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Manual Handling: Where Exoskeletons Fit Within Musculoskeletal Disorder (MSD) Prevention Strategies

Industry Implementation and Supporting Research – TMMC/UW

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Introduction

Seth Burt

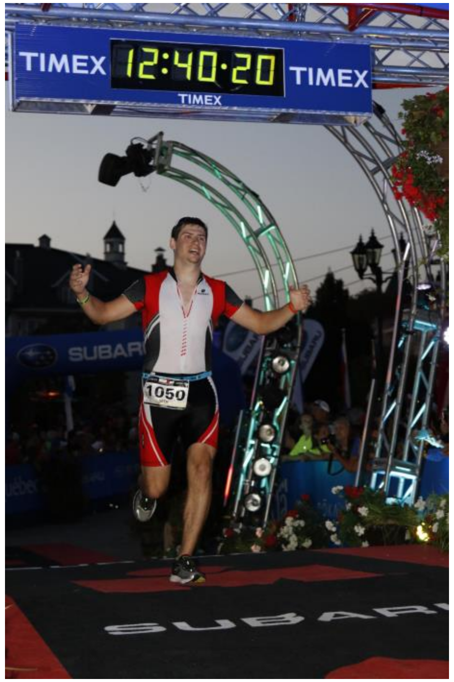
- Safety Manager, TMMC
  - Previously Safety Analyst for 6 years
- Bachelors in Kinesiology with an Ergonomics Specialization at the University of Waterloo
- Canadian Certified Professional Ergonomist (CCPE)
- Canadian Registered Safety Professional (CRSP)

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



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TOYOTA CARES Driving Safety/MSD Improvement Principles

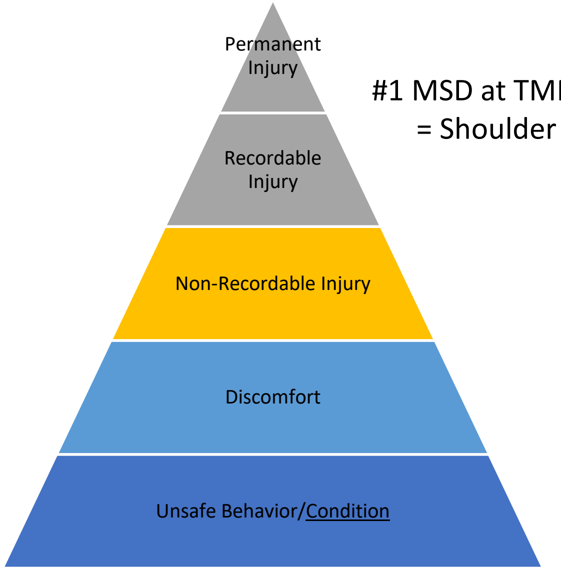
Toyota Safety Management System (TSMS)					
	Document name:	TMMC Ergonomics Standard			TOYOTA CARES
	Implemented:	April-1-2021			
TSMS ref: 4.4.6	Revision date:		Freq. of review:	24 months	Version 1.0
	Document ID: 446_28				

PURPOSE

To optimize human performance in the workplace and define organizational responsibilities, procedures, and programs that will prevent, reduce, and manage Ergonomic risk factors associated with injuries and discomfort.

Gap Analysis – Heinrich's Accident Triangle

High Shoulder Risk = Increased Probability of Shoulder Injury

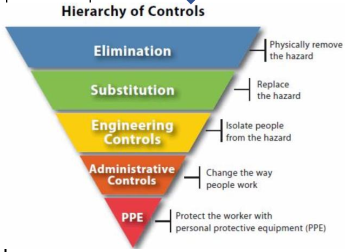


#1 MSD at TMMC = Shoulder

#1 Risk at TMMC = Shoulder

Counts of High Risk by Task/Plant/Line

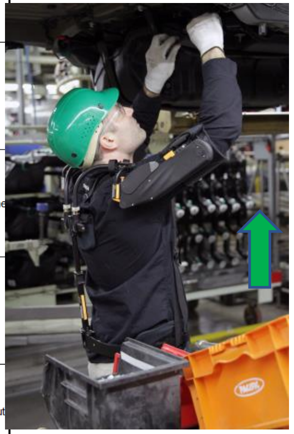
	North 320B			Current South			West 320B			Overall Totals			
Complex Items	Trim	Chassis	Final	Trim	Chassis	Final	Trim	Chassis	Final	TMMC	All Trim	All Chassis	All Final
Vertical Outer Vehicle Reaching	213	82	153	91	45	63	6	8	232	893	310	135	448
Overhead Work	67	169	2	141	126	0	75	159	58	797	283	454	60
Engine 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	
Inner Luggage Area	43	2	34	9	28	0	62	0	4	182	114	30	
Other (no specific category)	252	170	383	201	209	168	0	0	0	1383	453	379	



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



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TMMC Exoskeleton Roadmap

2017-2020

3 Year 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

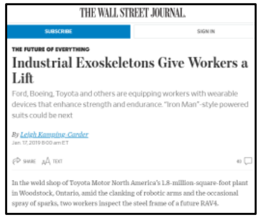
2018

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.

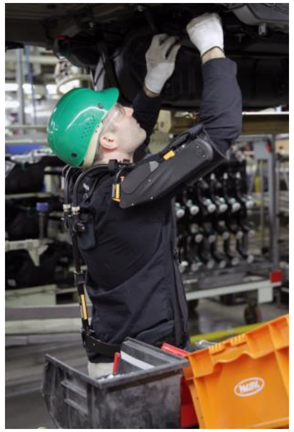
2019

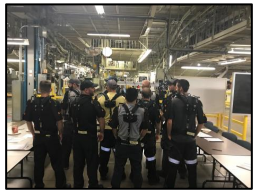
Q1 – 72 Exo "Assembly" Implementation + 24 Exo "Weld" Implementation
WG meetings, PFS, Training, Medical screens, surveys, fit support teams for nA and nW

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





2020-2022

UNIVERSITY OF WATERLOO

Exo Comparison Study + University of Waterloo Study + Extended Research and Development

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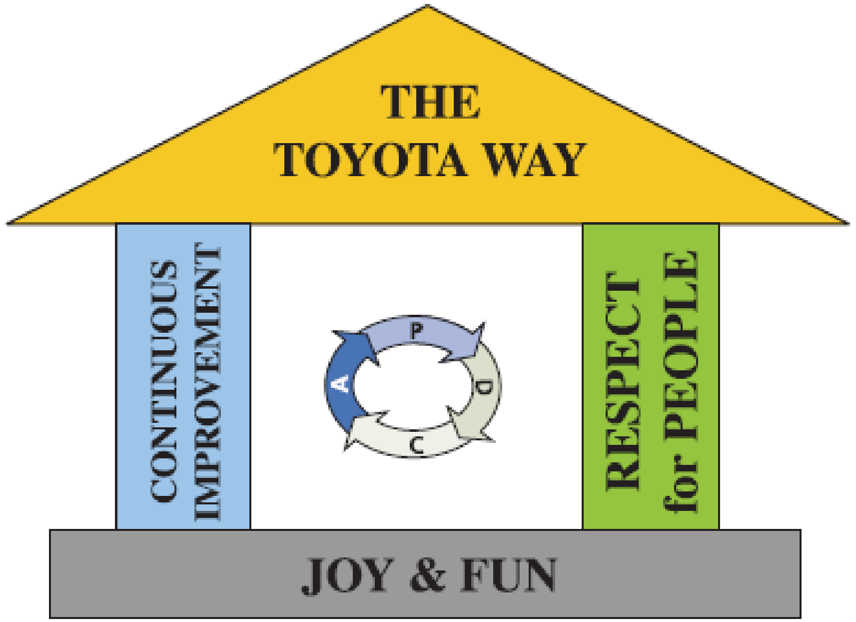
The Toyota Way = PDCA

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

ERG S 03 Exoskeletons Usage Standard

Toyota North American Standard

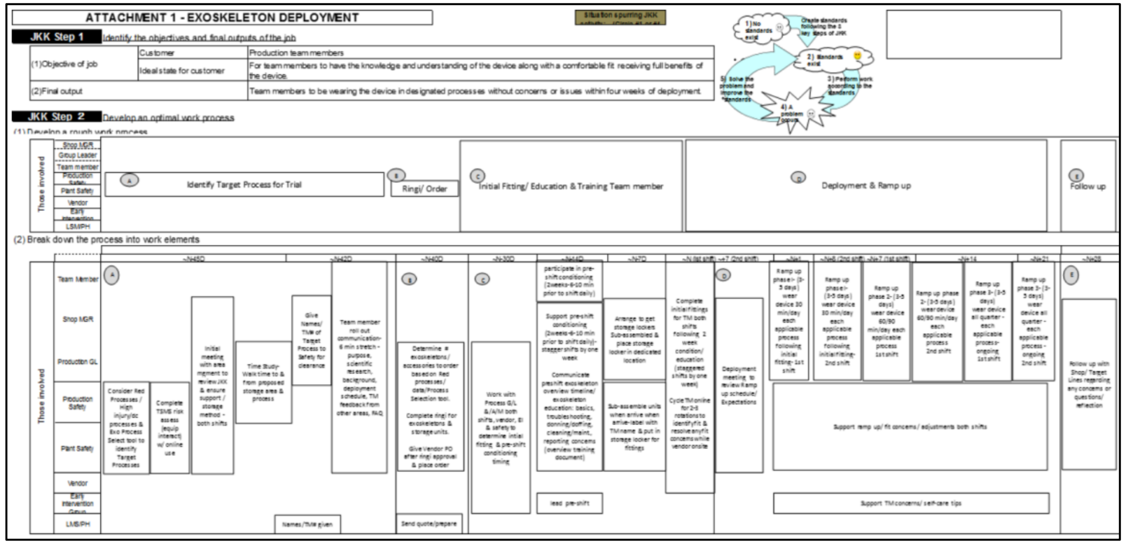
- Scope
- Purpose/Philosophy
- Roles and Responsibilities
- Definitions
- Procedures:
  - Exoskeleton Specifications
  - Selection Criteria
  - Training Requirements
  - Storage
  - Medical – Prior to First Use
  - Fit Testing
  - Issuance
  - Post Deployment:
    - Mandatory Usage/Volunteering Usage
    - 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.

