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THE CENTER FOR CONSTRUCTION
RESEARCH AND TRAINING

CPWR Small Study Program

September 29, 2021

Overview of Presentation

Overview of CPWR's Small Study Program, Trish Quinn

Protocol for assessing human-robot interaction safety risks, University of Alabama, Dr. Chukwuma Nnaji

Identification and assessment of musculoskeletal disorders risk for concrete formwork systems, Oregon State University, Dr. John Gambatese and Dr. Ziyu Jin

Q&A, Jessica Bunting

Small Studies Program

- CPWR initiated the Small Study Program in 1993 with a three-part mission:
  - to attract new investigators into the field of construction safety and health research
  - to help define problems, investigate targeted research priority areas, and
  - to conduct and pilot hypothesis-generating research
- Provides seed money of up to $30,000 and the flexibility to initiate short-term studies (up to 12 months)
- For a study to be considered, the topics must be related to CPWR's mission and respond to industry-driven priorities -- including NIOSH strategic goals, the National Occupational Research Agenda (NORA) for Construction, and more recently the 2018 NIOSH Construction Program Expert Panel Report recommendations.
- 127 studies have been awarded

Small Studies Program – Priority Areas

During the current funding period, priority is being given to studies aimed at:

- Finding innovative approaches to reduce the spread of COVID-19 in the construction industry through ventilation, distancing, and respirators
- Reaching high risk populations: small employers, vulnerable workers, residential and light commercial construction contractors
- Getting best practices adopted – research to practice (r2p) -- and finding ways to overcome the barriers for intervention adoption.
- Addressing emerging issues and exploring new technologies
- Improving safety culture and safety climate
- Exploring innovative or new directions in construction sciences
- Evaluating promising research translation products
- Disseminating good practices to small employers

CPWR is particularly interested in studies that plan to work with and/or target small employers (<20 employees) in the U.S. construction industry

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A-Z Index   Lista de recursos en español

Search

RESEARCH   TRAINING   SERVICE   NEWS & EVENTS   ABOUT CPWR

RESEARCH

Home › Research › Small Study Program

Small Study Program

CPWR is now accepting applications for funding from the Small Study Program

CPWR's Small Study Program provides seed money of up to $30,000 to investigate promising new research initiatives. Many major research projects began with a Small Study to demonstrate its viability or test the approach, and other studies have resulted in important stand-alone projects. A survey of researchers funded under this program found that more than 60 percent had published their findings in peer-reviewed journals.

We encourage innovative research proposals focused on:

- Reaching high-risk populations: small employers, vulnerable workers, residential and light commercial construction firms
- Developing applicable, practical interventions
- Engaging stakeholders, through partnerships and other means, to better understand the barriers to and motivators for adoption of best practices
- Addressing emerging issues and exploring new technologies
- Evaluating promising research translation products and dissemination strategies
- Disseminating good practices to small employers

← RESEARCH

Research Projects −

- Current Research
- Completed Research
- Published Research +
- Small Study Program

Data Center +

Research to Practice (r2p) +

Training and Awareness Programs from Research +

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Small Study Program Guidelines

Instructions for applying

June 2021

8484 Georgia Avenue
Suite 1000
Silver Spring, MD 20910

PHONE: 301.578.8500
FAX: 301.578.8572

How to apply

Deadline	A study may be proposed at any time by submitting a LOI (letter of intent)
Length of LOI	No more than 4 pages
Required LOI contents	Applicant organization PI credentials, contact information Study title
	Summary of the proposed study, including aims and objectives, methods, research/design, and selected references showing how this study contributes to knowledge in the field. The following are suggested questions to consider: ✓ What are the expected outcomes/products? ✓ How will the outcomes be measured? ✓ What does the investigator expect to find? What might be next? ✓ What partnerships and plans will help obtain access to workers/worksites? ✓ What is the dissemination plan? ✓ What is the plan for human subjects protection? ✓ What is the proposed timetable and estimated budget? Reminder: The funding ceiling for a study is $30,000 in total costs and must be completed in 12 months or less.

