North American Standard

- Scope
- Purpose/Philosophy
- Roles and Responsibilities
- Definitions
- Procedures:
  - Exoskeleton Specifications
  - Selection Criteria
  - Training Requirements
  - Storage
  - Medical – Prior to First Use
  - Fit Testing
  - Issuance
  - Post Deployment:
    - Mandatory Usage/Volunteering Usage
    - Medical Screens
    - Inspection and Fit Checks
    - Cleaning and Maintenance
    - Donning and Doffing
    - Cartridge Change-out Schedule
    - Auditing/Recordkeeping
  - Standard Forms
    - Comfort survey, strength testing/medical evaluation form, voluntary use forms, etc.

ERG S 03 Exoskeletons Usage Standard



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Plan: Ergonomic/H&S Management Systems

How does one decide what process/TM needs an Exoskeleton?

1. Process is flagged by selection tool*
2. No other control is feasible in short-term
3. Exoskeleton usage does not pose a safety risk

*Mathematical calculation based on % cycle with overhead work postures

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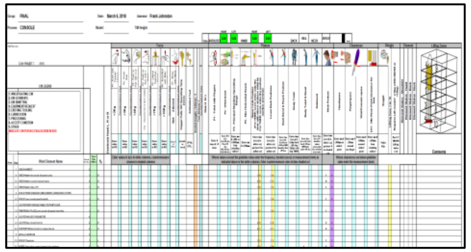
Plan: Ergonomic/H&S Management Systems

How does one decide what process/TM needs an Exoskeleton?

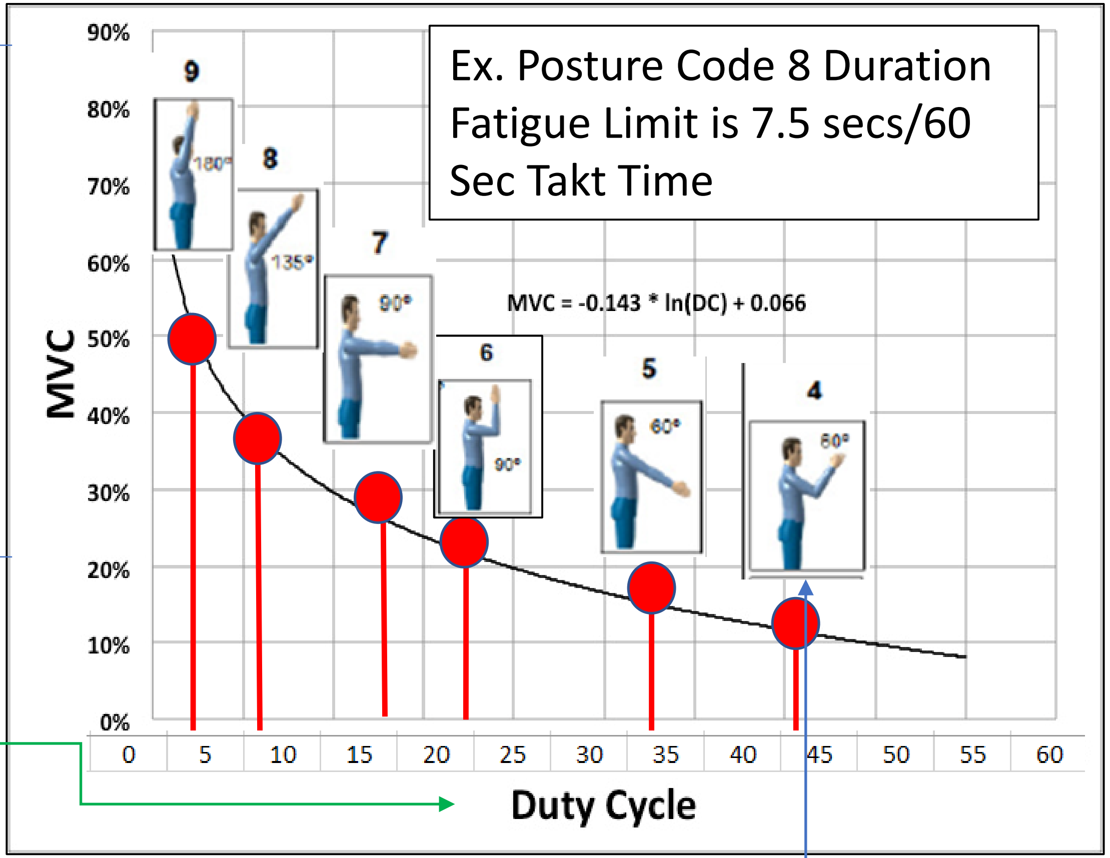
- **Risk Assessment Methodology**



TEBA Information on Takt Time, Duration, and Posture Codes

ACGIH - Upper Limb Localized Fatigue TLV

Upper Limb Localized Fatigue ACGIH® © 2016



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Plan: Ergonomic/H&S Management Systems

How does one decide what process/TM <u>needs</u> an Exoskeleton?

- Risk Assessment Methodology
- **Complete Risk Assessment (UPEST)**

Upperbody Postural Exoskeleton Screening Tool (UPEST)

North Assembly Chassis 1 320B

Takt Time (s) = 69

*If a process exceeds threshold, Exoskeleton use is prompted

			# OF RED RISKS								DURATION SPENT IN RED RISK POSTURES										
			Right Side				Left Side				Right Side				Left Side						
Shop	Line	Process	6	7	8	9	6	7	8	9	6	7	8	9	6	7	8	9	Total Right Shoulder Duration	Total Left Shoulder Duration	Exceeds One or More Threshold
North Assembly	Chassis 1 Group 1	FLOORTUBES	19	0	11	0	18	0	13	0	38	0	22	0	35	0	26	0	60	61	YES
North Assembly	Chassis 1 Group 1	BREATHER HOSE	21	0	5	0	26	0	4	0	35	0	8	0	45	0	8	0	43	53	YES
North Assembly	Chassis 1 Group 1	HV CABLE 2	3	0	7	2	8	0	7	2	6	0	15	3	16	0	13	3	24	32	YES
North Assembly	Chassis 1 Group 1	FUEL TANK INSTALL	2	0	0	0	10	0	0	0	8	0	0	0	24	0	0	0	8	24	YES
North Assembly	Chassis 1 Group 1	FUEL TANK TIGHTEN	25	0	0	0	27	0	5	0	40	0	0	0	62	0	14	0	40	76	YES
North Assembly	Chassis 1 Group 1	INLET PIPE INSTALL	10	0	5	0	8	0	5	0	16	0	12.6	0	14	0	10.6	0	28.6	24.6	YES
North Assembly	Chassis 1 Group 2	GROMMETS	3	0	12	0	4	0	11	0	6	0	26	0	8	0	24	0	32	32	YES
North Assembly	Chassis 1 Group 2	HOLE PLUGS	3	0	11	1	3	0	9	1	10	0	27	1	6	0	21	1	38	28	YES
North Assembly	Chassis 1 Group 2	RH ENGINE INSTALL	2	0	4	0	5	0	4	0	5	0	12	0	10.5	0	12.5	0	17	23	YES
North Assembly	Chassis 1 Group 2	BALL JOINT	2	0	6	1	8	0	5	1	2	0	16	1	16	0	15	1	19	32	YES
North Assembly	Chassis 1 Group 2	SHIFTER CABLE	21	0	7	0	10	0	19	0	53	0	13	0	29	0	38	0	66	67	YES
North Assembly	Chassis 1 Group 2	MOUNT TIGHTEN	10	0	0	0	3	0	8	0	22	0	0	0	9	0	17.6	0	22	26.6	YES
North Assembly	Chassis 1 Group 2	REAR EXHAUST	2	0	11	0	7	0	6	0	5	0	24	0	23	0	12	0	29	35	YES
North Assembly	Chassis 1 Group 2	HEATSHIELD	8	0	0	0	16	0	5	0	16	0	0	0	38	0	11	0	16	49	YES
North Assembly	Chassis 1 Group 2	FRONT EXHAUST	7	0	7	0	6	0	3	0	15.2	0	12	0	12.2	0	5	0	27.2	17.2	YES

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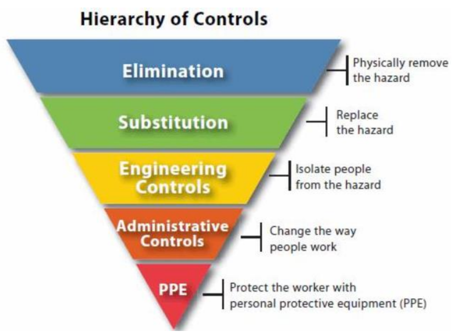
Plan: Ergonomic/H&S Management Systems

How does one decide what process/TM needs an Exoskeleton?