Benchmark: TMMC Respiratory Fit Program

Background Standards & Regulations Cited:

Section 79 of Ontario Regulation 851 made under the Occupational Health and Safety Act states that a worker required to wear or use any protective clothing, equipment or device shall be instructed and trained in its care and use before wearing or using the protective clothing, equipment or device.

The Ontario Occupational Health and Safety Act, section 28 (1)(b) A worker shall use or wear the equipment, personal devices or clothing that the worker's employer requires to be worn.



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Plan: Ergonomic/H&S Management Systems

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

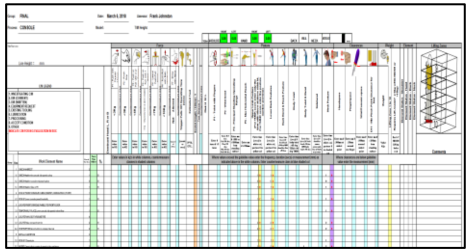
1. Process is flagged by selection tool*
2. No other control is feasible in short-term
3. Exoskeleton usage does not pose a safety risk

*Mathematical calculation based on % cycle with overhead work postures

Plan: Ergonomic/H&S Management Systems

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

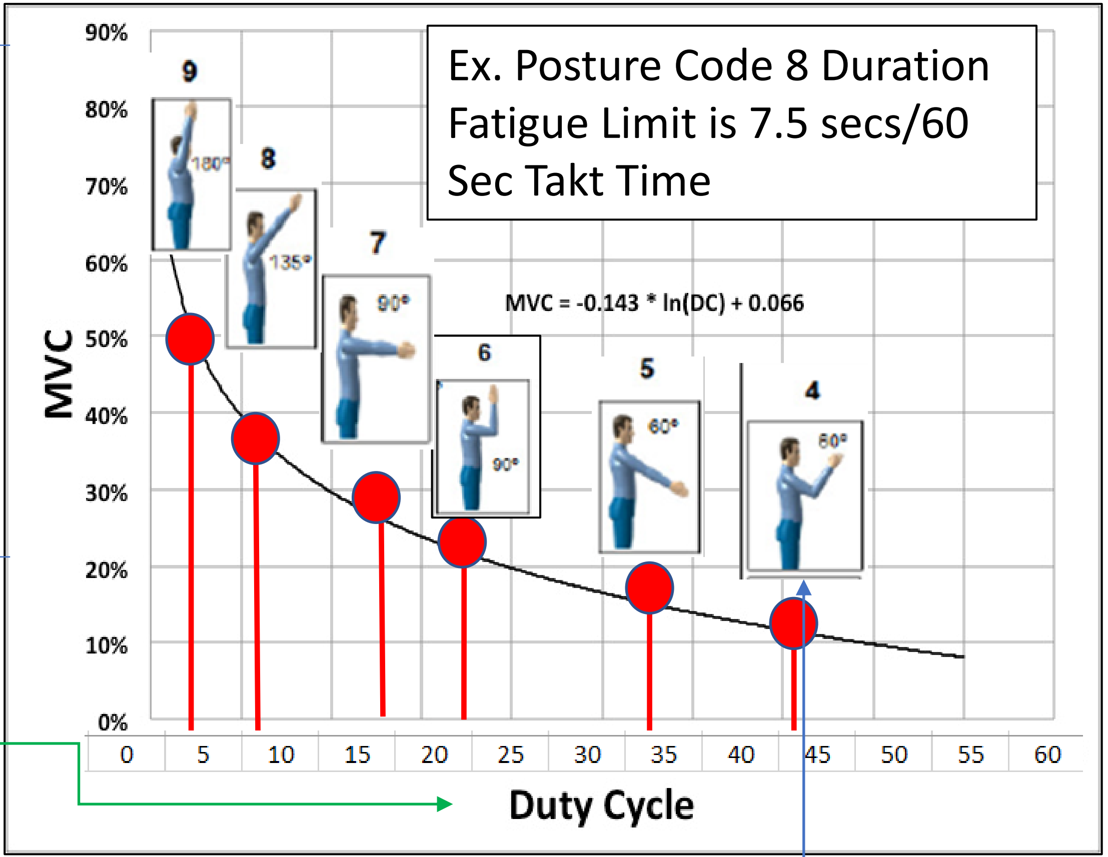
- **Risk Assessment Methodology**



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 needs 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	90° 6	90° 7	135° 8	180° 9	90° 6	90° 7	135° 8	180° 9	90° 6	90° 7	135° 8	180° 9	90° 6	90° 7	135° 8	180° 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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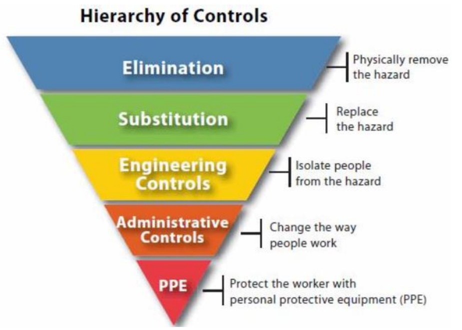
Plan: Ergonomic/H&S Management Systems

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 associocited with completing this trial:

Signature:______________________________

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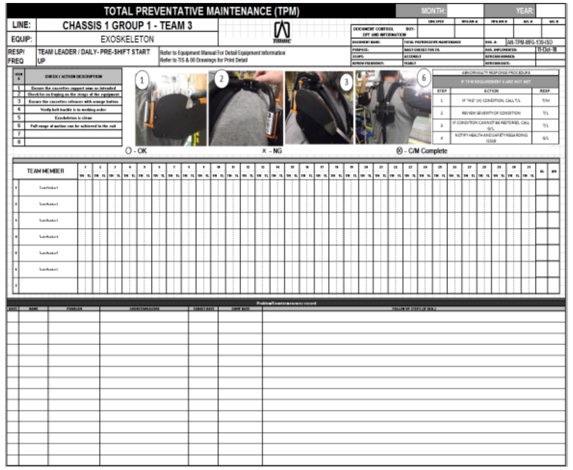
Plan: Other Considerations

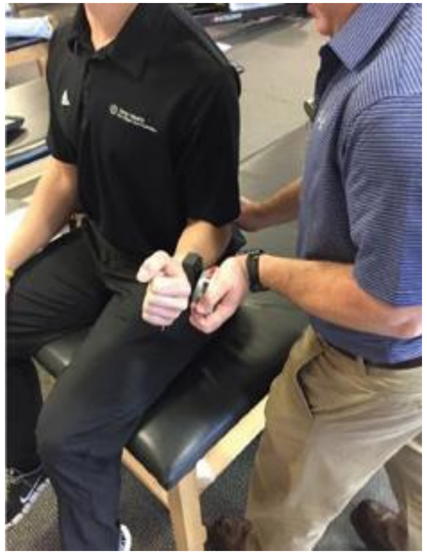
Addressing Users Fit/Comfort Concerns:

- Train/Educate Users
- Measure/Size Users for appropriate use
- Document Users concerns
- Work with vendor for product improvements



Checking System Function/Compliance:

- Create schedule for maintenance
- Review deficiencies and follow up
- Check and document users compliance/methods



Personal Condition Monitoring/Screening:

- Screen users to predict potential concerns
- Develop surveillance program
- Have means of contacting and review any arising issues

Equipment Storage/Location:

- Ensure units are stored close to task
- Create/maintain a clean and organized location

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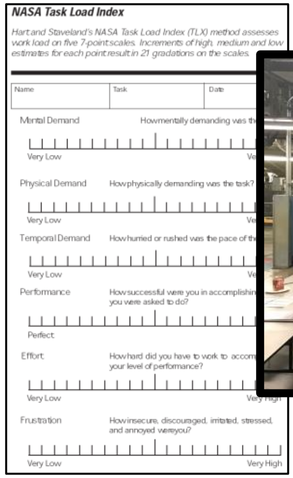
Do: Exoskeleton Implementation Action Items

