

# Transforming Construction Safety through Human-Centered Intelligence

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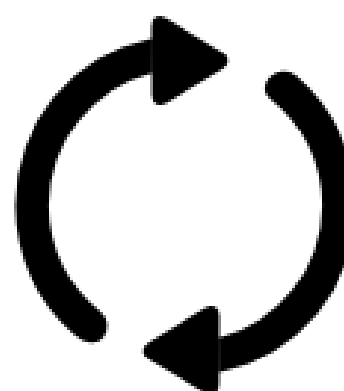


0.0 M

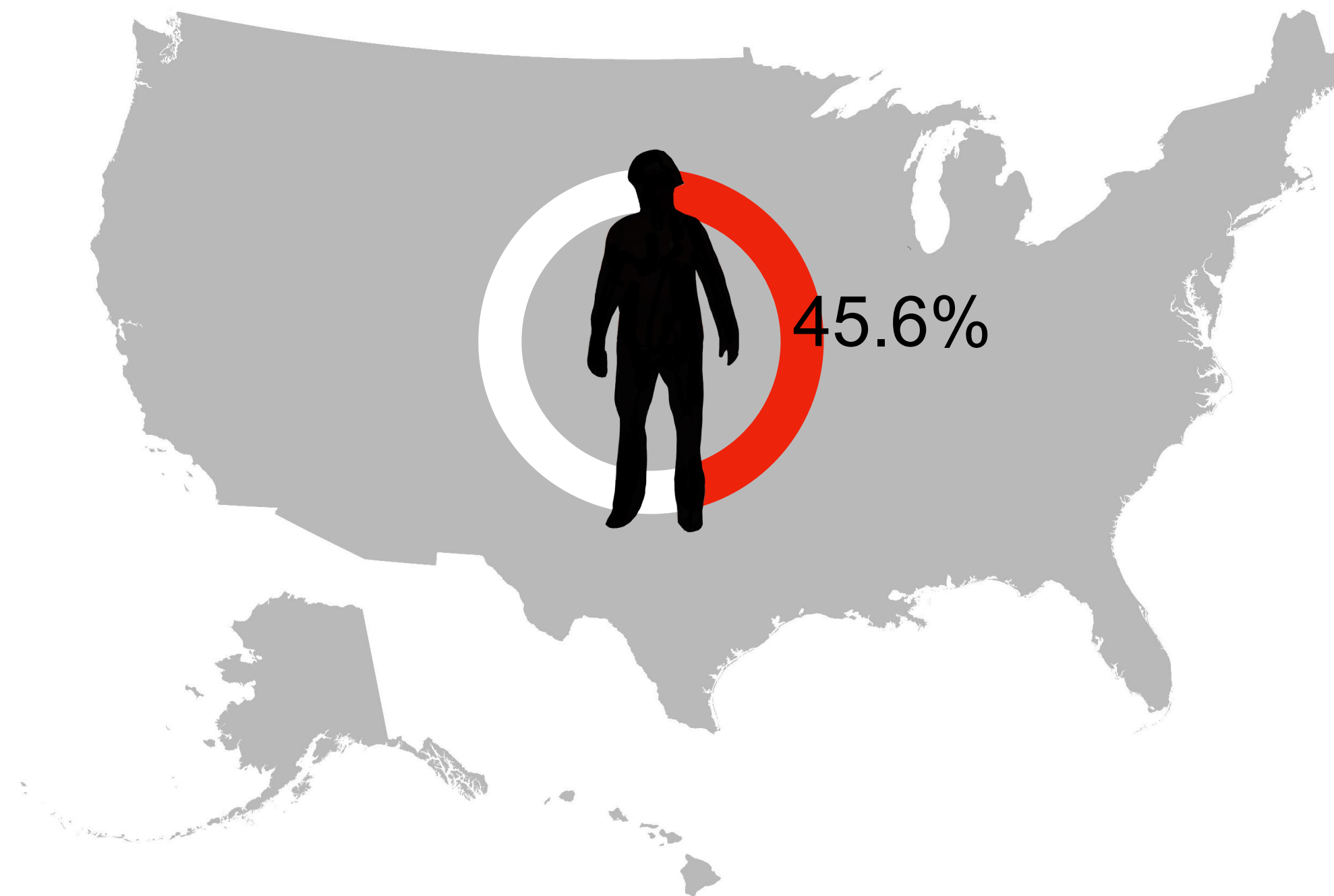