- Risk Assessment Methodology
- Complete Risk Assessment (UPEST)
- **Exhaust all other viable controls**



Shoulder Posture Risks	New Control Method	Proposed Countermeasures	Estimated Cost per Process	Estimated Timeline	Shoulder Posture Risk Impact	Cost/Impact
61	ELIMINATE TASKS (Engineering Controls)	- Robotic arms to pick, locate and install floor tubes into the vehicle - Robot to install grommets	All Robots: $700,000 - $1,300,000	- Approximately 1 year per robot (x2)	61 Eliminated	$11,475 – $21,312 per Risk Eliminated
	ELIMINATE RISKS (Engineering Controls)	- Rotating carriers (+/- 90 degrees): $70-80 million - 300 carriers, carrier structure & drives - Height adjustable platform (+/- 30cm): $35,000 - $100,000	Carriers, carrier structure, drives and height adjustable platforms: $2,801,400 - $3,204,000 **carrier cost divided by 25 processes on Chassis 1 conveyor*	- Carriers: 18 months (based on previous order) - Carrier structure and drives: Plant shutdown - Height adjustable platform: ~1 month	61 Eliminated	$45,925 – $52,525 per Risk Eliminated
	REDUCE RISKS (Engineering Controls)	- Height adjustable platforms - Hoists/lifts - Assist arms/tool balancers - Alternative tooling	Hoists/lifts to handle/position parts: $35,000 - $250,000 Height adjustable platform (+/- 30cm): $35,000 - $100,000	- Approximately 1 year for all equipment	2 Eliminated 2 Mitigated 57 Untouched	$35,000 - $175,000 per Risk Eliminated & Mitigated (with risk still present)
	MITIGATE RISKS (Engineering PPE Controls)	- Exoskeleton	10 Exoskeleton Suits: $40,000	- Approximately 1 month	61 Mitigated (Elimination TBD)	$656 per Risk Mitigated – Muscle activation lowered by 20-35%

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Plan: Ergonomic/H&S Management Systems

How does one decide what process/TM needs an Exoskeleton?

- Risk Assessment Methodology
- Complete Risk Assessment (UPEST)
- Exhaust all other viable controls
- **Complete Safety Risk Assessment**

Exoskeleton Trial - Risk identification and TM consent form

The following are the risks associated with using the exoskeleton equipment and corresponding countermeasures:

Hazard No.	Who (see HI-1)	Hazard - Risk	Evaluation		Countermeasure	Check	
1.6	Operator	Impact, Striking - Contact by spring mechanism	Severity	S1	1) Practical offline levitate training session completed by participating Team Member. TM taught how to remove device.	Severity	S1
			Exposure	F1		Exposure	F1
			Probability	P2		Probability	P1
			Risk Level	**M**		**Result**	**L**
			Medium			**Very Low**	
1.4	Operator	Entanglement	Severity	S1	1) Practical levitate user training session completed by participating Team Member. TM's taught how to quickly remove device.	Severity	S1
			Exposure	F1		Exposure	F1
			Probability	P2		Probability	P1
			Risk Level	**M**		**Result**	**L**
			Medium			**Very Low**	

Name:____________________
TM #:____________________

Supervisor:__________________________

Date:______________

Please sign below to acknowledge you understand the risks associcted with completing this trial:

Signature:__________________________________

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Plan: Shop Specific Management Systems

- How does one know which process are Exoskeleton required?
  - Visualization, EIS (Process Instructions)
- How/where does one store the Exoskeleton suit?
  - Storage requirements
- How does one know if the equipment is functioning properly?
  - Training and TPM
- How can one ensure TM's are wearing the Exoskeletons as required
  - Compliance – auditing
- Where can one review safety concerns with the Exoskeletons
  - Training and EIS – (pictures, key points of movement around pitch and equipment)

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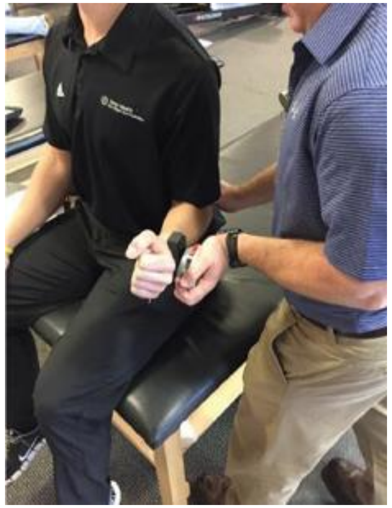
Plan: Addressing TM Concerns

- How does one addressing fit/comfort concerns?
  - Educate TMs on proper fit techniques developed by vendor
  - Measure/fit TMs to ensure proper equipment is purchased
  - Ensure adequate knowledge of fit is enacted when initially fitting the TMs
  - Set up a method to record TM concerns
  - Provide time for TMs to be re-fitted if required
  - Working with vendor to make product improvements

- Will one develop other direct or indirect injury/problems while wearing an Exoskeleton?
  - Medical screening of TMs to predict potential concerns
  - Develop surveillance program that will track TM's well-being
  - Conduct strength evaluations to measure condition of the TM over time while taking part in the program
  - Have a means of medical contact for immediate concerns
  - Conduct Safety assessment for each process to ensure external factors will not harm the TM



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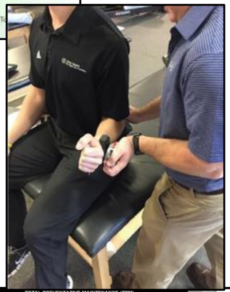
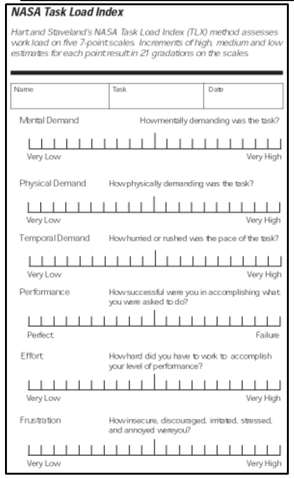
Do: Exoskeleton Implementation Action Items

Exoskeleton Implementation Plan																											
Implementation Activity	Group Responsible		Year																								Status
			Month1				Month2				Month3				Month4				Month5				Month6->				
	Lead	Support	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	
PRE-IMPLEMENTATION																											
Review potential exoskeleton process through UPEST	Health and Safety/Health Service Provider	Users/Management																									
Conduct hierarchy of control (exhaust all controls) review	Users/Management	Health and Safety/Health Service Provider																									
Conduct safety risk assessment per process	Users/Management	Health and Safety/Health Service Provider																									
Screen TMs for any potential medical concerns and add TMs to medical surveillance program	Health and Safety/Health Service Provider	Users/Management																									
Pre-Exoskeleton fit test for purchasing/Purchase Exoskeletons	Health and Safety/Health Service Provider	Users/Management																									
Conduct time study walk time to and from process to storage units and create storage lockers for TM suits	Users/Management	Health and Safety/Health Service Provider																									
Delivery training package/educate each TMs on history, storage, maintenance, fit, safety etc.	Health and Safety/Health Service Provider	Users/Management																									
Conduct initial strength/conditioning tests	Health and Safety/Health Service Provider	Users/Management																									
Conduct readiness/weekly meetings	Health and Safety/Health Service Provider	Users/Management																									
AT IMPLEMENTATION																											
Exoskeletons Arrive/Fit TMs with personalized Exoskeletons suits	Health and Safety/Health Service Provider	Users/Management																									
Provide 1 to 1 support for fitting	Health and Safety/Health Service Provider	Users/Management																									
Create ramp up schedule to allow transition from non-Exoskeleton to Exoskeleton	Users/Management	Health and Safety/Health Service Provider																									
Conduct initial surveys of TMs	Health and Safety/Health Service Provider	Users/Management																									
Complete TPM Sheets	Users/Management	Health and Safety/Health Service Provider																									
Add problem follow up sheets	Health and Safety/Health Service Provider	Users/Management																									
Continue weekly meetings	Health and Safety/Health Service Provider	Users/Management																									
POST-IMPLEMENTATION																											
Provide 1 to 1 support for fitting	Users/Management	Health and Safety/Health Service Provider																									
Continue regular survey/data collection	Health and Safety/Health Service Provider	Users/Management																									
Complete TPM Sheets	Users/Management	Health and Safety/Health Service Provider																									
Add problem follow up sheets	Health and Safety/Health Service Provider	Users/Management																									
Continue weekly meetings	Health and Safety/Health Service Provider	Users/Management																									
Feedback kaizen ideas to vendor	Health and Safety/Health Service Provider	Users/Management																									
Conduct periodic strength/conditioning tests	Health and Safety/Health Service Provider	Users/Management																									




NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?
Very Low — Very High

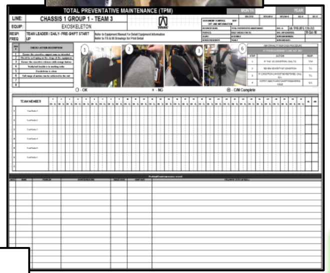
Physical Demand — How physically demanding was the task?
Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?
Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?
Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?
Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed were you?
Very Low — Very High



Check: Trial Comparison

	2017 - Initial	2019 - Current
Vehicle Type	Corolla (Sedan)	Rav4 (SUV)
Duration	2 Months	4 Months
# Exoskeletons/Users	24	72
# Processes/Jobs	9	6-5
Study Design	Exoskeleton Use vs. No Exoskeleton Use	Exoskeleton Use Only
Subjective Measures	Informal Feedback/RPE/Equipment Functional Scoring/Discomfort Survey	Informal Feedback/Equipment Functional Scoring/Discomfort Survey/NASA TLX
Objective Measures	Injury-Discomfort Rate/Strength Conditioning Testing/EMG(Limited)	Injury-Discomfort Rate/Strength Conditioning Testing(Limited) /Energy Expenditure(Limited)
Production Rate	Full 100% Build	3 Month Ramp Up to 100%

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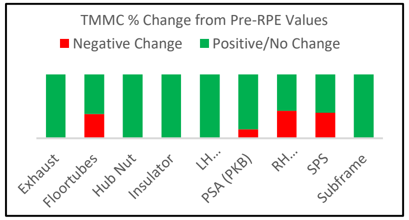
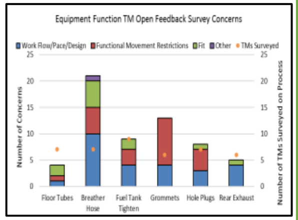
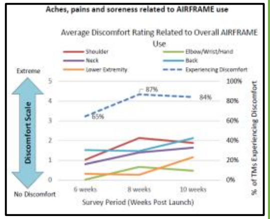
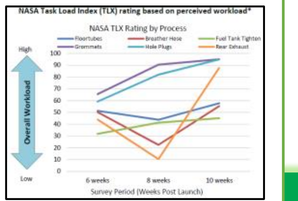
Check: Subjective Trial Measurables