More information

Trish Quinn

301-495-8521

pquinn@cpwr.com

Small Study Program – www.cpwr.com

CPWR Small Study No. 20-4-PS

Protocol for Assessing Human-Robot Interaction Safety Risks

September 29, 2021

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Oregon State University

Meet the Team

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Civil, Construction and
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The University of Alabama

John Gambatese, Ph.D., PE(CA)
Professor,
School of Civil and Construction
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Ifeanyi Okpala, MS, PMP
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Civil, Construction and
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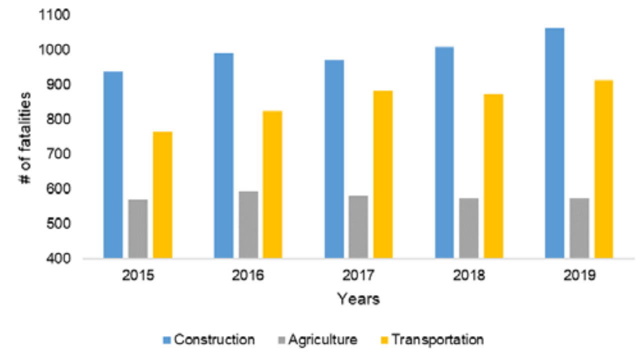
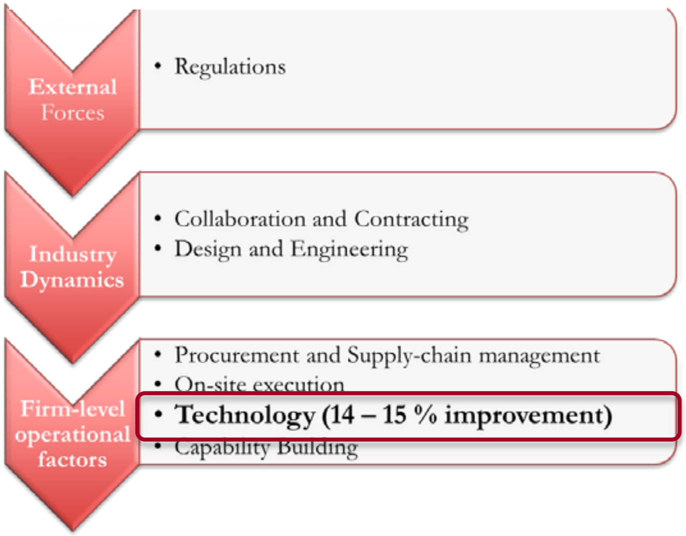
US Construction Industry Overview

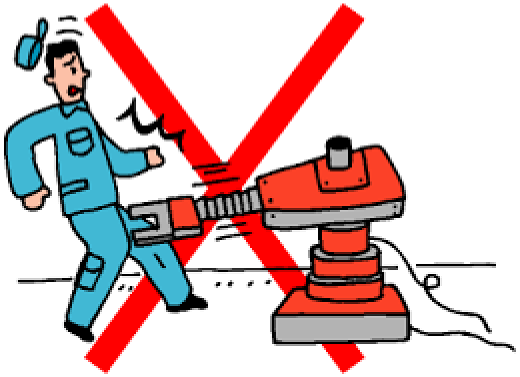
- ➢ Contributes approximately 4% of gross domestic product (GDP) (13%, globally)
- ➢ Employs ~ 9.6 million in US
- ➢ ~ $1.2 trillion in expenditure
- Growth in productivity alone could contribute $1.6 trillion globally
- Over $100 billion lost to accidents