Exoskeleton Implementation Plan

Implementation Activity	Group Responsible: Lead	Group Responsible: Support	Year: Month1 W1	W2	W3	W4	Month2 W5	W6	W7	W8	Month3 W9	W10	W11	W12	Month4 W13	W14	W15	W16	Month5 W17	W18	W19	W20	Month6-> W21	W22	W23	W24	Status
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 th
Very Low

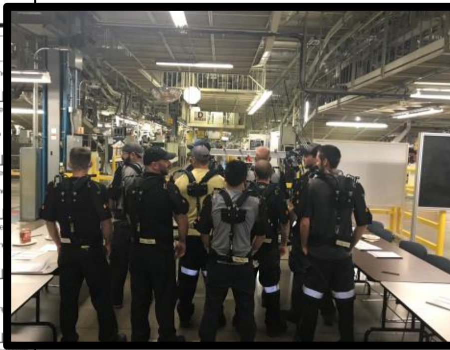
Physical Demand — How physically demanding was the task?
Very Low

Temporal Demand — How hurried or rushed was the pace of th
Very Low

Performance — How successful were you in accomplishin you were asked to do?
Perfect

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

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



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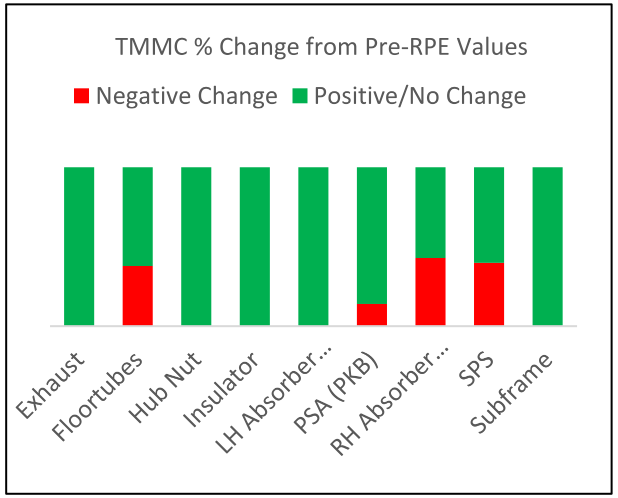
Check: Trial Comparison

	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%

*Internally Created

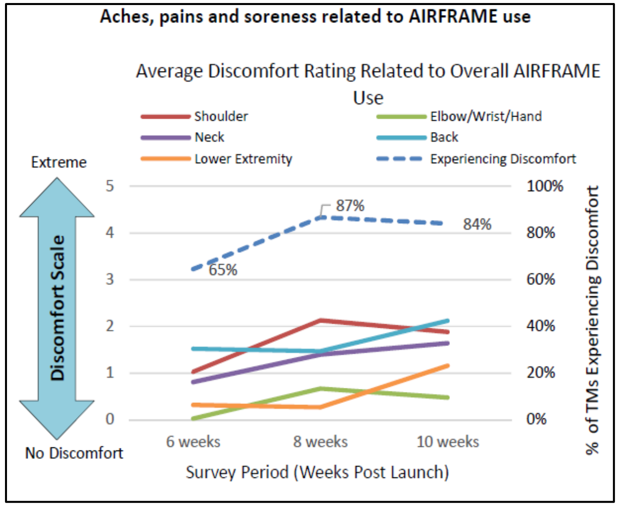
Check: Subjective Trial Measurables

Rating of Perceived Exertion (RPE)



Initial Results -5/9 Processes Evaluated at 100% Positive Change. Others at >50% Change

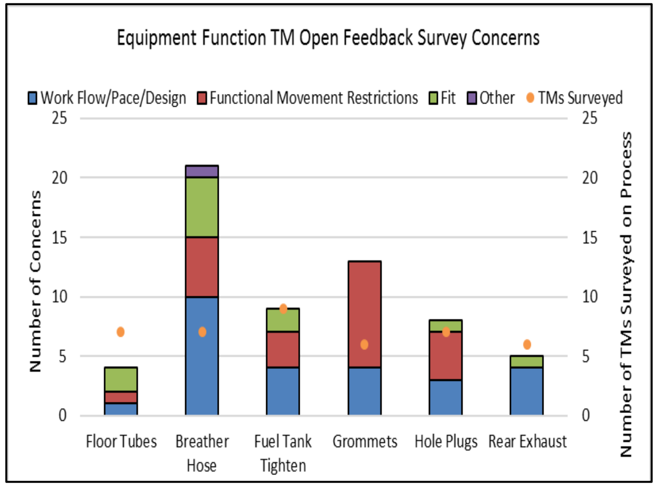
*Discomfort Survey



Initial Results - 88% Positive Change (Pre-Post Usage).

Current Results – TM discomforts increased overtime with increased production rate

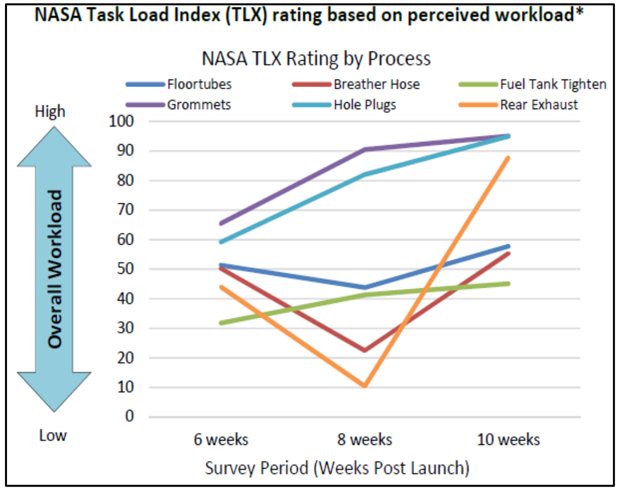
*Equipment Functional Scoring (EFS)



Initial Results - 93% Positive Change (Pre-Post Usage)

Current Results - TM's Concerns with Workflow/ Pace/ Design as the top issue

NASA Task Load Index (TLX)



Current Results – Perceived Workload increased overtime with increased production rate. Also validates Equipment Function Score

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Check: Objective Trial Measurables

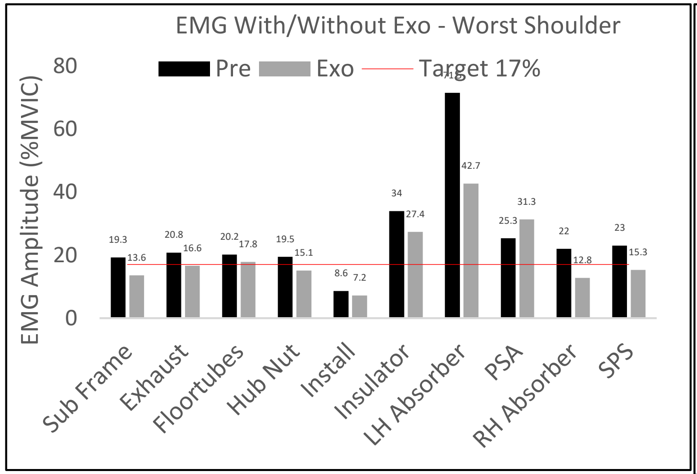
Injury/Discomfort Rate

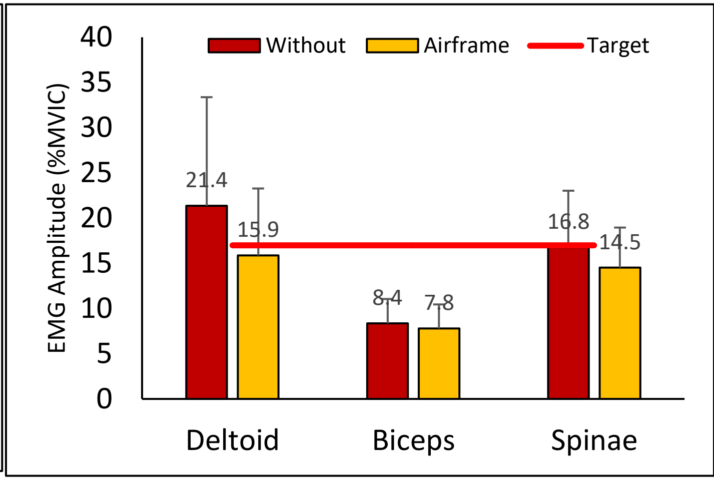
Initial Results – 200% Injury Rate Improvement Comparing Set periods of Exoskeleton Intervention vs Non-Intervention

Current Results – 133% Injury Rate Improvement comparing set periods of Exoskeleton Intervention vs Non-Intervention

Electromyography (EMG)/Muscle Fatigue

Initial Results - 8 out of 9 process show significant change in decreased %MVIC on larger shoulder and back muscle groups

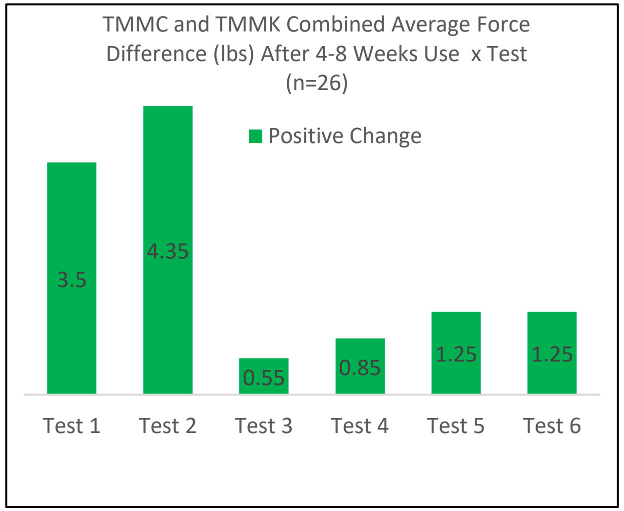




Gillette J.C. & Butler T. (2018). EMG-based ergonomic analysis of the Levitate Airframe at Toyota Canada. Toyota Motor Manufacturing Canada.