Measurable	Source	Purpose/ Measure	Exoskeleton Application	Current Results
Informal Feedback	Internally Created	Provides an opportunity to voice any positive or negative comments the TM may have with Exoskeleton management	These comments are useful to drive creating a better system for Exoskeleton Management	Good mix of positive and negative comments for Kaizen. Continues to range but initially on Fit concerns and then centered around process design
Rating of Perceived Exertion (RPE)	Borg's Scale (both Gunnar Borg of 6-10 and CR10 Scale)	Rating perceived exertion during exclusively physical activity	Determines by process the physical demands on the TM and measured with and without Exoskeleton	Initial Results -5/9 Processes Evaluated at 100% Positive Change. Others at >50% Change 
Equipment Functional Score	Internally Created	Rating the usefulness/effectiveness of the equipment (1-"Interferred" with their job tasks to 5 – "Very Helpful" in assisting their work) – Likert Scale	Determines process(Job Task)-Exoskeleton interactions and highlights potential improvements to job	Initial Results - 93% Positive Change (Pre-Post Usage). Current Results - TM's Concerns with Workflow/ Pace/ Design as the top issue 
Discomfort Survey	Internally Created	Measuring subjective discomfort of the TM (0 - "No Discomfort" to 5 – "Extreme Discomfort")	Identifying any discomforts with wearing the Exoskeleton both MSD discomforts or surface level concerns	Initial Results - 88% Positive Change (Pre-Post Usage). Current Results – TM discomforts increased overtime with increased production rate 
NASA Task Load Index (TLX)	Hart and Staveland's Developed Tool	Subjective, multidimensional assessment tool that rates perceived workload in order to assess a task, system, or team's overall effectiveness or other aspects of performance	Determining a holistic subjective demand of using an Exoskeleton while working on a process	Current Results – Perceived Workload increased overtime with increased production rate. Also validates Equipment Function Score 

PROTECTED 関係者外秘

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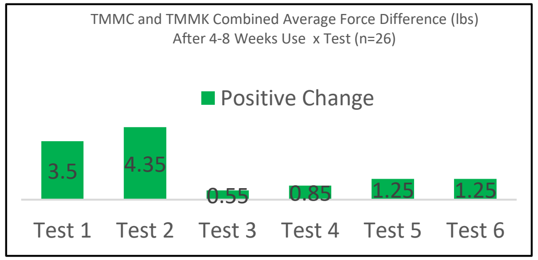
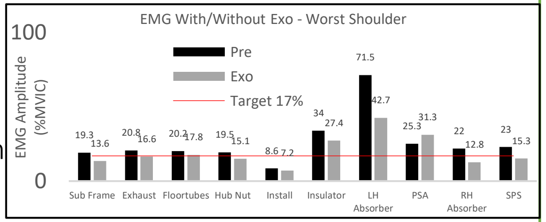
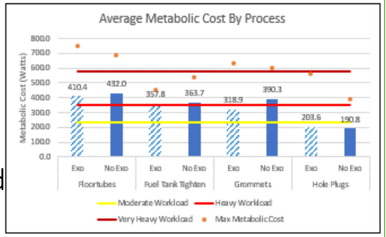
Check: Objective Trial Measurables

Measurable	Source	Purpose/ Measure	Exoskeleton Application	Current Results
Injury/Discomfort Rate	OSHA Recordability/ Occupational Health Evaluation	Measures any injury/discomfort the TM using the Exoskeleton may have	To determine if injury rate is improved or maintained from the use of Exoskeleton or any injury/discomfort attributed to wearing the Exoskeleton.	<u>Initial Results</u> – 200% Injury Rate Improvement Comparing Set periods of Exoskeleton Intervention vs Non-Intervention <u>Current Results</u> – 133% Injury Rate Improvement comparing set periods of Exoskeleton Intervention vs Non-Intervention
Strength Testing/Conditioning	Various special tests comply practiced by Kinesiologist/Physical Therapist	Maximal Voluntary Isometric Contraction (MVIC) Tests for specific isolated muscle groups measured by force gauge	To determine over time if the TM will loose muscular condition/strength	<u>Initial Results</u> – No evidence on strength conditioning loss during Exoskeleton intervention 
Electromyography (EMG)	Cram and Steger EMG sensing device	Electric diagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles through the use of MVIC	Measures the increase or decrease in %MVIC in a process to measure against ACGIH fatigue curve (2016) or between use and non-use	<u>Initial Results</u> - 8 out of 9 process show significant change in decreased %MVIC on larger shoulder and back muscle groups  Gillette J.C. & Butler T. (2018). EMG-based ergonomic analysis of the Levitate Airframe at Toyota Canada. Toyota Motor Manufacturing Canada.
Energy Expenditure (HR/VO2)	Hill concept of maximum oxygen update	Predictive VO2 is the predictive maximum rate of oxygen consumption measured during incremental exercise. Measures cardiorespiratory fitness and endurance	Identifying TMs and processes that are experiencing high level of exertion between long duration or between use and nonuse	<u>Current Results</u> - 5 TMs - 4 processes were evaluated. 3/4 according to NIOSH thresholds are considered "Heavy Workload". Exoskeletons reduced workload but not enough 

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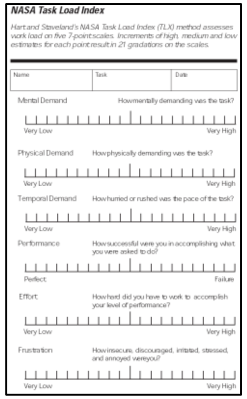
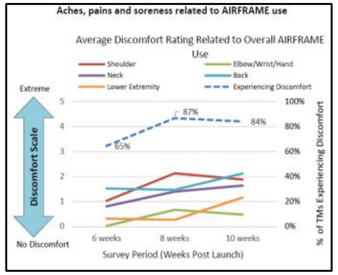
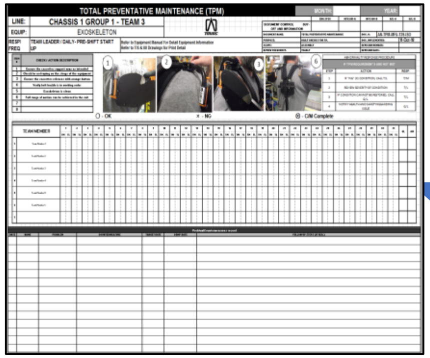
Act: Results to Program or Redesign - Initial

Subjective Results

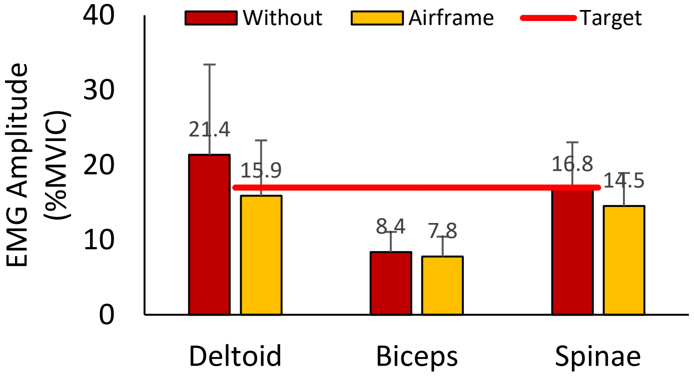


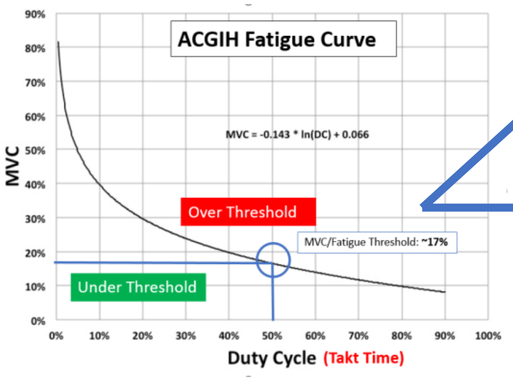




Equipment Design

Objective Results

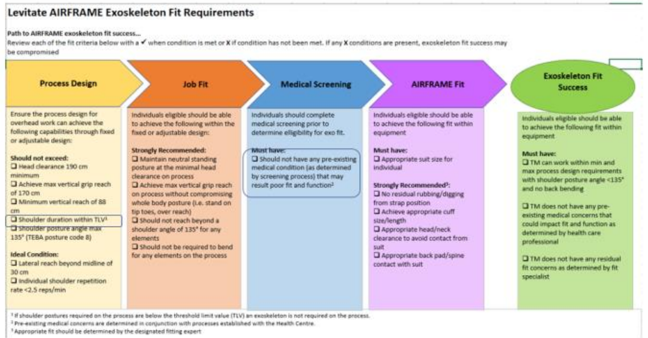




Gillette J.C. & Butler T. (2018). EMG-based ergonomic analysis of the Levitate Airframe at Toyota Canada. Toyota Motor Manufacturing Canada.