9.9 M

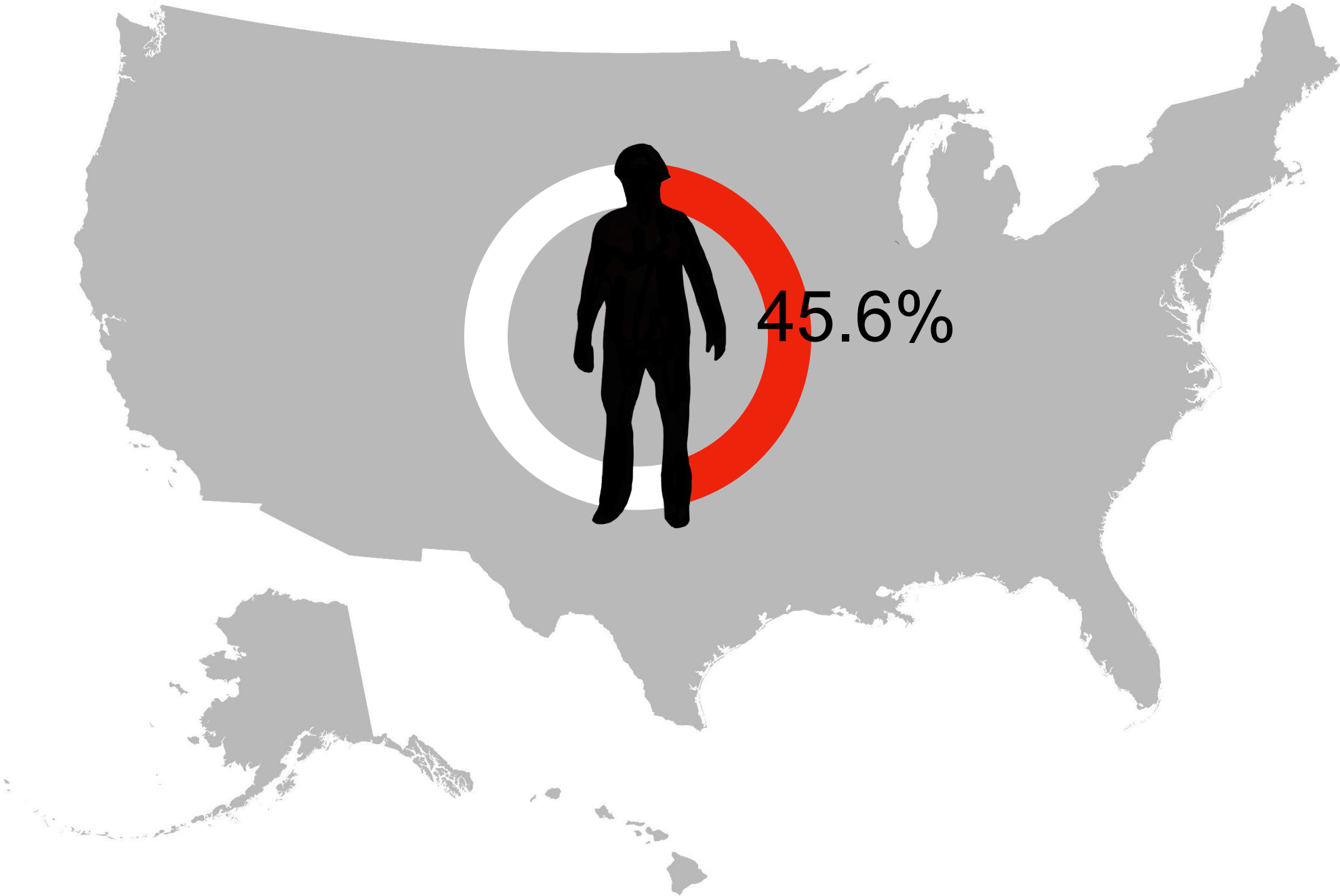




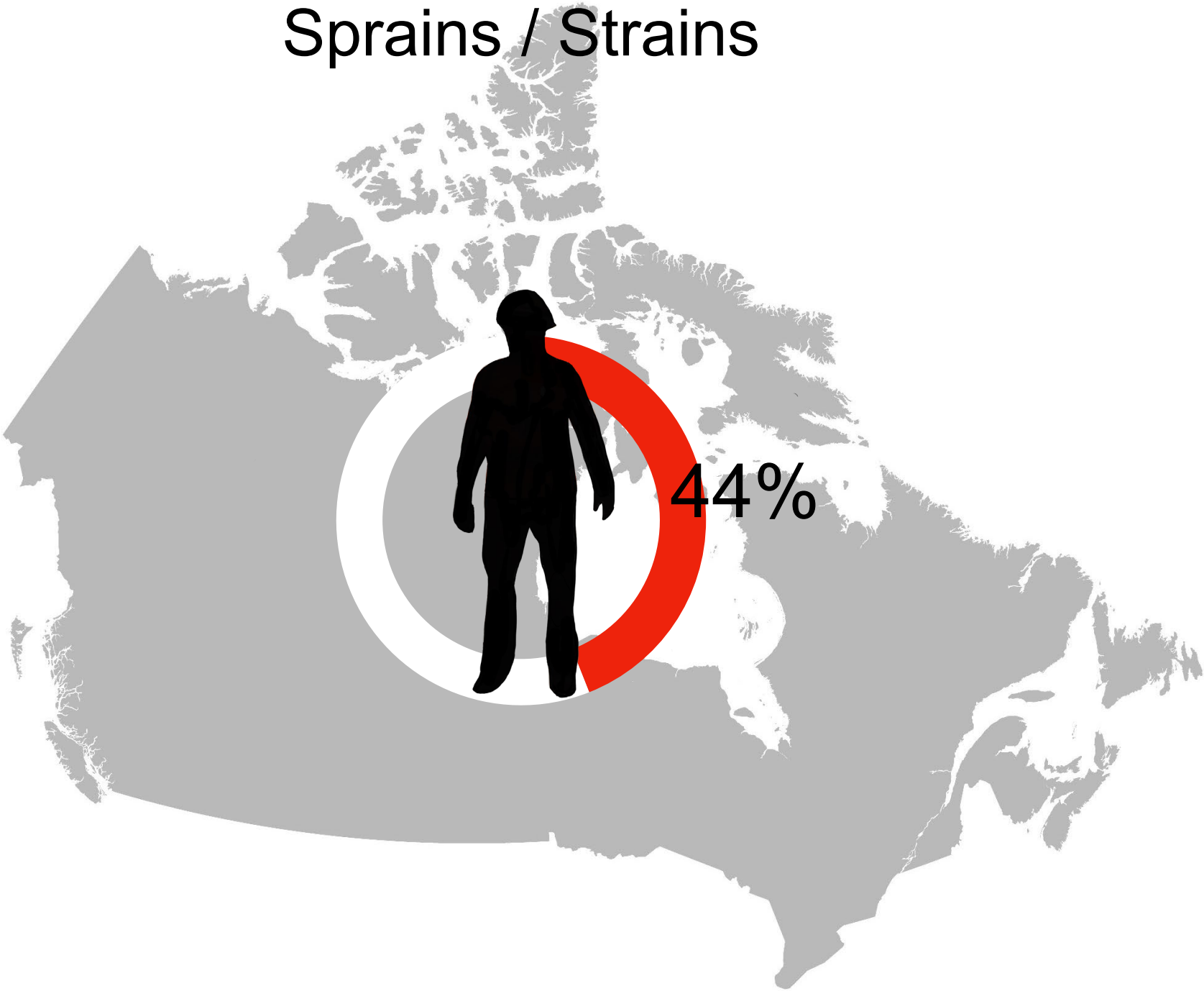
## Musculoskeletal Disorders



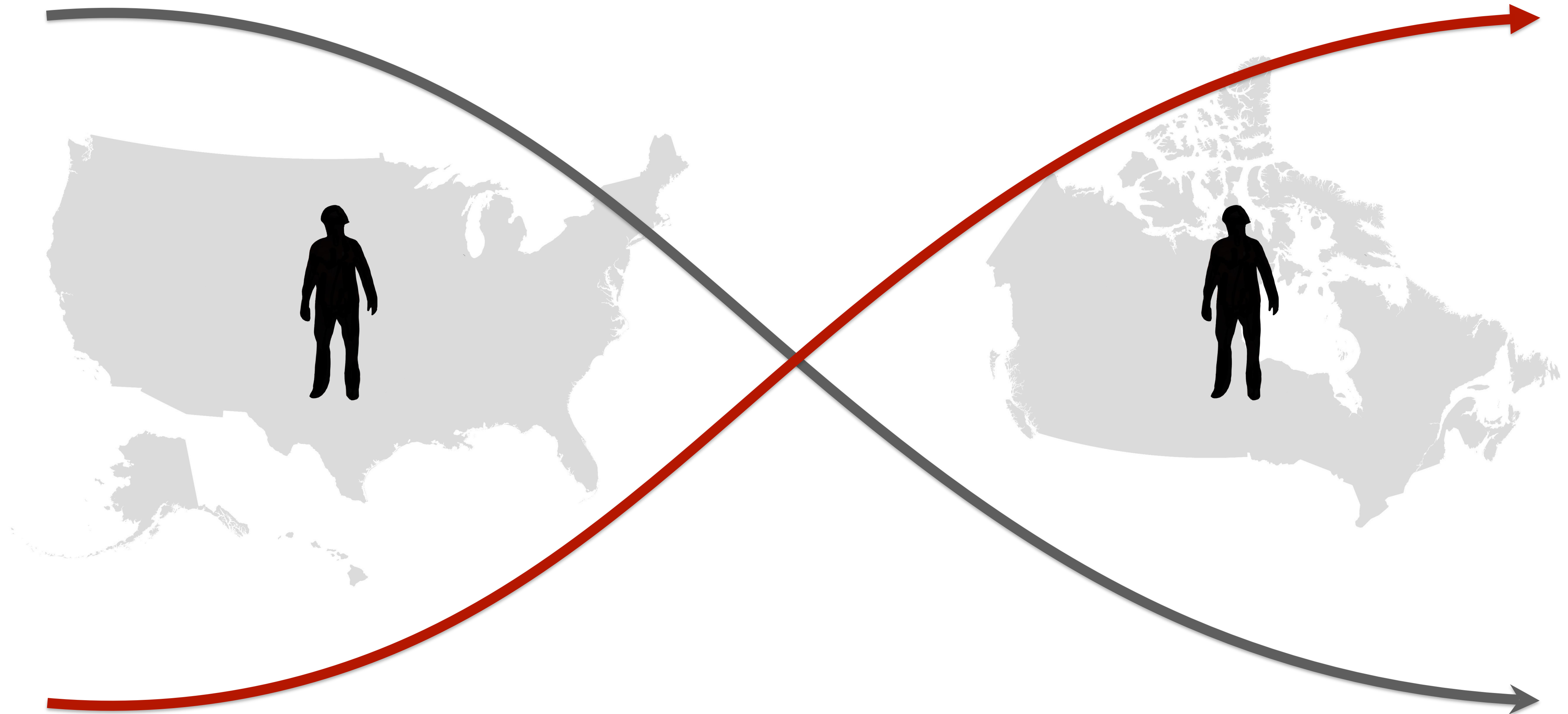
Musculoskeletal Disorders



Sprains / Strains