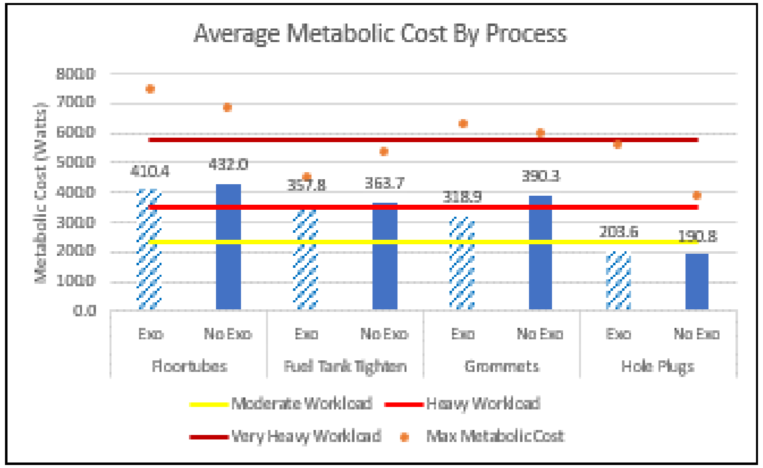
Strength Testing/Conditioning

Initial Results – No evidence on strength conditioning loss during Exoskeleton intervention



Energy Expenditure (HR/VO2)

Current Results - 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: Suit Integration Requirements – "Levitate"

Path to successful integration of Levitate Airframe exoskeleton...

Review each of the criteria below with a ✔ when condition is met or **X** if condition has not been met. If any **X** conditions are present, successful exoskeleton integration may be compromised

Process Design

Ensure the process design for overhead work can achieve the following capabilities through fixed or adjustable design:

Should not exceed:

- ☐ Head clearance 190 cm minimum
- ☐ Achieve max vertical grip reach of 170 cm
- ☐ Minimum vertical reach of 88 cm
- ☐ Shoulder duration within TLV[1]
- ☐ Shoulder posture angle max 135° (TEBA posture code 8)

Ideal Condition:

- ☐ Lateral reach beyond midline of 30 cm
- ☐ Individual shoulder repetition rate <2.5 reps/min

Job Fit

Individuals eligible should be able to achieve the following within the fixed or adjustable design:

Strongly Recommended:

- ☐ Maintain neutral standing posture at the minimal head clearance on process
- ☐ Achieve max vertical grip reach on process without compromising whole body posture (i.e. stand on tip toes, over reach)
- ☐ Should not reach beyond a shoulder angle of 135° for any elements
- ☐ Should not be required to bend for any elements on the process

Medical Screening

Individuals should complete medical screening prior to determine elligibility for exo fit.

Must have:

- ☐ Should not have any pre-existing medical condition (as determined by screening process) that may result poor fit and function[2]

AIRFRAME Fit

Individuals eligible should be able to achieve the following fit within equipment

Must have:

- ☐ Appropriate suit size for individual

Strongly Recommended[3]:

- ☐ No residual rubbing/digging from strap position
- ☐ Achieve appropriate cuff size/length
- ☐ Appropriate head/neck clearance to avoid contact from suit
- ☐ Appropriate back pad/spine contact with suit

Exoskeleton Integration Success Determination

Individuals eligible should be able to achieve the following fit within equipment

Must have:

- ☐ TM can work within min and max process design requirements with shoulder posture angle <135° and no back bending
- ☐ TM does not have any pre-existing medical concerns that could impact fit and function as determined by health care professional
- ☐ TM does not have any residual fit concerns as determined by fit specialist

[1] If shoulder postures required on the process are below the threshold limit value (TLV) an exoskeleton is not required on the process.

[2] Pre-existing medical concerns are determined in conjunction with processes established with the Health Centre.

[3] Appropriate fit should be determined by the designated fitting expert

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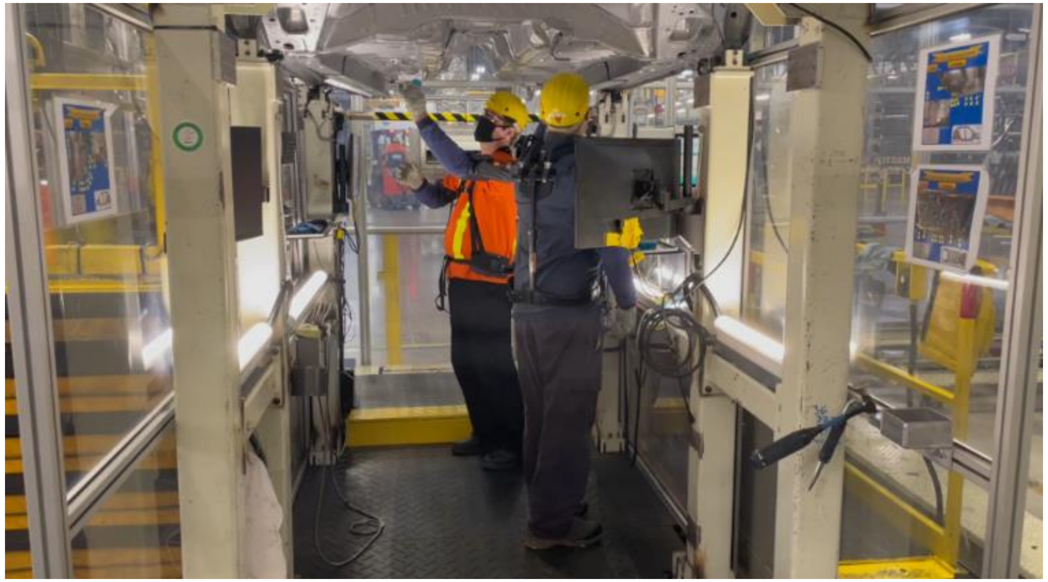
Act: Comparison of Successes and Challenges

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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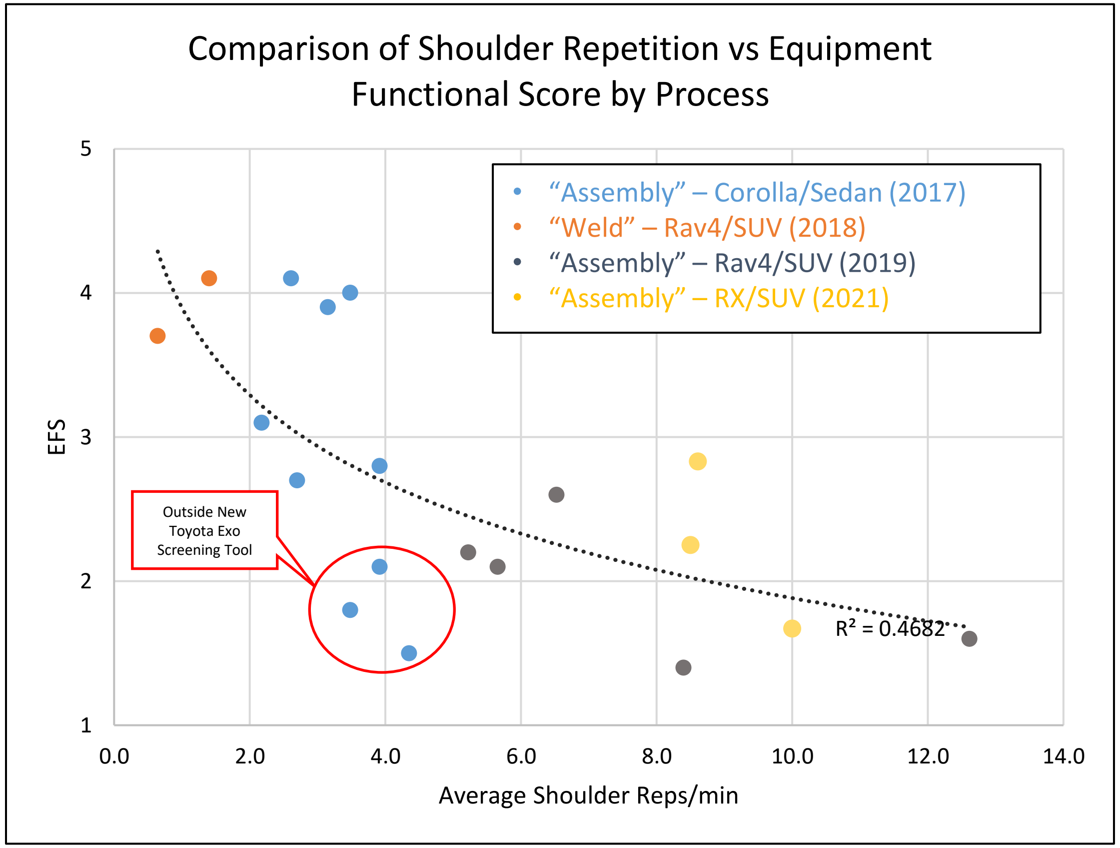
Act: Comparison of Successes and Challenges