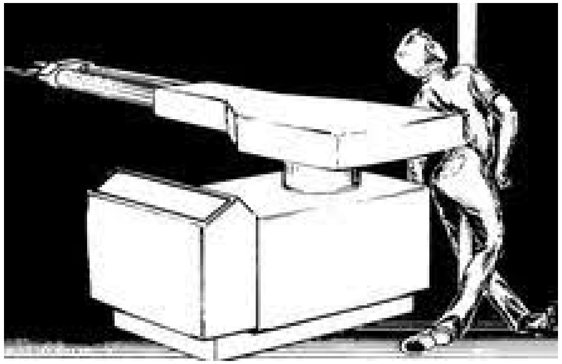




Source: Statista (2017)
BLS (2020). https://stats.bls.gov/iif/oshwc/cfoi/cfch0014.pdf
OECD; WIOD; GGCD-10, World Bank; BEA; BLS; national statistical agencies of Turkey, Malaysia, and Singapore; Rosstat; McKinsey Global Institute analysis

Human-Robot Interaction (HRI) Safety Risks





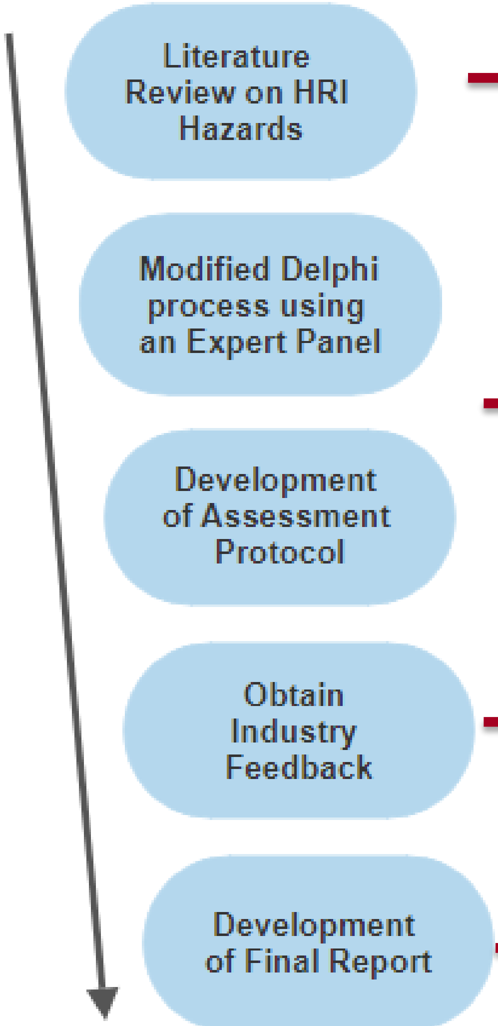
Robot and Automation (RA)

Goal and Objectives

- **Goal**: provide practical resources for practitioners to identify and quantify human-robot interaction (HRI) hazards

- **Objectives**:
  I. Identify HRI hazards associated with the use of RA
  II. Assess the safety risk level of each hazard across RA levels and tasks
  III. Identify effective strategies for eliminating or reducing the impact of the safety risk on workers
  IV. Develop an HRI safety risk assessment protocol

Methodology



Reviewed gray and academic literature

- Google Scholar, Web of Science, and Scopus, NSC, CPWR, Construction Drive, ENR

Select expert panel

- Industry and Academia
- 3-round process

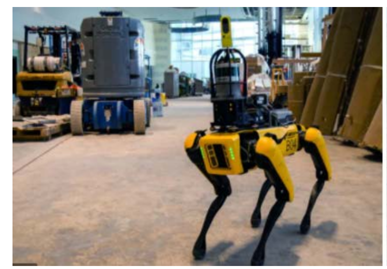
Interview safety professionals

Final Report

- Robotic Systems Assessment Manual
- HRI Assessment Protocol

Results: Review

- **40** hazards associated with the use of RA for construction operations
- **Three** levels of RA
- Classified RA-related hazards into **seven** groups
- **22** potential strategies for mitigating Human Robot Interaction (HRI) safety risks
- **26** RA adoption factors



Delphi RD 1: Hazards Associated with RAs

- **29** complete responses (representing 17 academics and 12 from practice)