**590,000 new workers**



**Skilled craft workers**



**Safety**

**Health**

**Productivity**



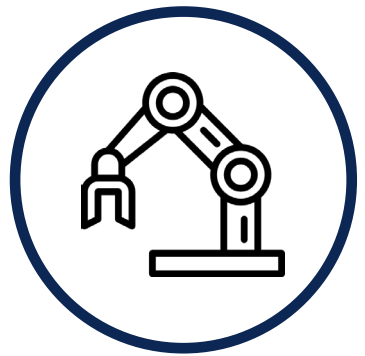
**Safety**

**Health**

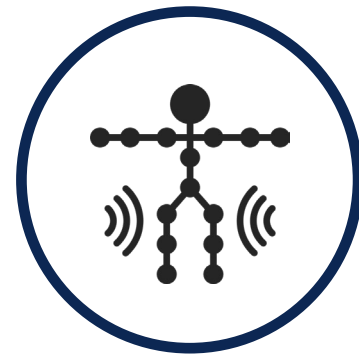
**Productivity**



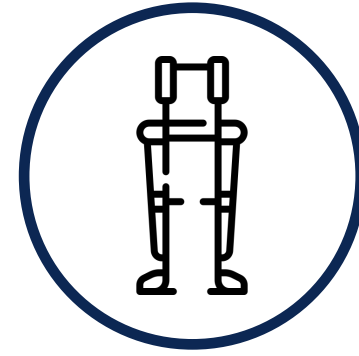
# Human-Centered Intelligent Systems



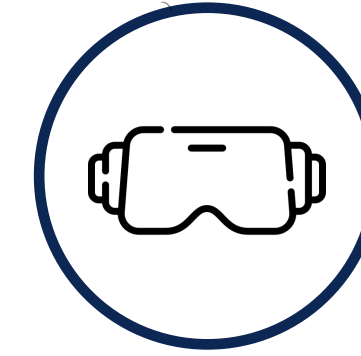
Automation/ Robot



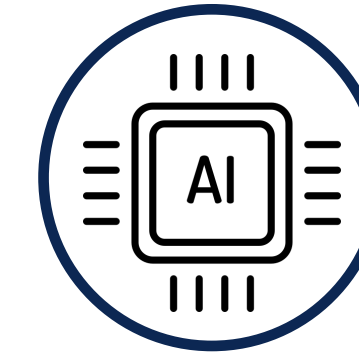
Sensors



Exoskeleton



AR/VR/MR



AI (ML)