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 4 Years

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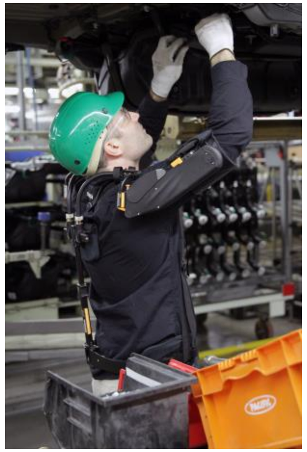
Act: A Call For Research - Current

Why is this task adopted as mandatory by users and management…………………….. but not this?



2018 → 2022+

202X?

Long Term Usage:
- Determine the long term affects of continued Exoskeleton usage

How to Engage More Assembly Usage:
- Define "dynamic" vs "static" work task benefit/limitations and improve process selection tool/process design variables

National Institute for Occupational Safety and Health
NIOSH

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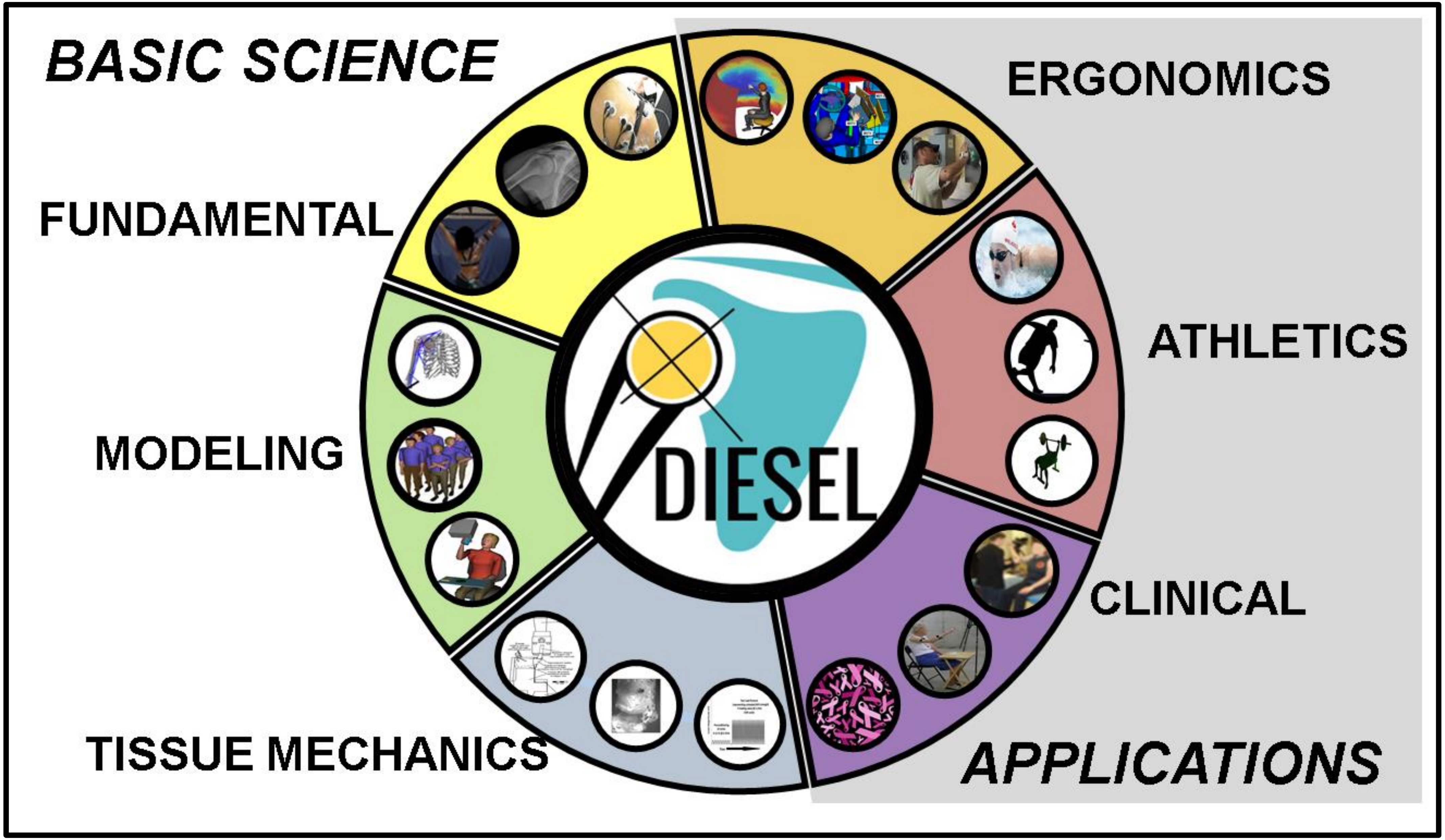

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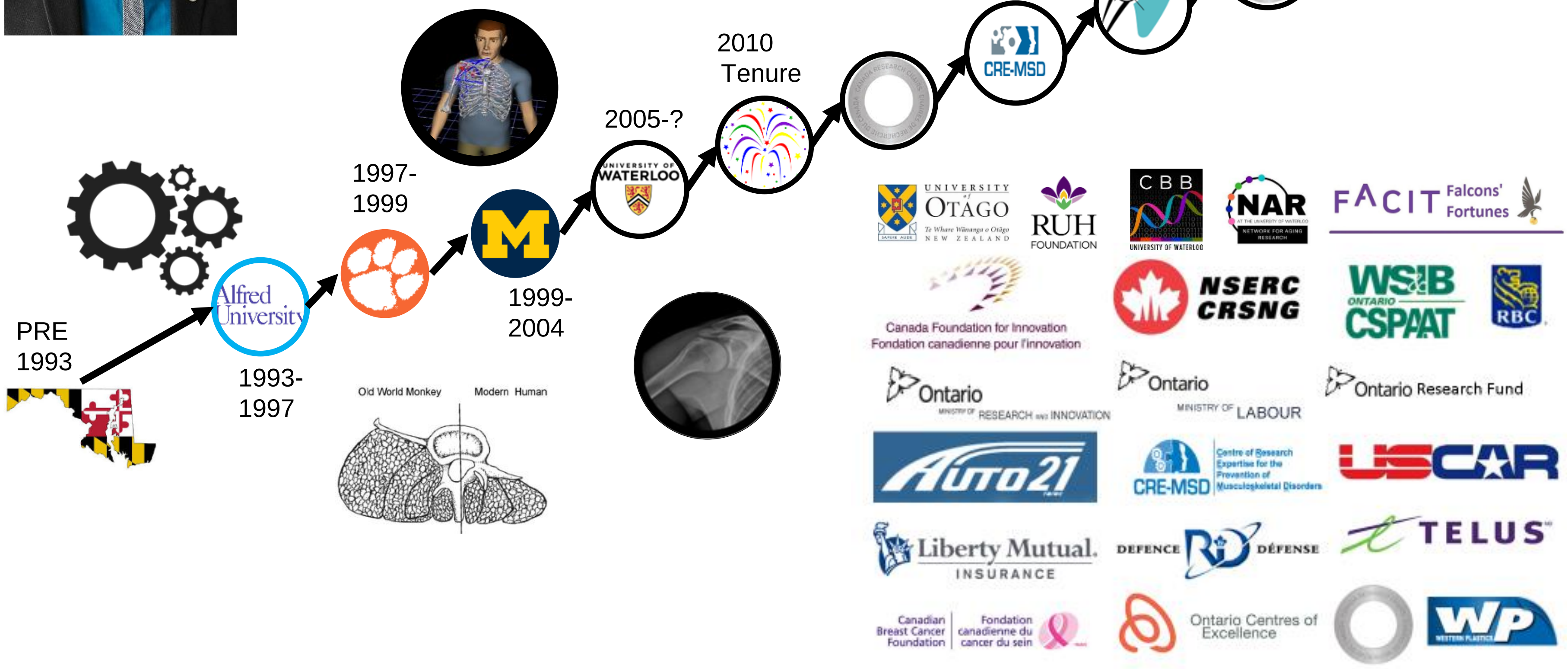
~29 Years Mechanics (23 Shoulder)