- Expert panel is predominantly familiar (**>86.2%** of the panelists) with all three RA categories/levels

- Identified hazards strongly associated with each RA level
  - Wearable robots (**13**)
  - Remote operated robot (**11**)
  - Single-task robots (**12**)

Delphi RD 2: Safety Risk Rating

- Panel assigned risk level (frequency and severity) to each hazard for the different tasks and RA
- Determine different safety risk levels using safety risk assessment structure utilized in different industries (Neubauer et al. 2015)
- Group agreement (Kendall W, Standard deviation, Cronbach's alpha, P-value)

Severity scale conversion				
Near miss	Negligible	Minor first aid	Lost worktime	PD, Fatality
0	1	17	158	14282
Frequency scale conversion				
1/10years	1/year	1/month	1/week	1/day
0.000044	0.00044	0.0053	0.0333	0.111

Frequency \ Severity	0	1	17	158	14282
0.000044	0	0.000044	0.000748	0.006952	0.628408
0.00044	0	0.00044	0.00748	0.06952	6.28408
0.0053	0	0.0053	0.0901	0.8374	75.6946
0.0333	0	0.0333	0.5661	5.2614	475.5906
0.111	0	0.111	1.887	17.538	1585.302

E= Extremely high risk	>6.3
H = High Risk	0.0334 - 6.3
M = Moderate Risk	0.00045 - 0.0333
L = Low Risk	< 0.00044

Delphi RD 3: Risk and Mitigation Strategy Pairing

- Evaluated the thresholds used for the safety risk levels;
- Confirmed safety risk ratings derived from Round 2 that failed to meet the consensus requirements; and
- Established strategies for preventing or reducing the impact of hazards attributed to HRI

Hazard	Strategies	Effectiveness of strategy on risk reduction		
		Median	Mean	SD
Worker has limited mobility	• Provide clear, concise, available and up-to-date job aids accepted by the intended user population; • Incorporate manufacturer safety requirements into written company safety procedures; • Observe and adhere to the manufacturer's information on the scope of use; • Observe safety distances; • Use only robots that have been shown to be effective; • Ensure that only robots without sharp edges, crushing points or other dangerous surfaces are used; • Design work to be less complex; • Fit each worker individually with the robot before use	8	7.62	1.72

Feedback on Research Products

Focus Group Demographics				
No.	Experience (Years)	Highest Degree	Organization Type	Professional Registrations and Certifications
1	6 - 10	Graduate degree	Education	OSHA 30 or more (e.g., OSHA 510, OSHA 500)
2	6 - 10	Graduate degree	Education	OSHA 30 or more (e.g., OSHA 510, OSHA 500)
3	11 - 15	Graduate degree	Education	OSHA-authorized safety trainer
4	11 - 15	Graduate degree	Education	OSHA 10 Certification
5	11 - 15	Graduate degree	Owner Agency/ Client	- OSHA 30 Certification or more (e.g., OSHA 510, OSHA 500) - LEED Accredited Professional
6	6 - 10	Graduate degree	General Contractor	- Certified/Associate Safety Professional - OSHA 30 or more (e.g., OSHA 510, OSHA 500) - Safety Management Certificate
7	6 - 10	Graduate degree	Owner Agency/ Client	Certified/Associate Safety Professional

Tool Assessment		JHA	SDS
Ref	Verification Statement	Median	Median
Q1	Information is easy to understand.	8	8
Q2	Tool is practical (i.e., provide accurate and consistent information).	9	8
Q3	Tool would be easy to use on projects.	8	7.5
Q4	Tool is adaptable (i.e., easy to integrate into existing sheets/forms).	9	8
Q5	Tool is engaging (prompts) while being used.	9	7.5
Q6	Tool is effective (sufficient in breadth and depth).	9	9

"The safety data sheets that you have created is excellent and comprehensive. These will definitely be useful as technological solutions are increasingly adopted in construction workplaces."

"The tool is also very user-friendly and intuitive to use."