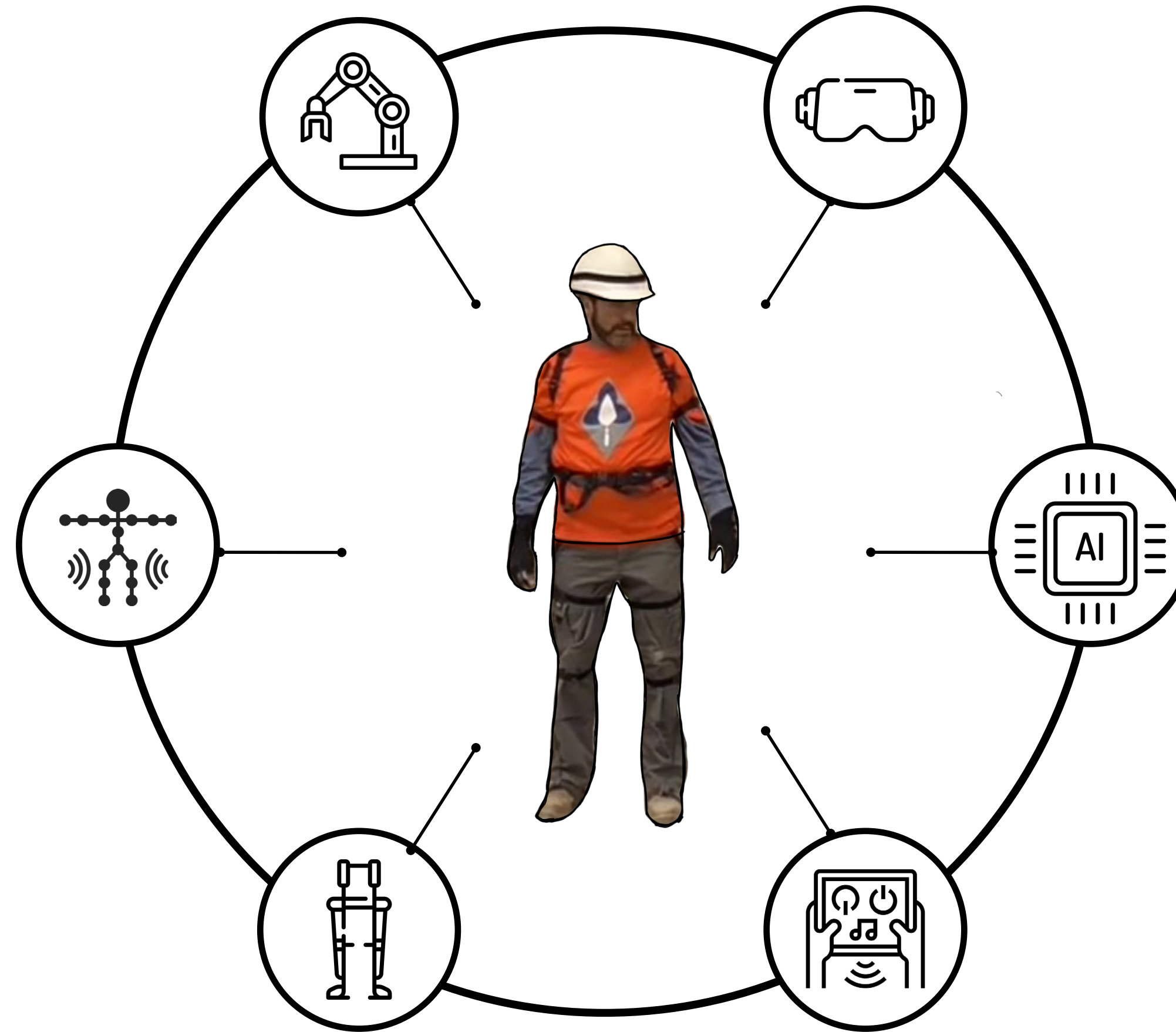


Industrial IoT





# Human-Centered Intelligent Systems

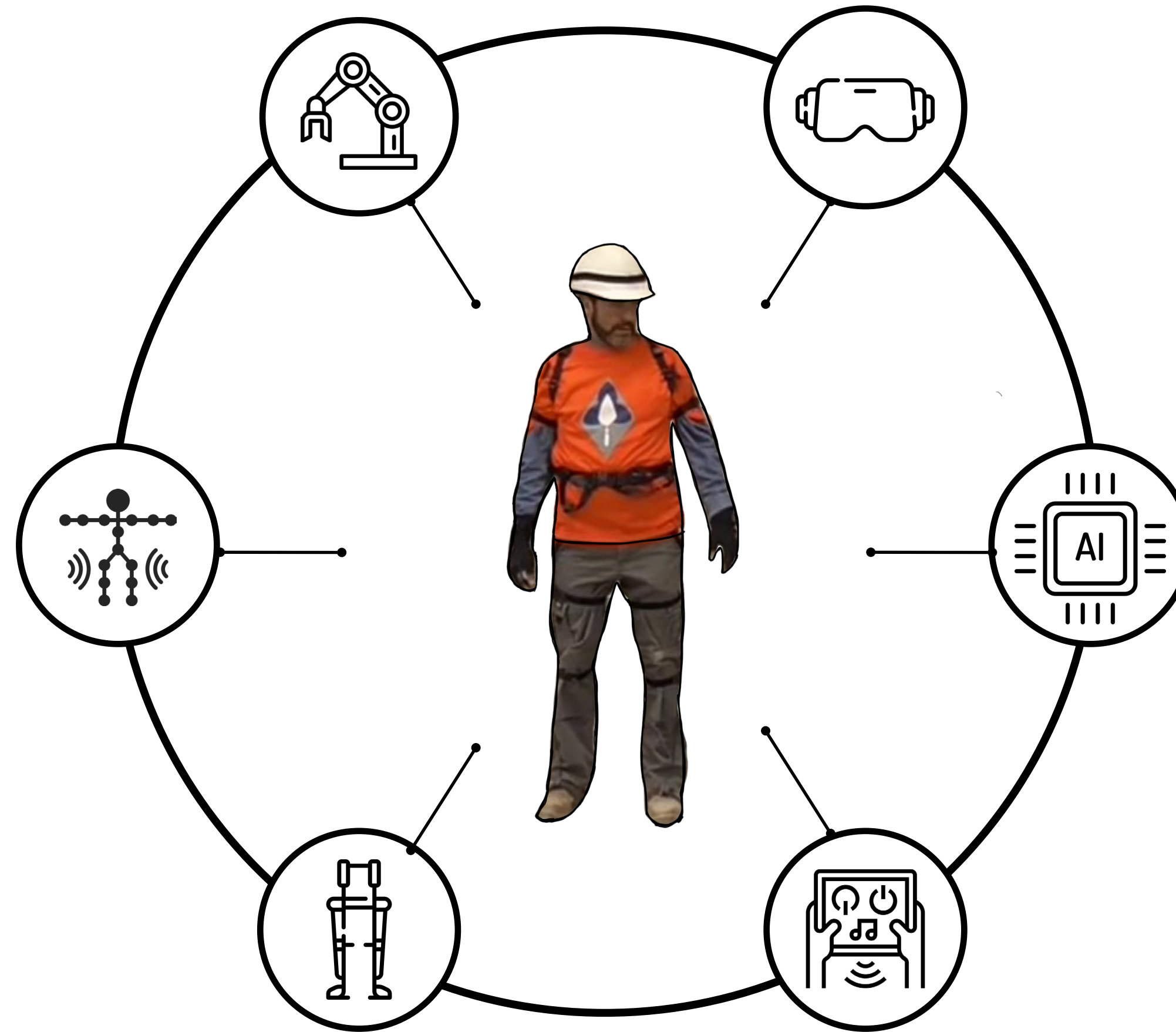


**Unique Dynamics of Humans in Work Environment using