Clark Dickerson , PhD, CCPE

Professor & Canada Research Chair,
University of Waterloo



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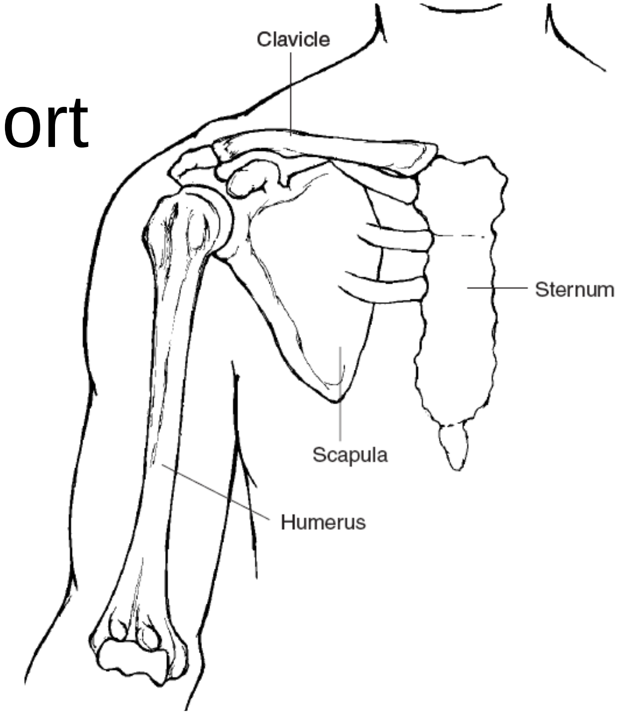
Shoulder Pathomechanics

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



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

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Special Issue

Between Two Rocks and in a Hard Place: Reflecting on the Biomechanical Basis of Shoulder Occupational Musculoskeletal Disorders

Clark R. Dickerson, **Alison C. McDonald**, University of Waterloo, Canada, and
Jaclyn N. Chopp-Hurley, York University, Canada

Why Supraspinatus

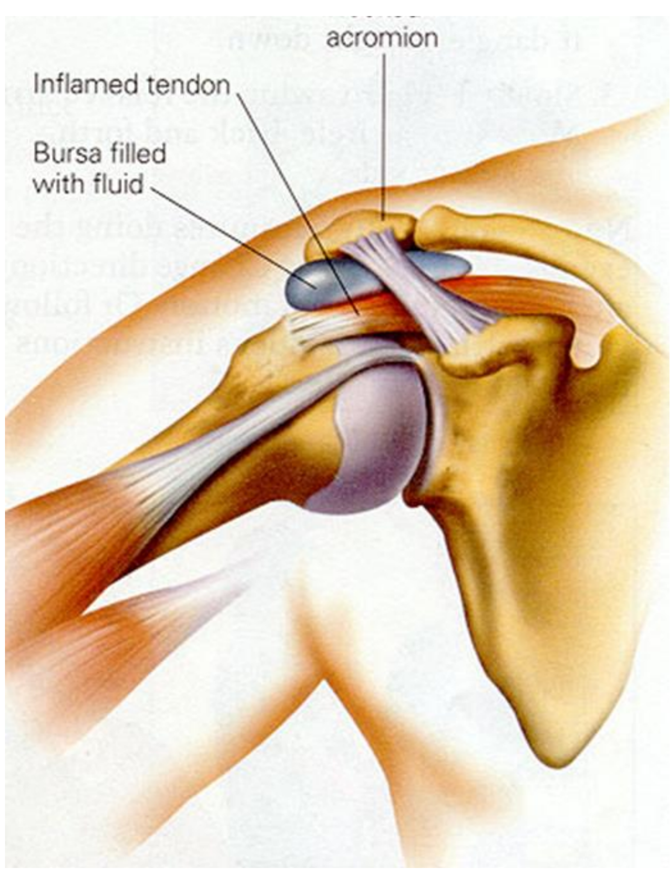
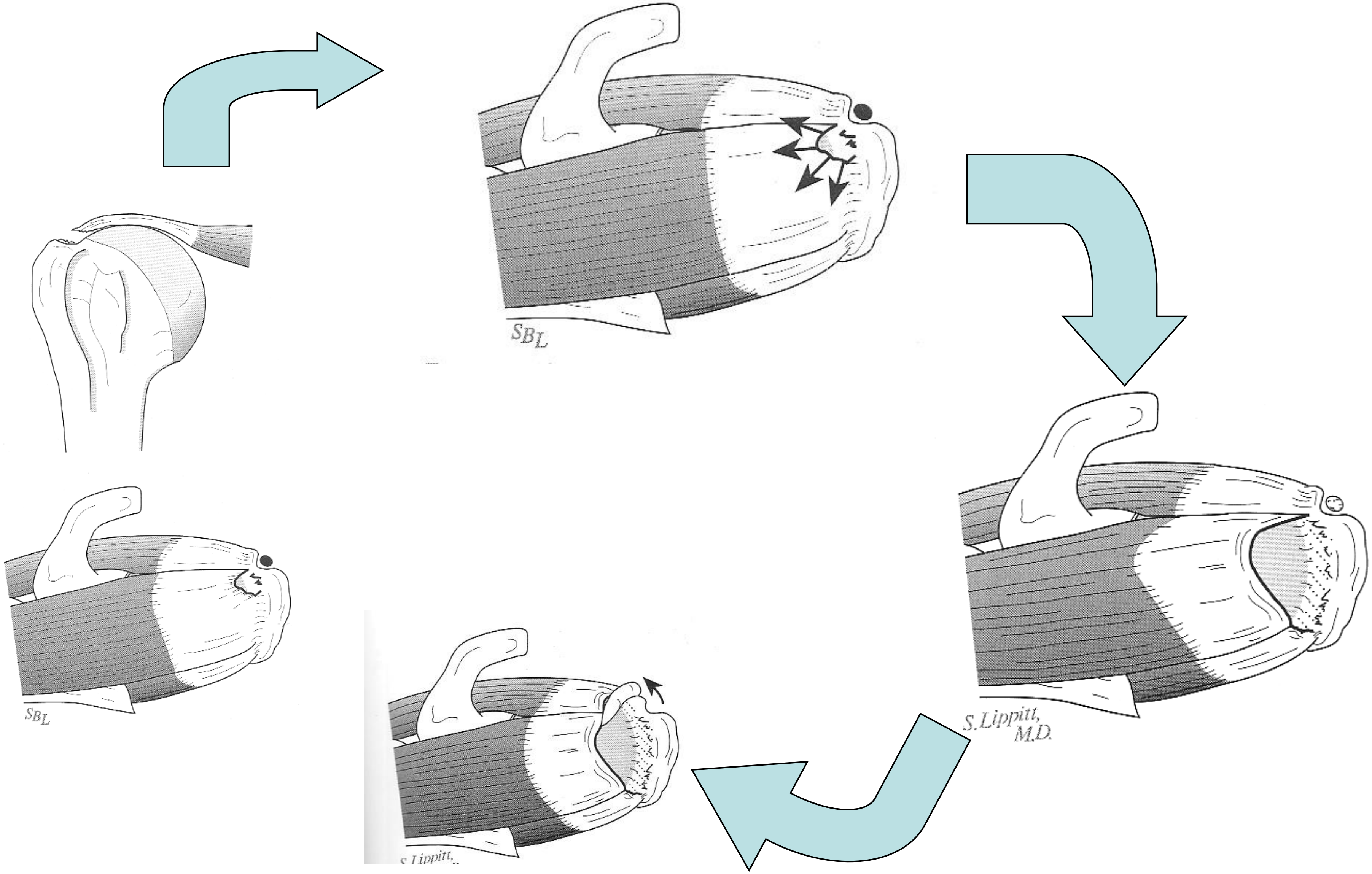


TABLE 1
Site of Rotator Cuff Tears

Torn tendons	No. of shoulders
Supraspinatus	19
Supraspinatus + infraspinatus	11
Supraspinatus + infraspinatus + subscapularis	5
Total	35

(Itoi, Kido, Sano, Urayama, & Sato, 1999)

Progressive Rotator Cuff Deterioration



(modified from Masten et al., 1994)

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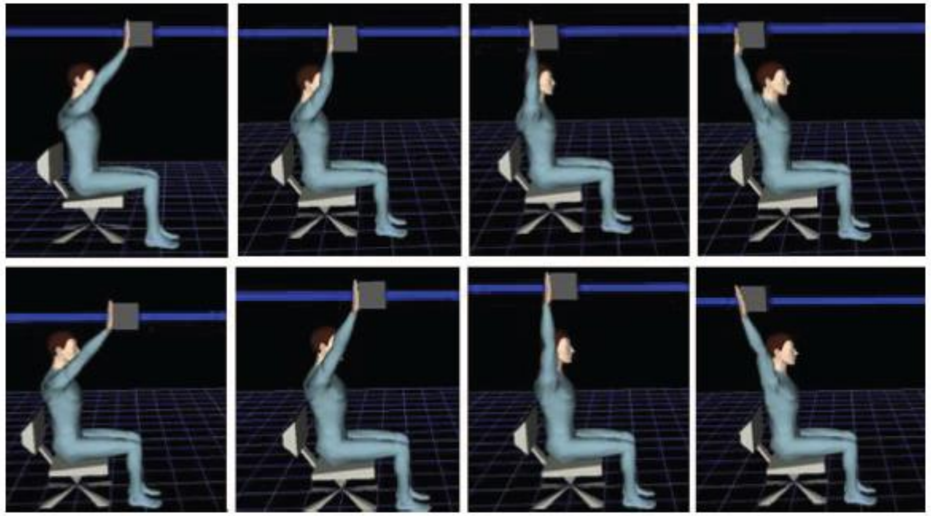
Overhead Work