Key Findings – Summary

- **40** hazards (within **7** groups) associated with the use of RA for construction operations
- Safety risk ratings for critical hazards particular to **3** levels/categories of RA technologies, when used for **3** tasks
- **22** preventive strategies for mitigating HRI safety risks during construction operations
- **2** practical tools for hazard prevention and control

<Link to Final Report>

Oregon State University

CPWR THE CENTER FOR CONSTRUCTION RESEARCH AND TRAINING

Research Output

Robotic Systems Assessment Manual

Chukwuma Nnaji, John Gambatese, and Ifeanyi Okpala

The University of Alabama

Oregon State University

CPWR Small Study No. 20-4-PS

Safety Protocol

Assessing Human-Robot Interaction Safety Risks

Researchers:
Chukwuma Nnaji
John Gambatese
Ifeanyi Okpala

Affiliation:
The University of Alabama
Oregon State University

July 2021

Thank you for listening!

Oregon State University

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Identification and Assessment of Musculoskeletal Disorders (MSDs) Risk for Concrete Formwork Systems

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September 29, 2021

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Oregon State University

Introduction – MSDs

- **Musculoskeletal disorders (MSDs): injuries to soft tissues**
  (e.g., muscles, tendons, ligaments, joints and cartilage, and the nervous system)

- **Construction workers at significant risk of developing MSDs**
  - MSD incidence rate per 10,000 full-time workers (BLS, 2020):
    - Construction - 28.9
    - All private industries combined - 27.2
  - 34% of construction workers had at least one type of MSD symptom (Dong et al., 2020)
  - MSD rates vary by age, occupation, and work activities

Image: https://www.ishn.com/articles/112352-four-tips-to-prevent-reduce-musculoskeletal-disorders

Introduction – Concrete Formwork

- **Formwork construction - high rate of MSD injuries** (Schneider and Susi, 1994)
  - Physically demanding; awkward postures and motions

- **Types of Formwork**
  - Conventional (job-built timber/plywood) formwork
  - Prefabricated/engineered (including modular) formwork
    - Prefabricated/engineered formwork
    - Modular formwork

Research Objectives and Flow

Horizontal Formwork (Slab Formwork)

Objective #1
Identify activities related to job-built forms and prefabricated/engineered form systems

- Literature Review
- Surveys
- Observations

Objective #2
Identify work-related MSD symptoms and risk factors of form workers

- Literature Review
- Surveys

Objective #3
Determine major causes of work-related experienced by form workers

- Literature Review
- Surveys
- Observations

Objective #4
Quantify MSD risks associated with the use of different types of formwork systems (prefabricated/engineered and modular forms)