Proposed Process Exoskeleton Selection Scheme

Trials in Assembly and Weld provided the basis of this requirement scheme based on subjective and objective feedback



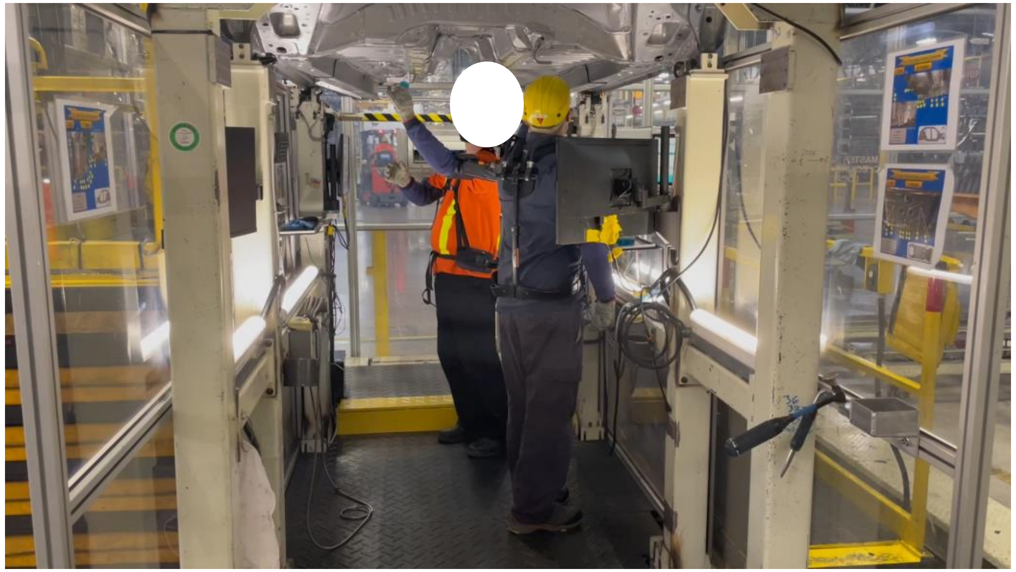
*Next steps are to confirm or disprove this selection scheme through similar cycled processes

TOYOTA CARES

Act: Comparison of Successes and Challenges

A comparison of our “Weld” vs “Assembly” Exoskeleton Applicable Processes

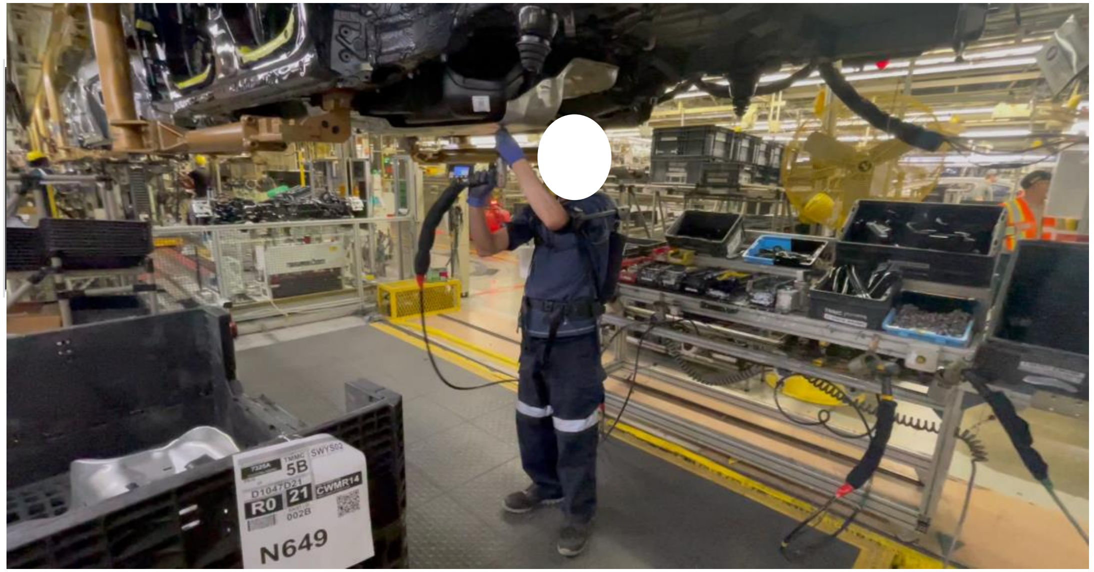
“Weld” Process



Cycle Time – 20 Minutes/Vehicle

Average time spent in one overhead Shoulder Rep/Position – 120 Seconds

“Assembly” Process



Cycle Time – 1 Minute/Vehicle

Longest time spent in one overhead Shoulder Rep/Position – 8 Seconds

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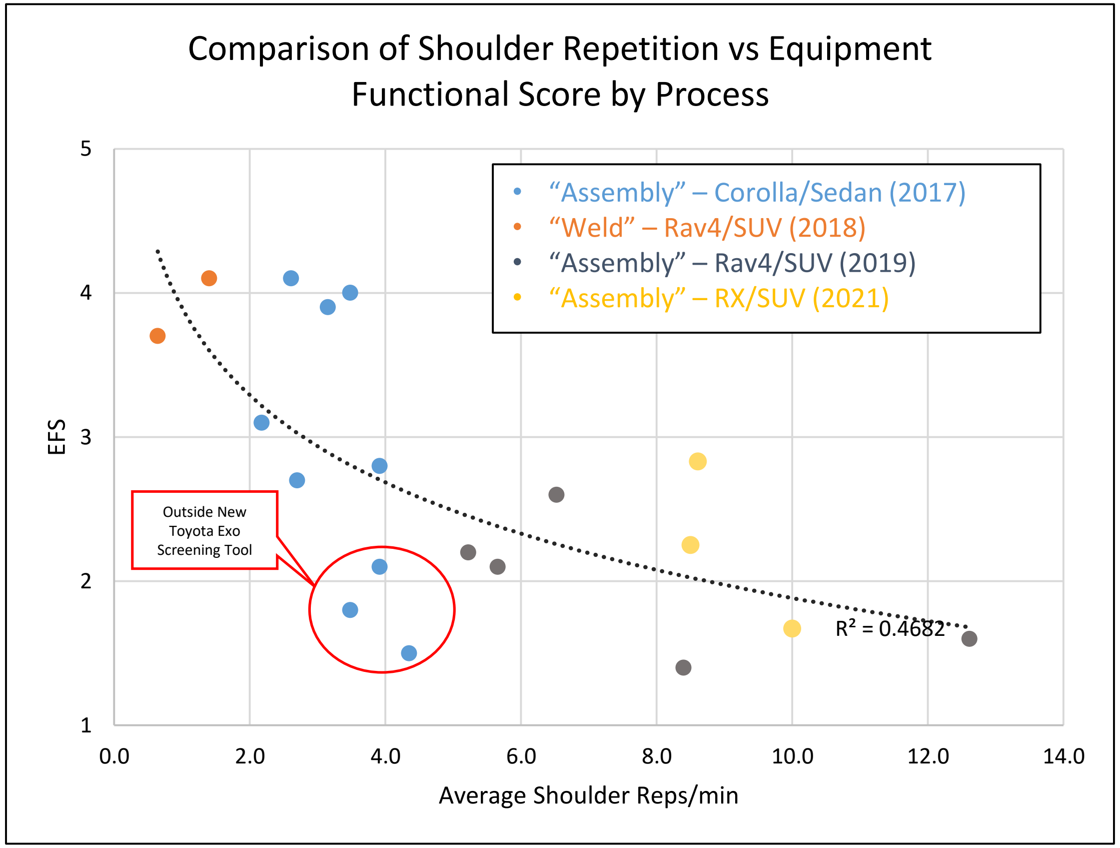
Act: Comparison of Successes and Challenges

A comparison of our "Weld" vs "Assembly" Exoskeleton Applicable Processes

Process Design Variables	Shops	
	Weld	Assembly
Head clearances minimally 190cm	○	×
Max Vertical Reach does not exceed 170cm	○	×
Min Vertical Reach of 88cm (No bending)	○	×
Shoulder duration within TLV	○	○
Shoulder posture angle less than 135 degree	○	×
Lateral reach is less than 30cm (No twisting)	○	×
Individual shoulder reps rate <2.5 reps/min	○	×
Pace/Cadence	○	×
Temperature	△	△
Rest/Fatigue reduction	○	×
Walking	○	△

Highlight refers to dynamic work



*Optional Exoskeleton Usage Only after 3 Months of Required Use

*Required Exoskeleton Issued Process for 2+ Years

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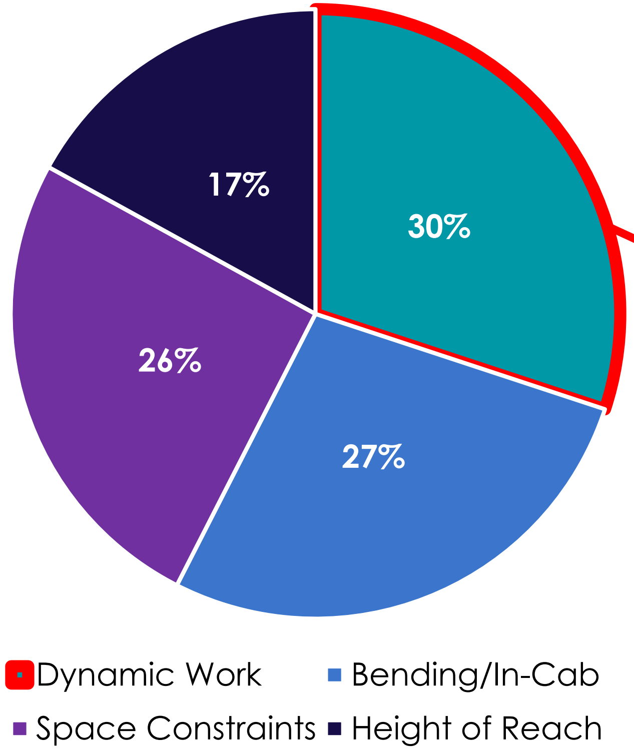
Act: A Call For Research - Current