Overhead work: Identification of evidence-based exposure guidelines

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



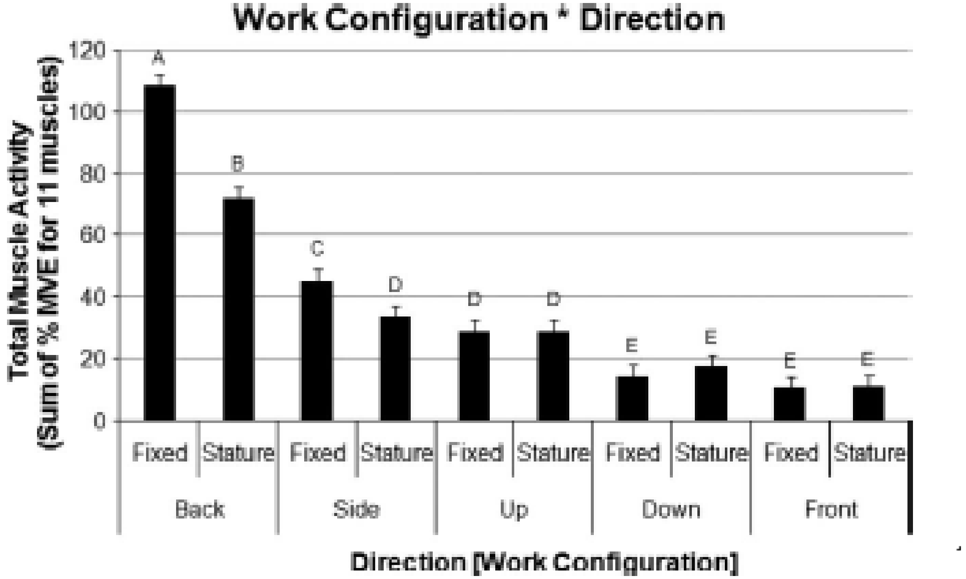


Table 1 Key factors to consider for jobs that include overhead work (extracted from Fischer *et al.*[30])

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

Work Presentation also influences responses


Journal of Biomechanics 48 (2015) 2911–2918

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journal homepage: www.elsevier.com/locate/jbiomech www.JBiomech.com

The influence of cycle time on shoulder fatigue responses for a fixed total overhead workload

Clark R. Dickerson [a,*], Kimberly A. Meszaros [a], Alan C. Cudlip [a], Jaclyn N. Chopp-Hurley [a], Joseph E. Langenderfer [b]

[a] Faculty of Applied Health Sciences, University of Waterloo, 200 University Ave W, Waterloo, Ontario, Canada ON N2L 3G1

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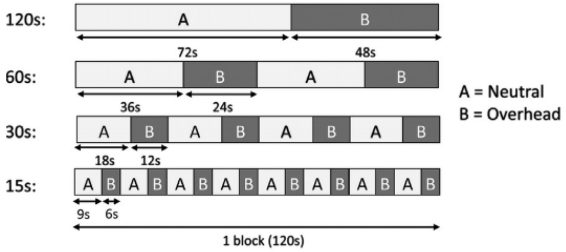
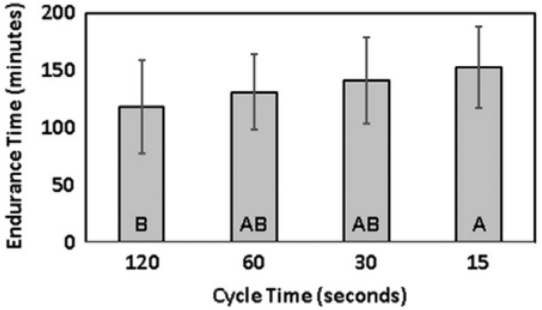
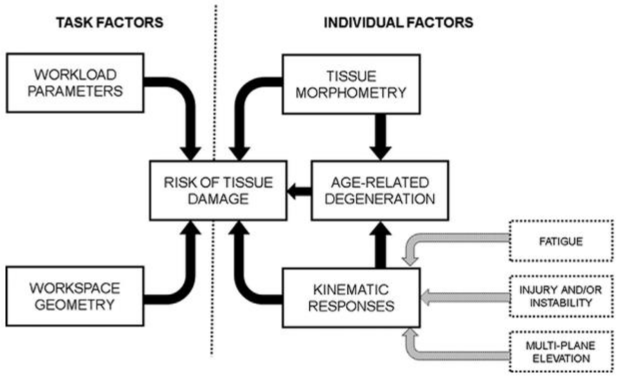
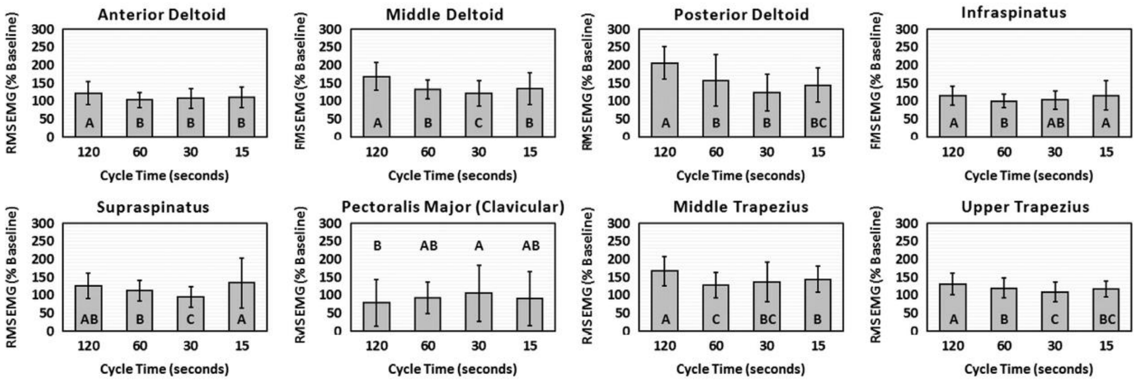