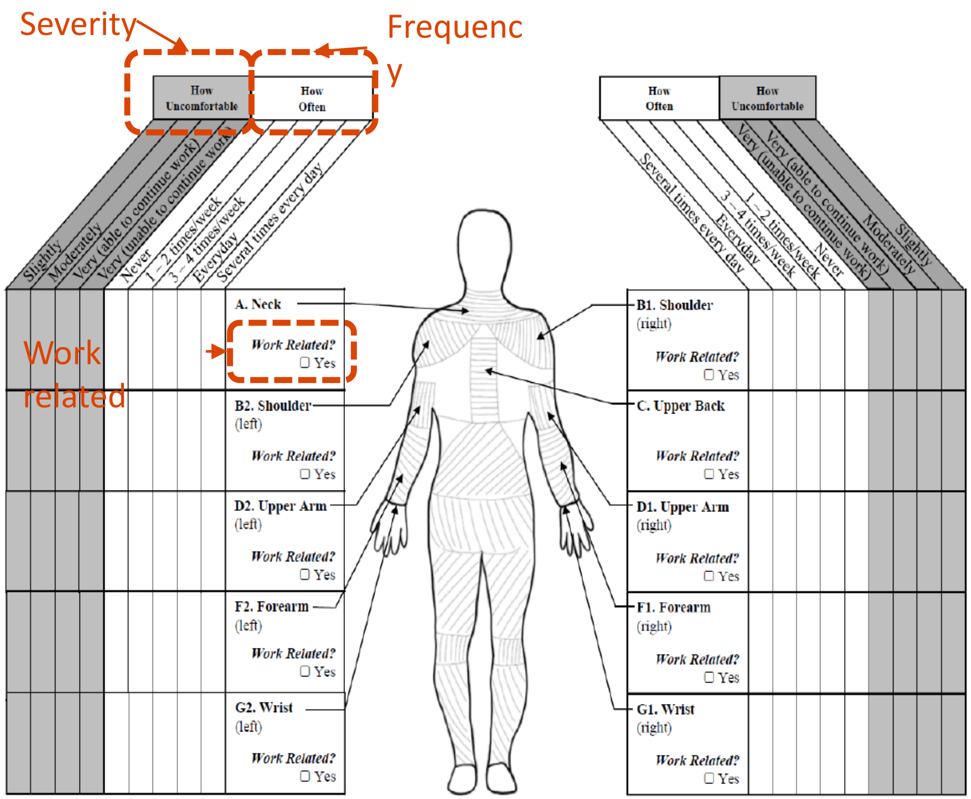
- Observations

Objective #5
Provide recommendations for MSD prevention during formwork construction

Research Methods – Self-Reports using Survey Questionnaire

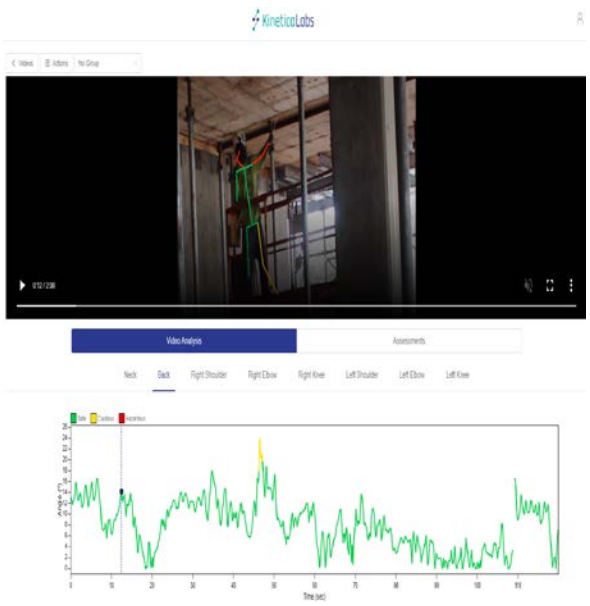
- **Survey Questions**
  - Background information
  - Formwork construction
  - MSD discomfort

- **Survey Purpose**
  - Prevalence of MSDs symptoms
  - Frequency and severity
  - Work related
  - Cause or aggravating factors



Research Methods – Observational Method for Postural Analysis

- **Observational Method**: Researcher observations or video recordings
- **Rapid Entire Body Assessment (REBA) method**
  - A whole-body postural analysis system
  - Assesses the selected posture
  - Scores each body region
  - Provides a single score
- **Ergonomic risk assessment app - KineticaLabs**



Action Level	REBA Score	Risk Level	Action
0	1	Negligible	None necessary
1	2-3	Low	May be necessary
2	4-7	Medium	Necessary
3	8-10	High	Necessary soon
4	11-15	Very High	Necessary now

Case Study Projects

Project	Location	Project Description	Type of Formwork Used	Formwork Operation Observed	Days of Visits	Worker-Hours of Observations (Approx.)
A	Beaverton, OR	Four-story apartment building	Prefabricated/ Engineered	Removal	2	9
B	Tigard, OR	Six-story apartment building	Prefabricated/ Engineered	Erection and Removal	2	13
C	Portland, OR	Two new structures and one cast-in-place underground parking structure (long-term care facilities)	Modular	Erection and Removal	3	12
D	Portland, OR	25-story mixed-use building, with four below grade floors for parking	Prefabricated/ Engineered	Erection	2	10
E	Tacom[illegible]	Six-story mixed-use building (retail space on the [illegible]	Prefabricated/ [illegible]	Erection and [illegible]	[illegible]	14