Technology**





# Human-Centered Intelligent Systems

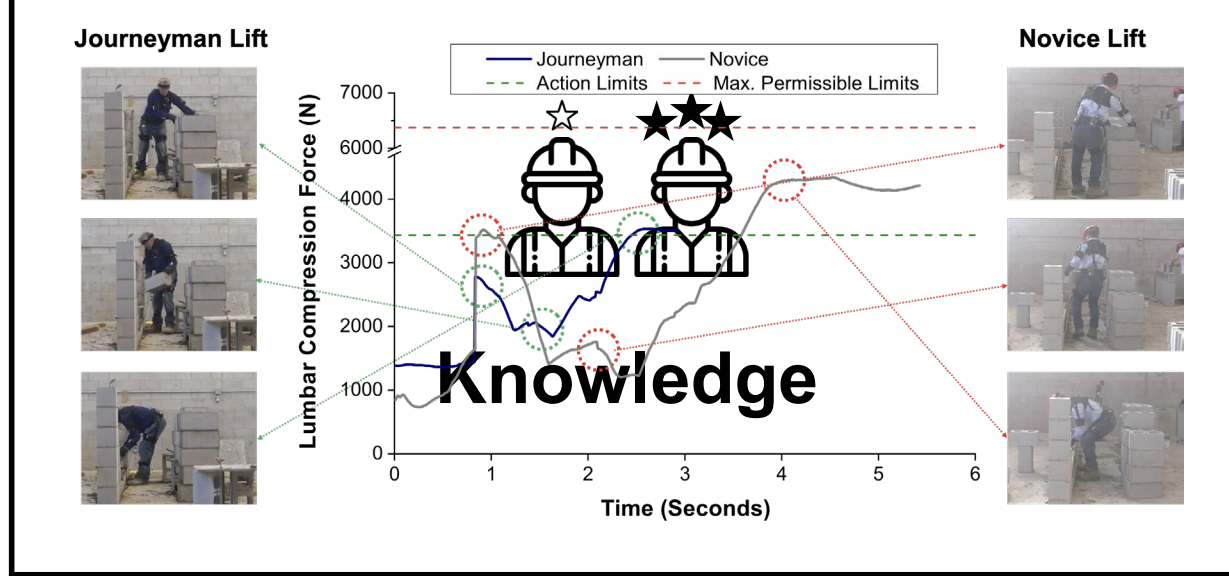


**Unique Dynamics of Humans in Work Environment using Technology**

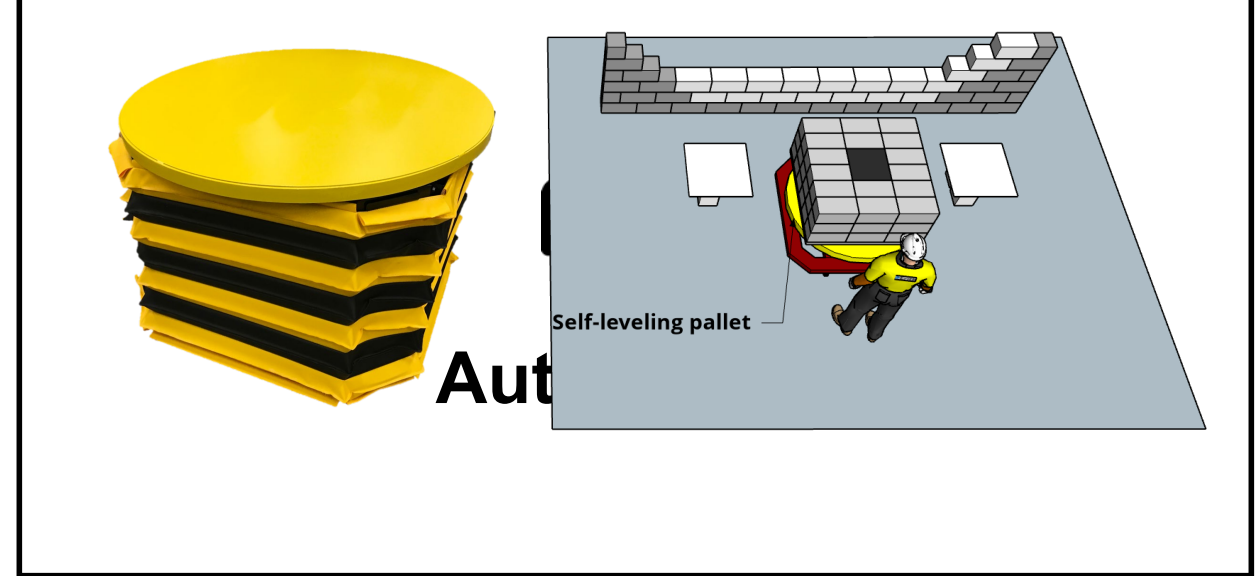