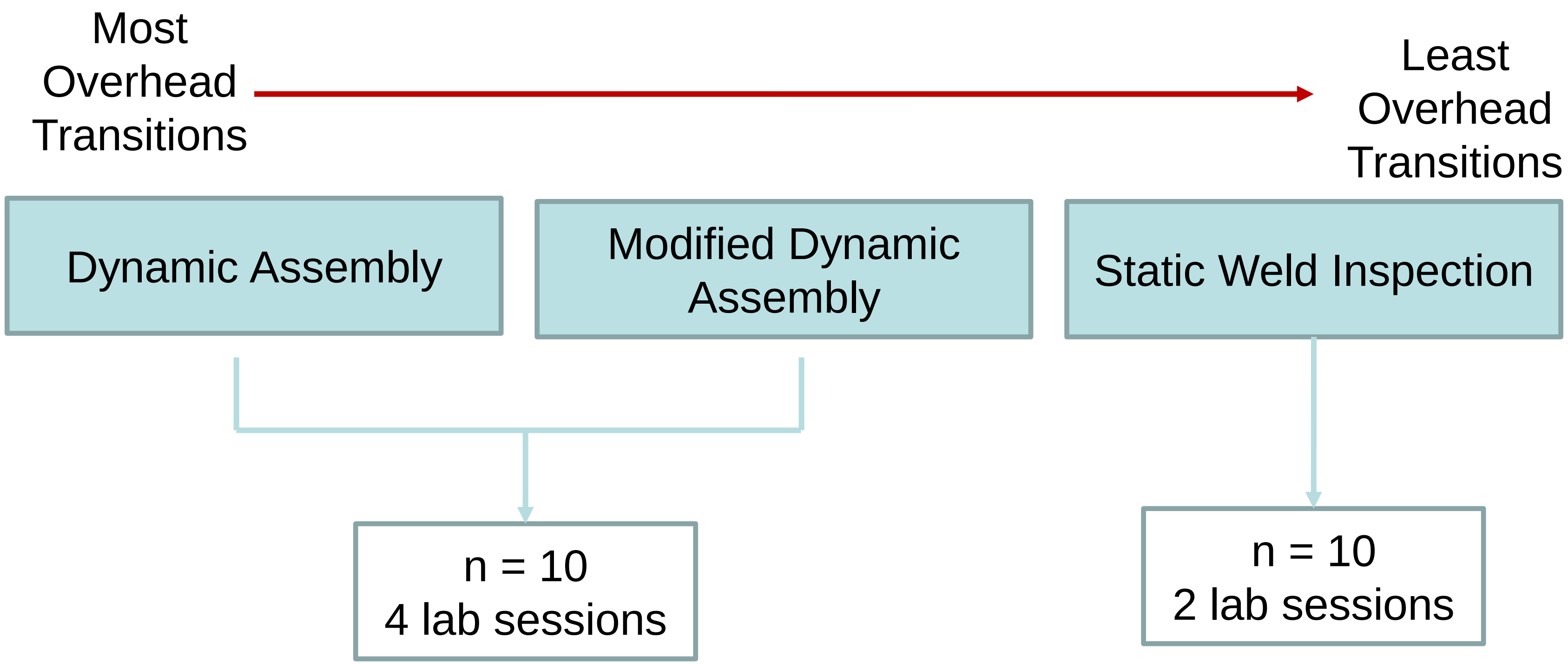




Goals of the UW/Totoya Partnership

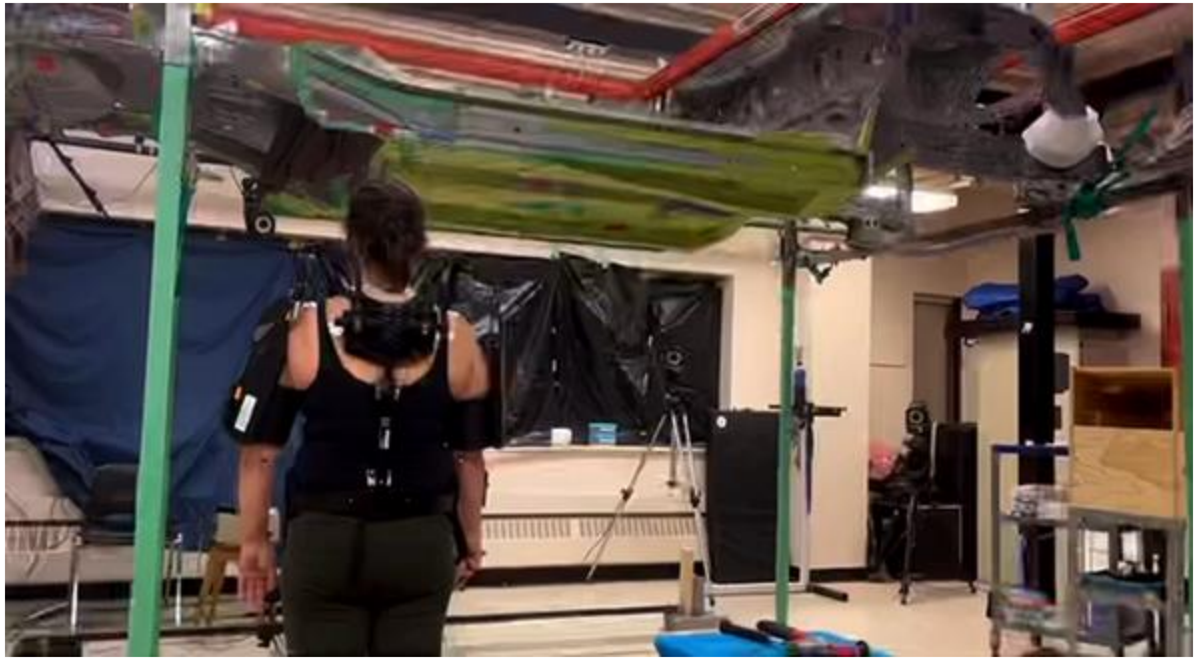
- Assess exoskeleton effectiveness
  - New metrics (fatigue, kinematics, cuff)
  - More varied and workplace emulative tasks
    - Sustained overhead vs intermittent (2 levels)
    - Represented actual tasks
  - Advanced fatigue evaluation
  - Evidence-based implementation guidance

Task Types


Most Overhead Transitions
Least Overhead Transitions
Dynamic Assembly
Modified Dynamic Assembly
Static Weld Inspection
n = 10
4 lab sessions
n = 10
2 lab sessions

Static Weld Check Task

- Total cycle time = 20 minutes
  - Ultrasound gel application
  - Ultrasound check
    - Unilateral static holds
  - Hit check
    - Bilateral tool use



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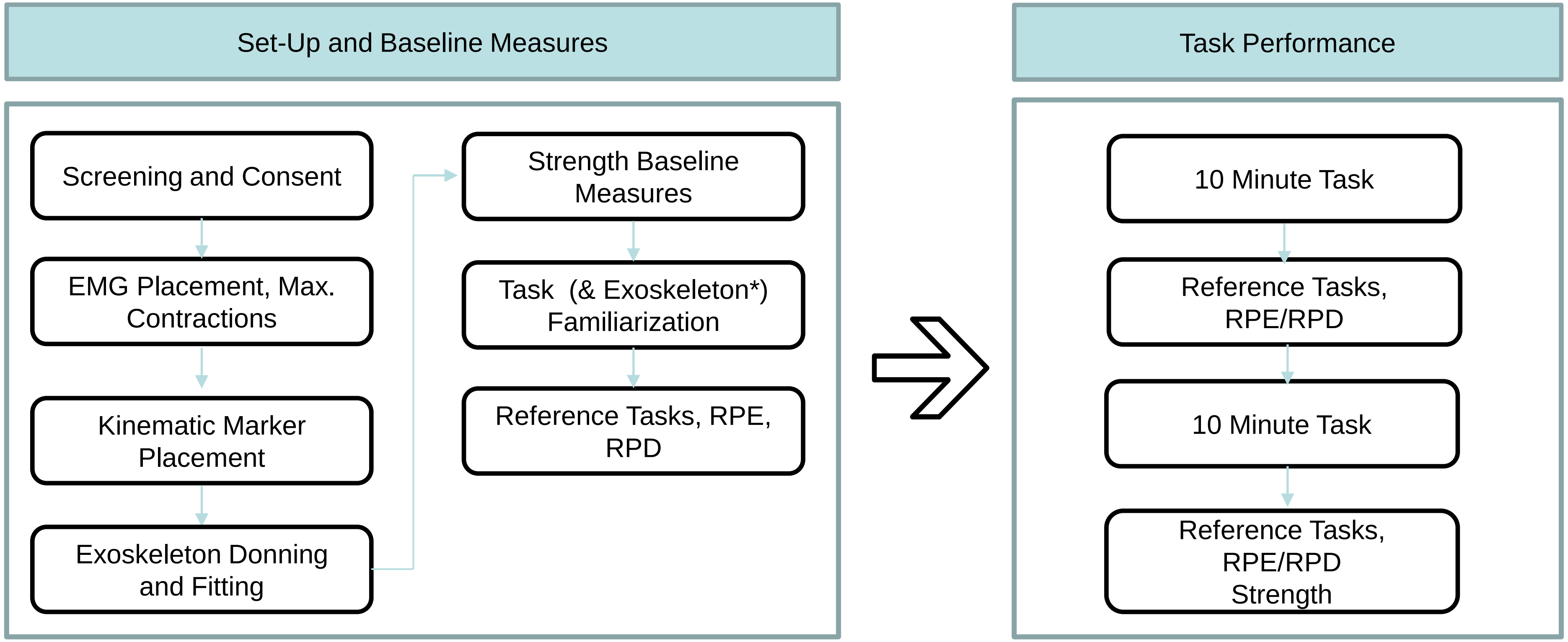
Dynamic Assembly Tasks

DYNAMIC

MODIFIED DYNAMIC

Cycle time = 67 seconds

Experimental Protocol



Various Experimental Measures

- Kinematics
  - Upper arm, forearm, hand
  - Torso
- Electromyography (muscle activity)
  - Anterior Deltoid
  - Middle Deltoid
  - Upper trapezius
  - **Supraspinatus**
  - **Infraspinatus**
  - Upper and lower erectors
  - Abdominals
- Subjective feedback
  - Perceived Effort
  - Perceived Discomfort at multiple body regions
- Strength
  - Arm elevation
  - External Rotation
  - Back Extension

Strength Assessments

External Rotation

Elevation

Back Extension

Fatigue Reference Tasks

Kinematic Reference Task
Reaching

EMG Reference Task
Static Hold in Scapular Plane

Study Data 'Sneak Peek'

- Limited to discussion of:
  - Perception data
  - Supraspinatus fatigue assessment (partial)

- Note much more to come:
  - Kinematic changes
  - Many more muscles
  - Strength assessments
  - Detailed individual and pooled comparisons
  - Holistic integrated response data
  - Implementation guidance

Research to Application

The primary questions to be addressed by this study are:

1. Does the exoskeleton produce both transient (immediate) and persistent (fatigue resistance) EMG changes? Do short-term responses correspond to complete shift changes?

2. Does exoskeleton support level result in different muscular demands for fundamentally different work tasks in terms of static or dynamic requirements (example tasks would be Weld and Assembly processes at TMMC)

3. Which muscles are influenced by exoskeleton use? Are there differences in muscular fatigue indicators?

4. Are strength changes throughout the shift modulate by exoskeleton use?

5. Are there postural or kinematic strategy differences with and without the exoskeleton?

6. Does the device modulate psychophysical (discomfort) responses, and if so how much does this depend on the type of work occurring?

Answers….. TBD

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Q&A

TOYOTA CARES

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