Causes for No Implementation across 5 Plants, 2019-2020



Countermeasures:

All Concerns:

- Onsite plant support (pending travel condition)
- Create manual on how to address common problems

Dynamic Work Concern:

- Define "dynamic" and improve process selection tool and process design variables

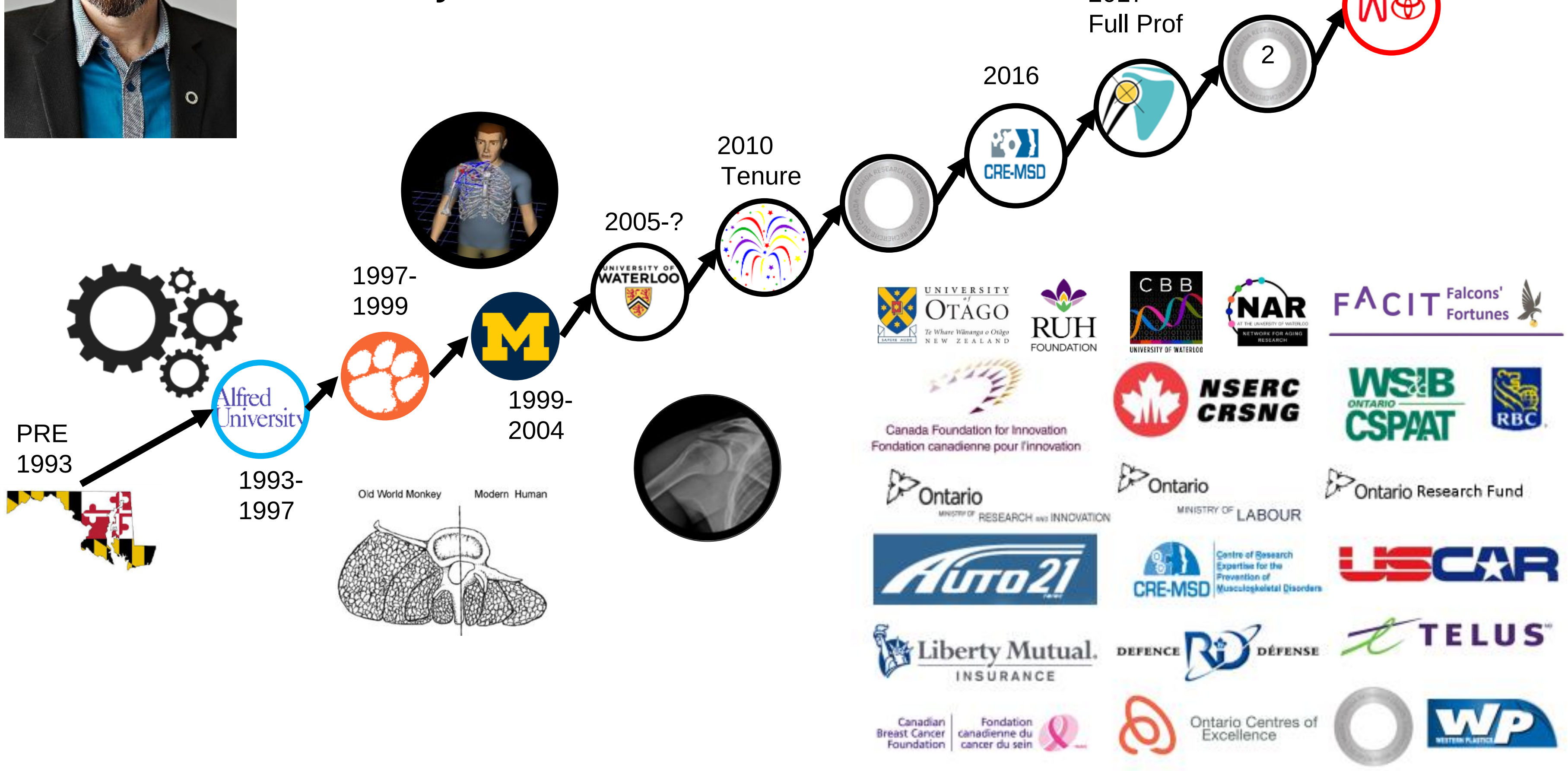
UNIVERSITY OF WATERLOO

CRE-MSD Centre of Research Expertise for the Prevention of Musculoskeletal Disorders

~28 Years of Mechanics

Clark Dickerson , PhD, CCPE

Professor & Canada Research Chair, University of Waterloo



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MUSCULOSKELETAL DISORDERS

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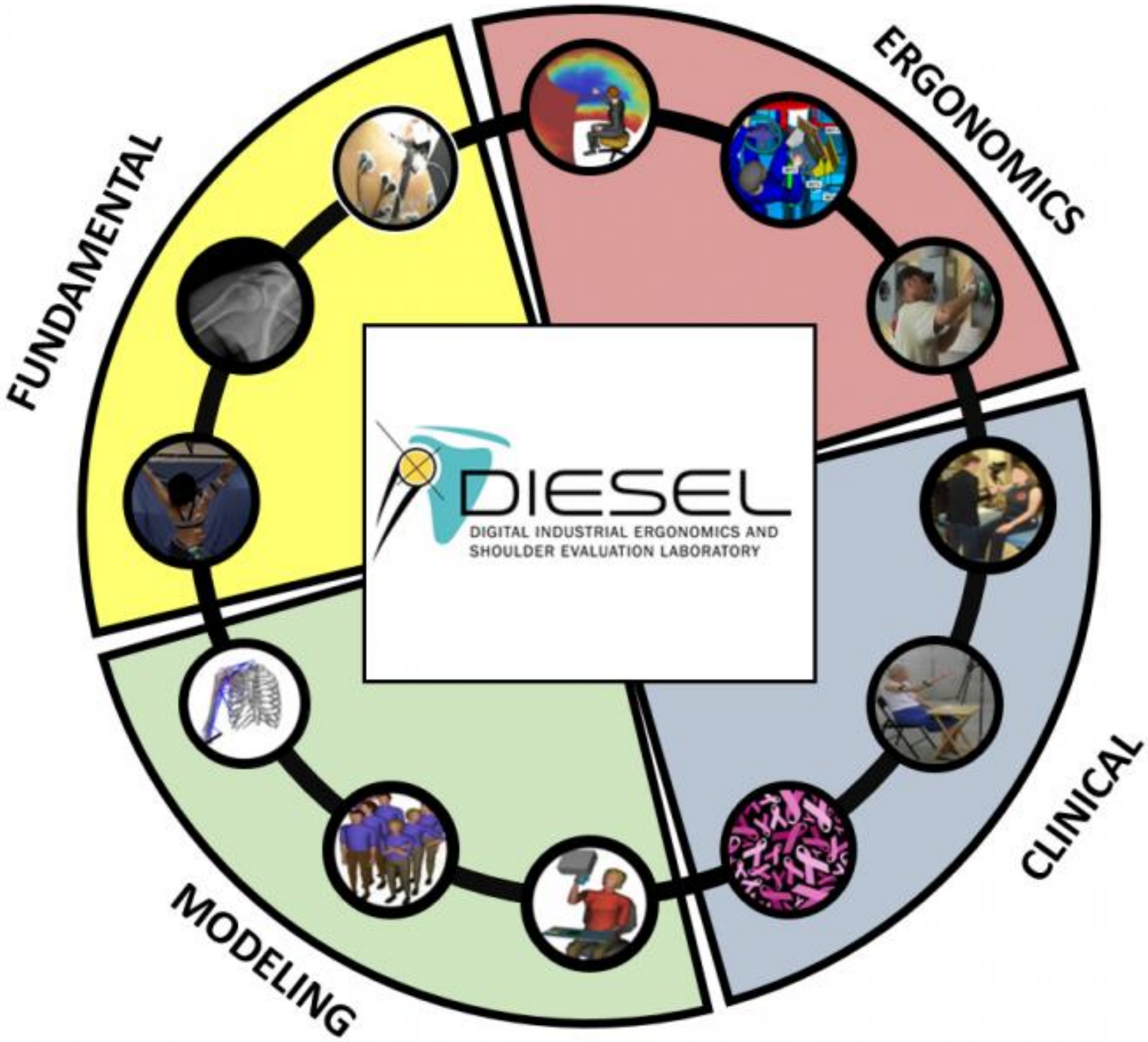
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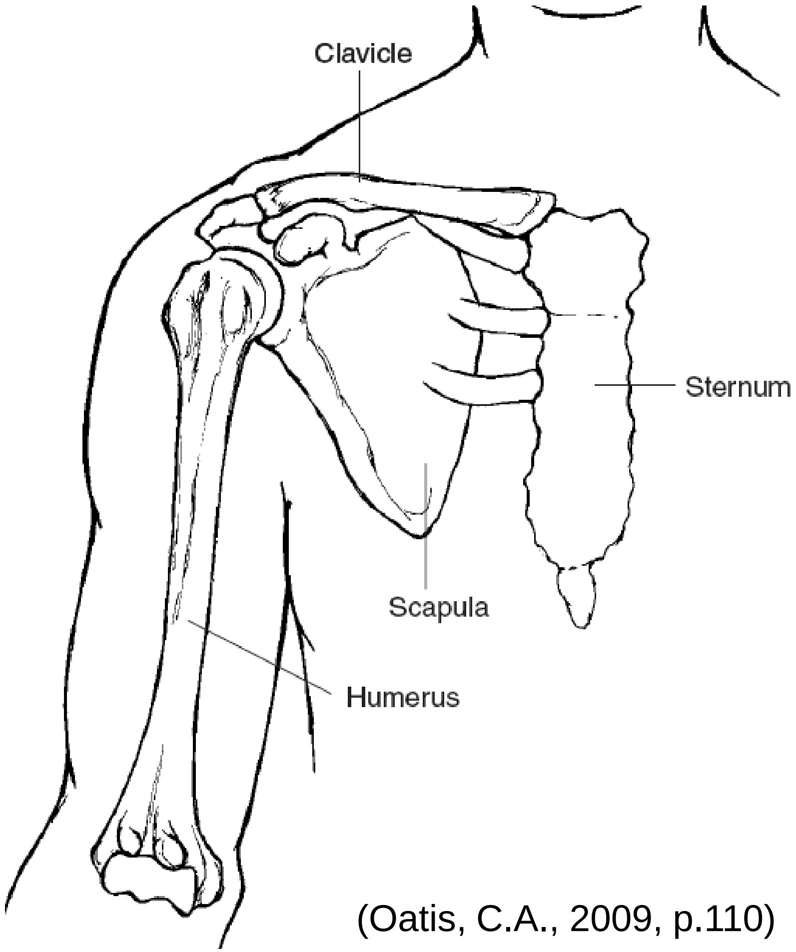
DIGITAL INDUSTRIAL ERGONOMICS AND
SHOULDER EVALUATION LABORATORY