Project A

Project B

Project C

Project D

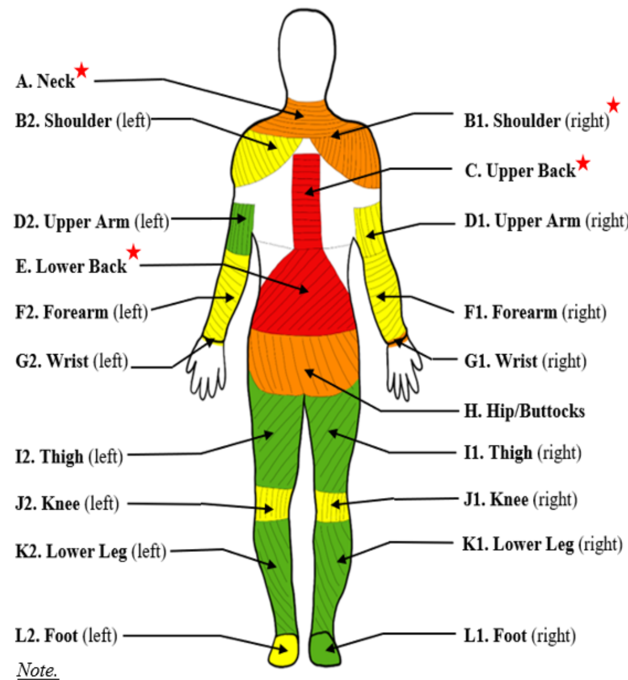
Project E

Results - Self-Reports using Survey Questionnaire

- **Participants:** 29 male workers
  - Carpenters or carpenter apprentices (76%), foremen (17%), and laborers (7%)
- **Differences in Conventional Job-Built and Prefabricated/Engineered (including Modular) Formwork Construction**
  - **Activity level:** no distinct difference
  - **Task level:** when constructing with prefabricated/engineered (including modular) formwork, less work in sawing/cutting, nailing/screwing/drilling components or other materials
  - **Participants' opinions:**
    - Prefabricated/engineered (including modular) formwork: easier and faster to build; crane/manlift
    - Conventional job-built formwork: more versatile and time-consuming

Results - Self-Reports using Survey Questionnaire (Cont'd)

- **MSD Discomfort**
  - 93% had MSD symptoms
  - MSD Risk Score: $\frac{1}{n}\sum_{1}^{n}(Frequency_i \times Severity_i)$
- **Tasks that Lead to MSD Symptoms**
  - Holding materials or components (72%)
  - Pushing/pulling formwork or other components (69%)
  - Lifting/lowering materials (69%)
  - Carrying materials (66%)
  - Hammering (66%)
- **Contributing Physical Factors**
  - Repetition (93%)
  - Awkward posture (86%)
  - Use of force (83%)



Note.
★ The aches, pain, or discomfort in the body part is considered to be ***work-related*** (specially related to concrete formwork construction)

MSD Risk Score	MSD Risk
Risk Score < 1.5	Low Risk
1.5 ≤ Risk Score < 2.5	Moderate Risk
2.5 ≤ Risk Score < 3.5	High Risk
Risk Score > 3.5	Critical Risk