## Research Thrusts



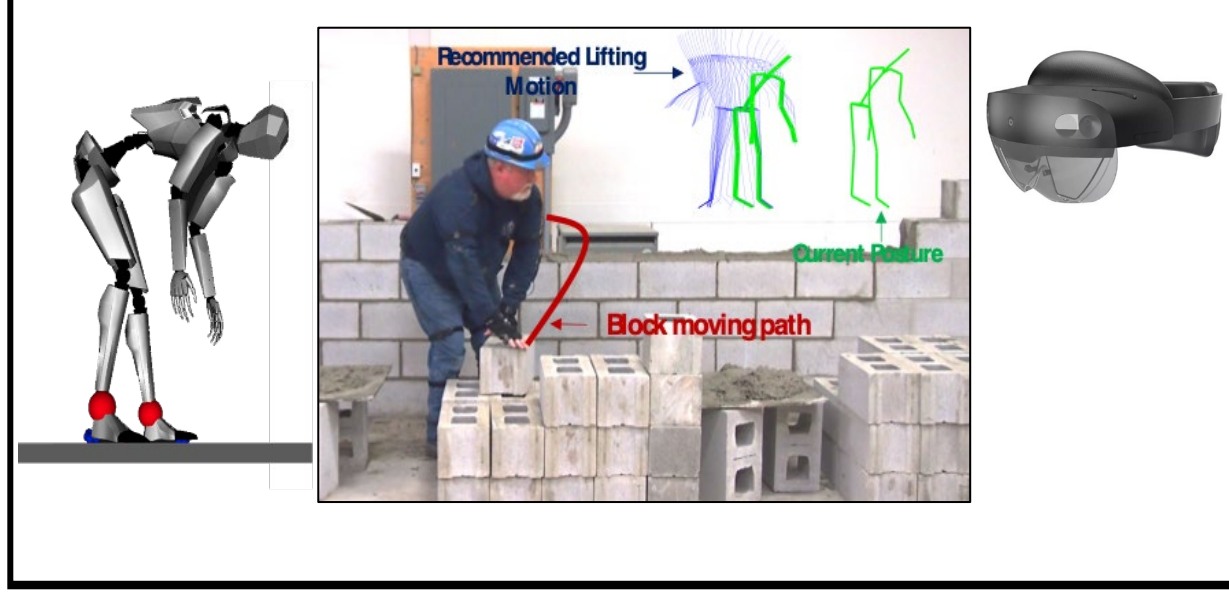
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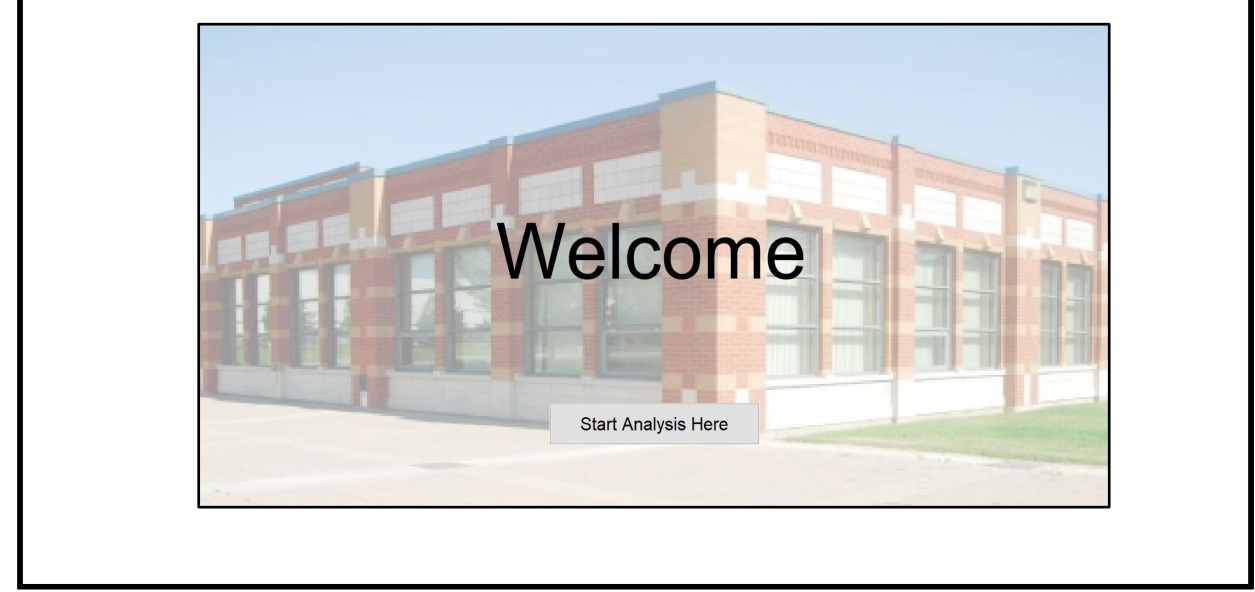
### Workplace Design