About Shoulders

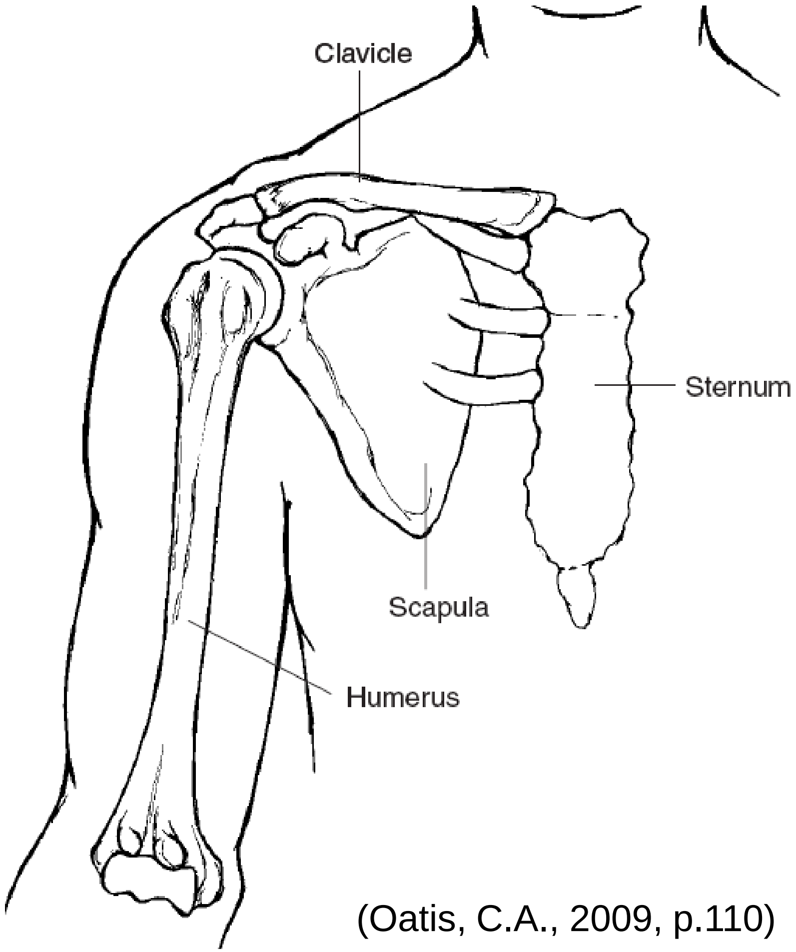
- A 'complex', not a joint
- Complexity of issues complicates effective, simple responses
- Many components can and do fail for various nuanced reasons



(Oatis, C.A., 2009, p.110)

Shoulder Characteristics

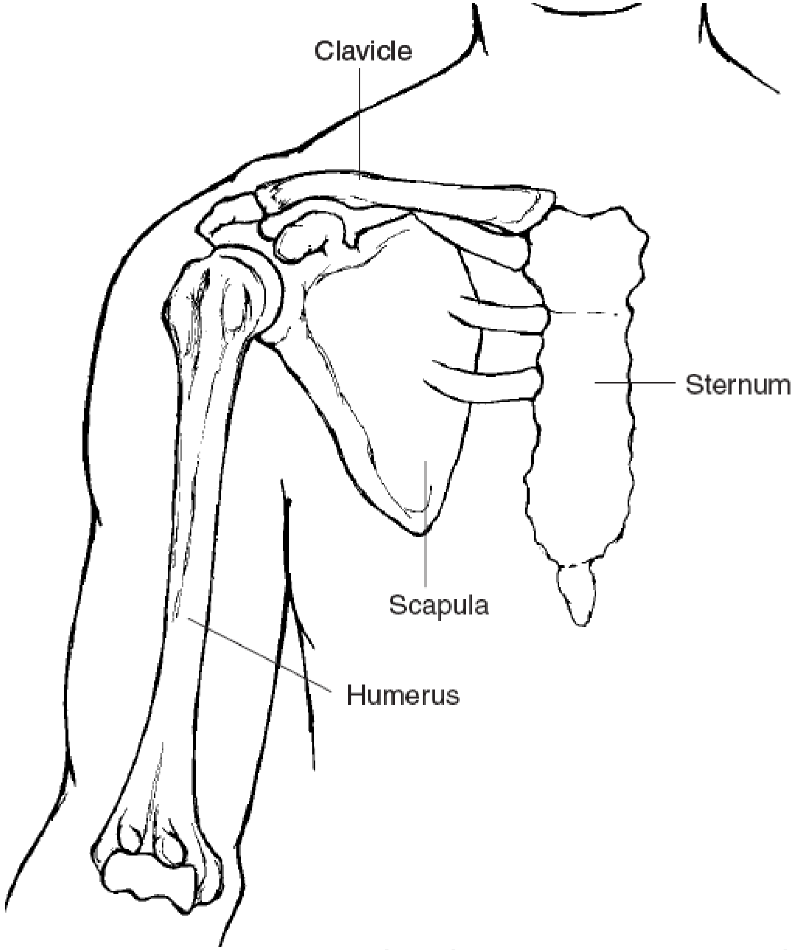
- Extreme mobility
  - 3.5 joints move in rhythm
  - Many contributions to hand placement in space
- Instability
  - Highly susceptible to perturbation
  - Muscles major contributors



(Oatis, C.A., 2009, p.110)

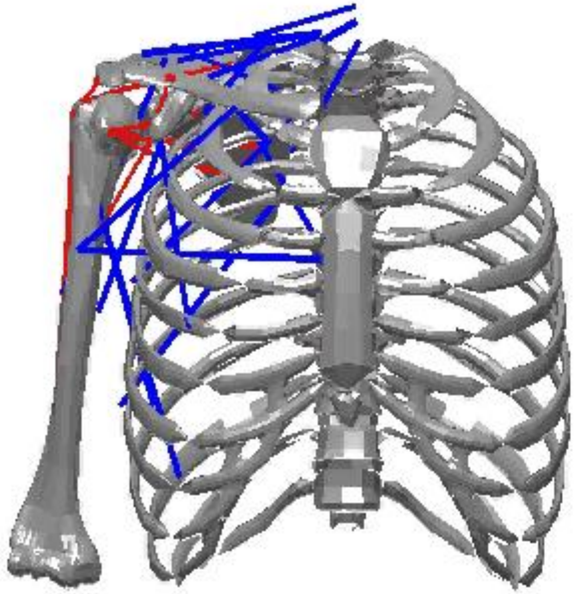
Shoulder Pathomechanics

- Soft-tissue dominated
  - Muscular fatigue
  - Ligamentous joint support
  - Tendon failure/damage (particularly rotator cuff)