Body Part	MSD Risk Score	MSD Risk
A. Neck ★	3.17	High
B1. Shoulder (right) ★	2.98	High
B2. Shoulder (left)	2.26	Moderate
C. Upper Back ★	3.71	Critical
D1. Upper Arm (right)	2.34	Moderate
D2. Upper Arm (left)	1.07	Low
E. Lower Back ★	6.66	Critical
F1. Forearm (right)	1.84	Moderate
F2. Forearm (left)	2.19	Moderate
G1. Wrist (right)	2.60	High
G2. Wrist (left)	1.62	Moderate
H. Hip/Buttocks	3.17	High
I1. Thigh (right)	0.98	Low
I2. Thigh (left)	1.28	Low
J1. Knee (right)	1.52	Moderate
J2. Knee (left)	1.66	Moderate
K1. Lower Leg (right)	0.76	Low
K2. Lower Leg (left)	1.00	Low
L1. Foot (right)	1.24	Low
L2. Foot (left)	1.93	Moderate

Results - Posture Analysis using REBA method

- **Construction Tasks Analyzed**
  1. Carry formwork components
  2. Lift/lower form components
  3. Place sheathing/modular panels
  4. Plumb shoring posts
  5. Hold form components in place
  6. Adjust form components with body parts
  7. Adjust form components using tools (e.g., hammers or pry bars)
  8. Ascend/descend a ladder or use a scissor lift
  9. Nail/screw/drill
  10. Inspect
- **Postures Analyzed:** 389 working postures

Lift a main beam

Hold a shoring post in place

Place a sheathing panel

Nail a sheathing panel to supporting members

Plumb a shoring post

Loosen a modular panel with a pry bar

Inspect with a level

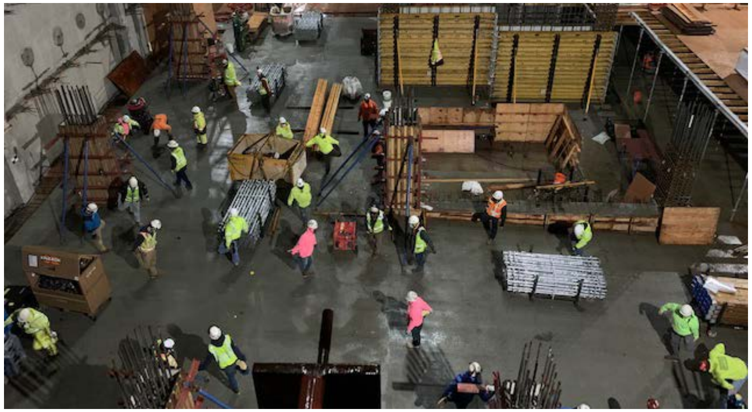
Results - Posture Analysis using REBA method (Cont'd)

- The majority of formwork tasks expose workers to between **medium and high** MSD risk levels, with REBA scores ranging from 4 to 10

- **Physical Contributing Factors**
  - Awkward postures: bend and twist; work at height with overhead reaching
  - Repetition: use of hammers
  - High force: weight of form components > 22 lbs.

- **Prefabricated/Engineered Forms vs. Modular Forms**
  - Working with prefabricated forms exposes workers to higher risk levels
    - Sheathing panels: weight (over 40 lbs.) and size (4' x 8')
    - Modular forms: size is relatively small; weight is light; integrated pieces

MSD Prevention



- **Substitution**
  Use of modular panel systems
- **Engineering Improvements**
  Use of lift assists and/or lifting devices, adding handles and/or grips into formwork components, and developing ergonomic tools for formwork construction
- **Administrative Controls**
  Well-planned, clear workspace and sequencing tasks, rotating form workers, and having frequent and short rest breaks
- **Work Practices Modifications**
  Making sure the work area is within workers' comfortable reach zone, and having two people to lift form components (> 51 lbs.)

Conclusions

- A **high prevalence** of MSD symptoms exists among form workers
- **Contributing factors**: repetition, awkward working postures, and use of force
- **High risky body regions**: lower back, upper back, neck, and shoulder
- Formwork tasks and activities create **medium- and high-level MSD risk**
- Compared to prefabricated/engineered formwork systems, **modular formwork systems create less ergonomic exposure** to workers
- **Suggestions** for MSD prevention and improvements
  - Substitution
  - Engineering improvements
  - Administrative controls
  - Work practice modifications

Thank you!