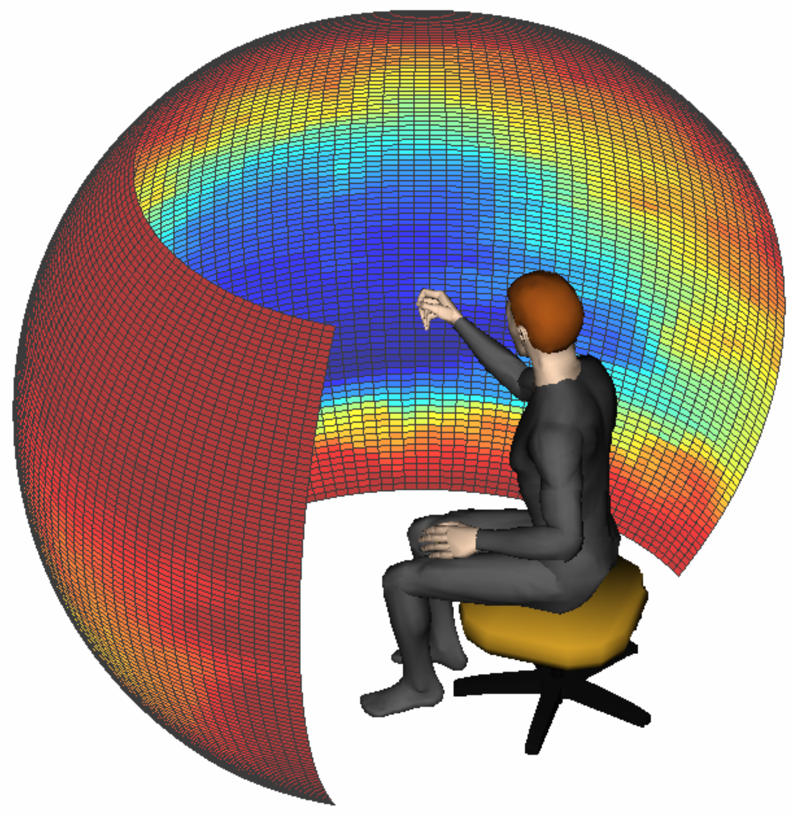


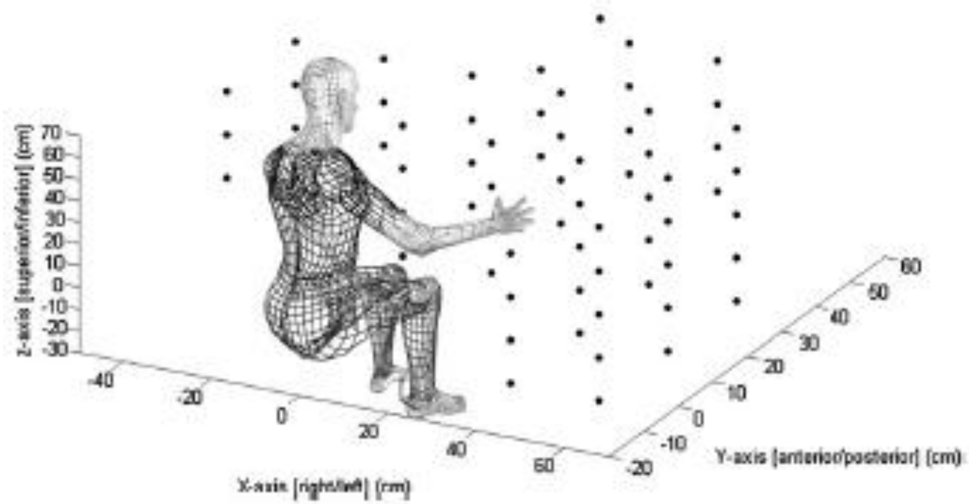
(Oatis, C.A., 2009, p.110)

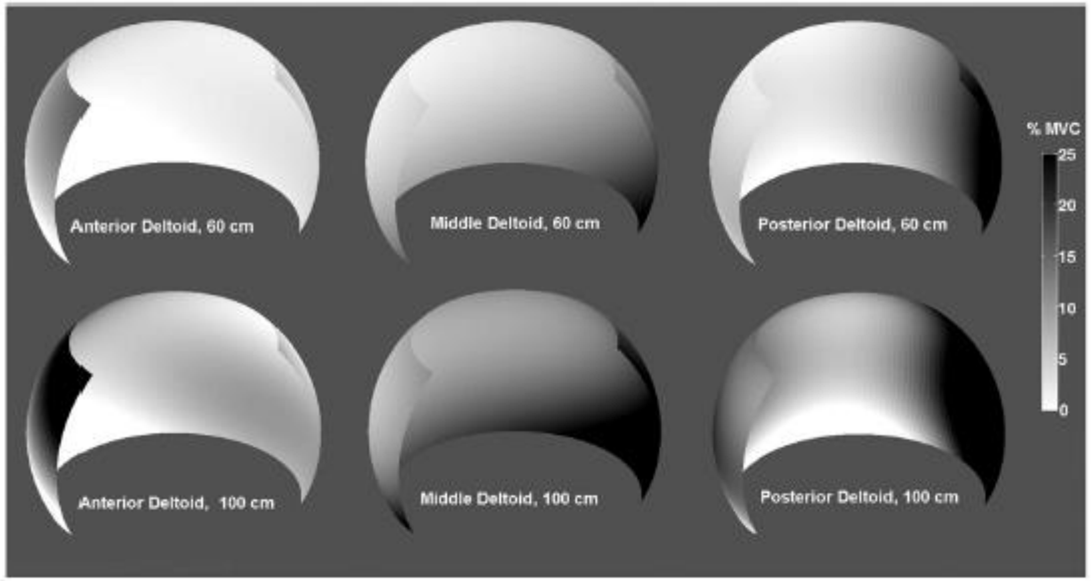
An Intricate Symphony



Defining Capacity







Nadon, McDonald et al., 2012+

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Overhead Work

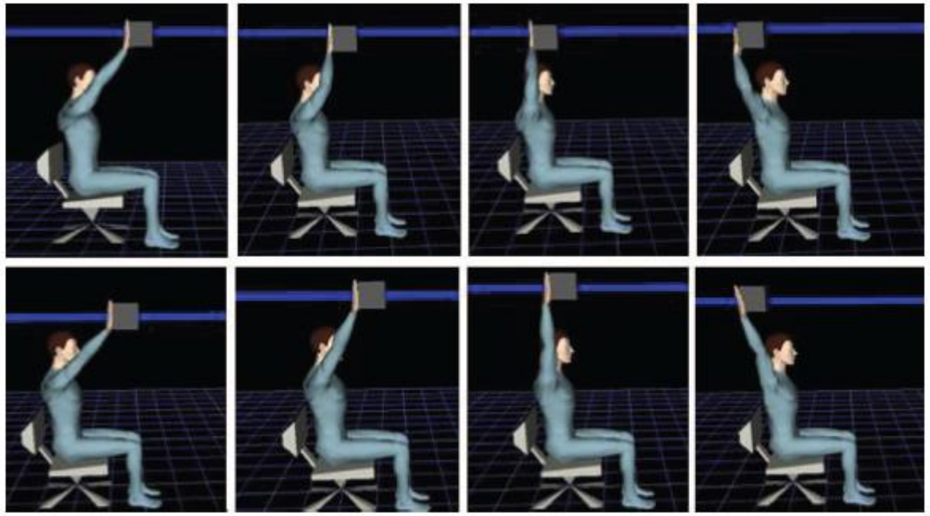
Overhead work: Identification of evidence-based exposure guidelines

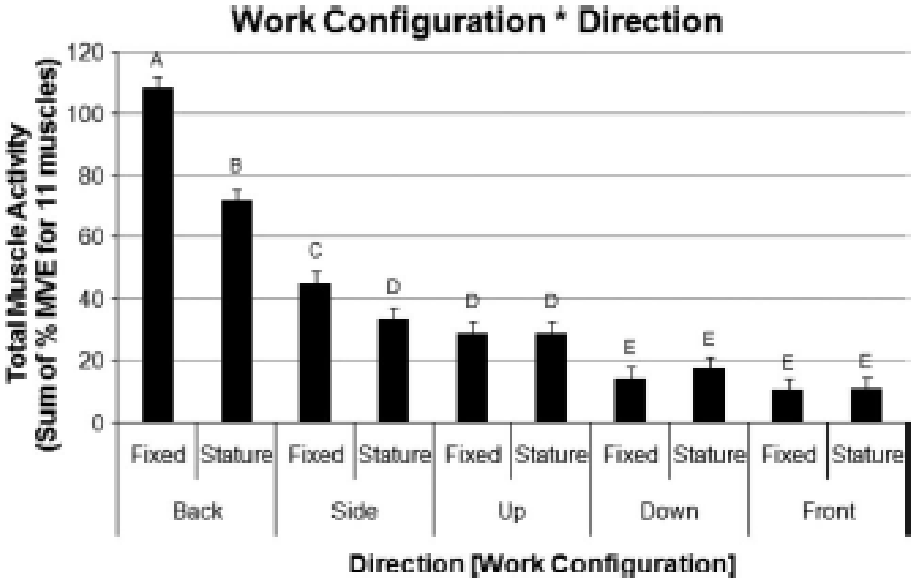
Jason R. Grieve and Clark R. Dickerson*
Department of Kinesiology, University of Waterloo, Waterloo, Ontario, Canada

Table 1 Key factors to consider for jobs that include overhead work (extracted from Fischer *et al.*[30])

Factors that reduce risk	Factors that increase risk
• Work is close to the body	• Extended reaches
• Low frequency of arm elevation	• High frequency of arm elevation
• Low precision requirements	• High precision requirements
• Duty cycles less than 50%	• Duty cycle greater than 50%
• Primary applied force is in the vertical plane	• Primary applied force is in the horizontal plane
• Arm at less than 60° elevation	• Arm elevations in 60–120° range
• Arm free to rotate externally	• Arm forced to rotate internally
• Arm elevated >90° for less than 10% of work shift	• Arm elevated >90° for more than 10% of the work shift
• Low hand force requirements	• High hand force requirements

Overhead Work





Chopp et al., 2010+

Upper Extremity Passive Exoskeletons

- Intention is to reduce shoulder demands

- Most quantifications of effectiveness focus on specific muscle demands
  - These may or may not relate to injury
  - They are often defined for very short exposures
  - Effectiveness across jobs and with respect to fatigue are very partially known

RESEARCH MEETING PRACTICE TO
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MUSCULOSKELETAL DISORDERS
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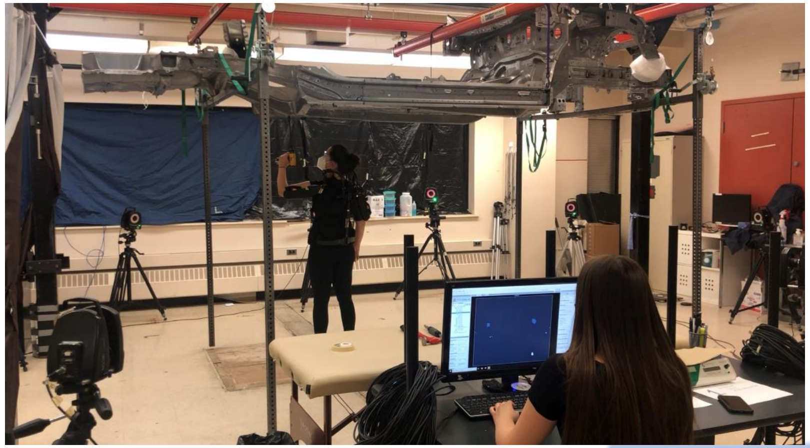
Goals of the Partnership

- Assess exoskeleton effectiveness
  - New metrics (fatigue, kinematics)
  - More varied tasks
  - Advanced fatigue evaluation
  - Improved rotator cuff characterization
  - Evidence-based implementation guidance



It’s not just me…is it?

- Researching the impact of industrial-use exoskeletons on muscular fatigue and kinematics of the shoulder will continue to provide a more robust appraisal of their efficacy to reduce shoulder-related MSD.

  – McFarland & Fischer, 2019

Why work together?

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Musculoskeletal Disorders

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Act/Plan: Kaizen/Next Steps

Evidence Based Research

- Evaluate internally using accessible tools to measure/survey Exoskeleton usage

- Partnering with local Universities (UW) to produce more internal research on current and future Exoskeleton products to measure: Benefits, Limitations and Impact/Application

- Continue partnership with ASTM and others to support gathering more external research on Exoskeleton usage to ensure healthy and safe users of equipment

Strong Long-Term Gain

- Review and improve current process design around Exoskeleton use, evaluate long term usage, and determine ROI/burden reduction through research

- Continue partnership with ASTM to support stronger management systems for our management team and end-users by sharing and learning best practices in Exoskeleton management

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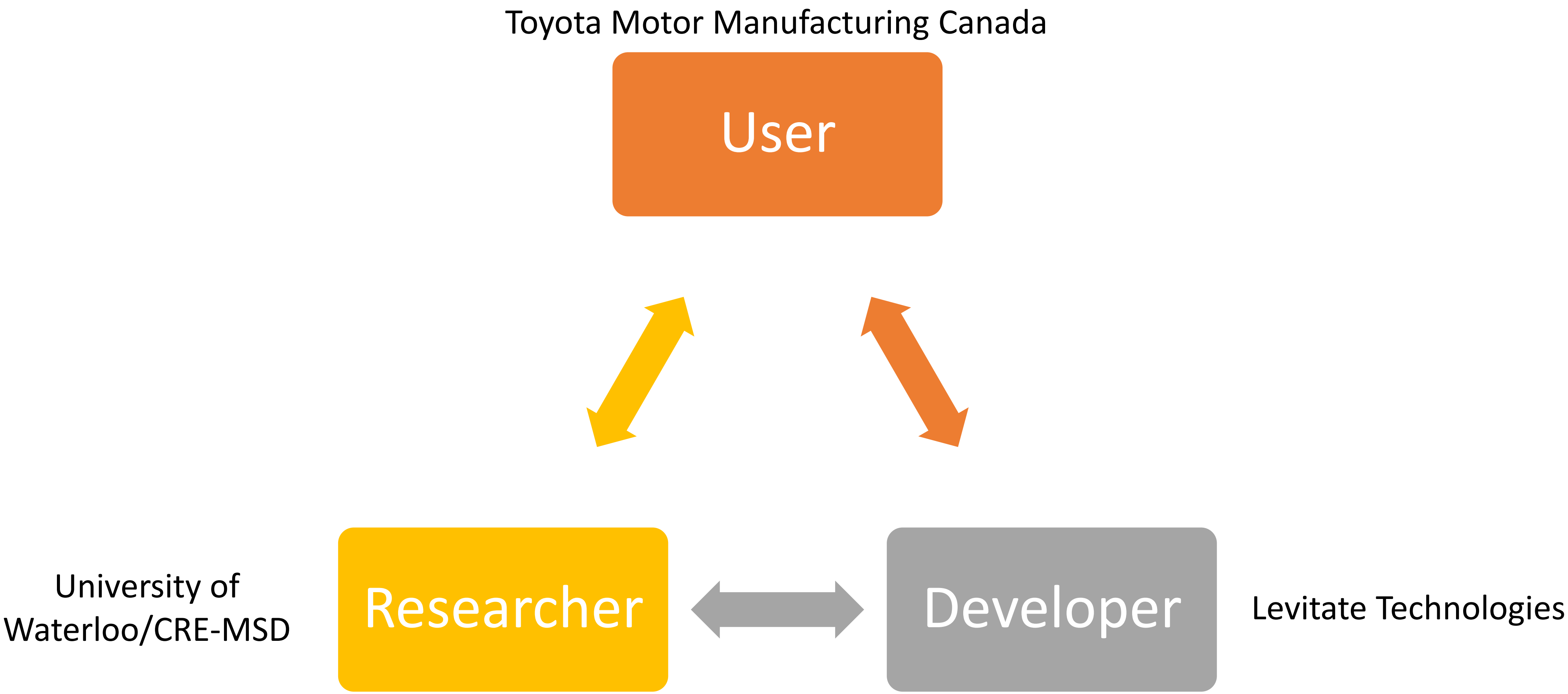
TMMC's Exoskeleton Product Triangle



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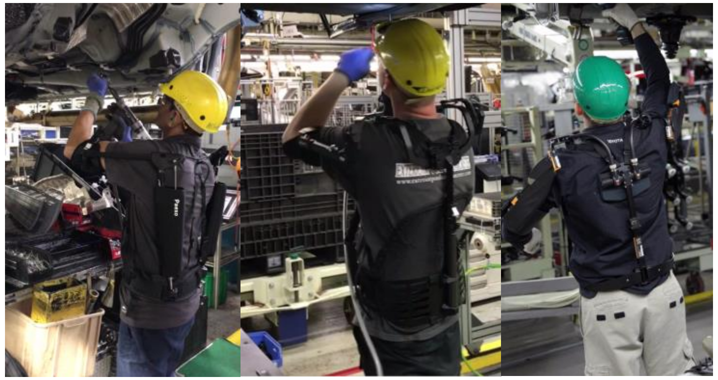
Exoskeleton Developers – New Innovation

"So Far"

- Upper Body Exoskeletons (Levitate - Airframe, Esko Bionics - EksoVest, Ottobock - Paexo, SuitX – ShoulderX)



- Lower Body Exoskeletons (Noone – Chairless Chair, SuitX – LegX)

- Other emerging/related technologies (GoX Labs, LifeBooster, Ansell/ProGlove)

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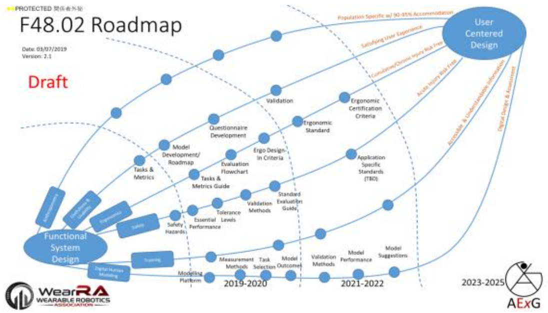
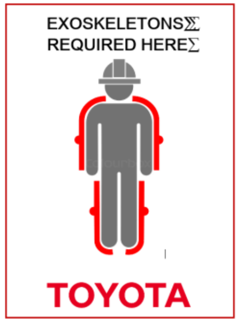
Exoskeleton User - Standards/Info Sharing

"No secrets in Safety"

- ASTM F48 Exoskeletons and Exosuits Committee: First International Exoskeleton Standard.
- Toyota North America Exoskeleton Usage Standard: First Industrial Working Exoskeleton Standard
- Automotive Exoskeleton Group: Partnership Program Across Automotive/Aeronautical Manufacturing groups sponsored by Wearable Robotics Association



ERG S 03 Exoskeletons Usage Standard



Member Status

Company	BMW	Nissan	Honda	Toyota	Ford	VW
Number of Devices	71	10	2	400	100	2
Shops	Assy, Paint	Assy	Assy	Assy, Paint, Weld	Vehicle Assembly, Powertrain Assembly, Vehicle Scanning Team	Assy
Data Collected	Discomfort Survey, Perceived Benefit/Fatigue Reduction	Discomfort Survey, overhead work tolerance, Shoulder range of motion w/ and w/o device	Team member subjective comments regarding comfort and mutilation	RPE, Equipment Survey, Discomfort Survey, 2 EMG studies	Subjective TM feedback, some EMG, kinematics,	Subjective feedback on comfort
Structure	Mgmt system is still a work in progress	Still in trial phase, no standards have been created	Still in trial phase	Created internal standard and process flow for Exo deployment. 72 units have been deployed as mandatory PPE	Internal usage standards for NA, Global Exo Team to manage and provide governance for trials in other regions	Still in trial phase

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Exoskeleton Research – Short/Long Term Studies

- IOWA State University: First Partnership with Levitate Technologies
- NIOSH: Longitudinal Effects of Shoulder Exoskeletons
- University of Waterloo/DIESEL/CRE-MSD: Dynamic work study

Q&A

Clark R. Dickerson, Ph.D., CCPE

Canada Research Chair in Shoulder Mechanics

Professor

Department of Kinesiology
Faculty of Applied Health Sciences
Cross-appointed, Systems Design Engineering
Chairperson, International Shoulder Group (2019-2023)
Associate Director, Research, Centre for Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD)
Principal Investigator, Digital Industrial Ergonomics and Shoulder Evaluation Laboratory (DIESEL)

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