### Innovative Training Systems



### On-site Assessment Tools

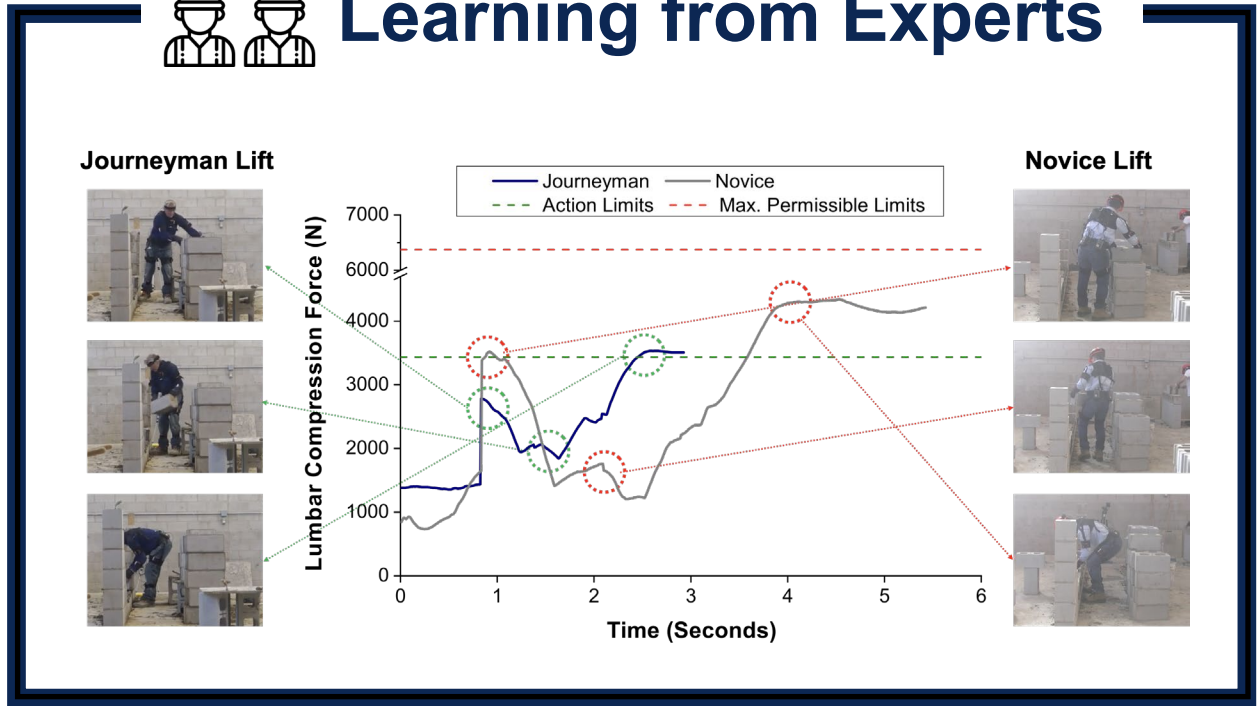




## Research Thrusts



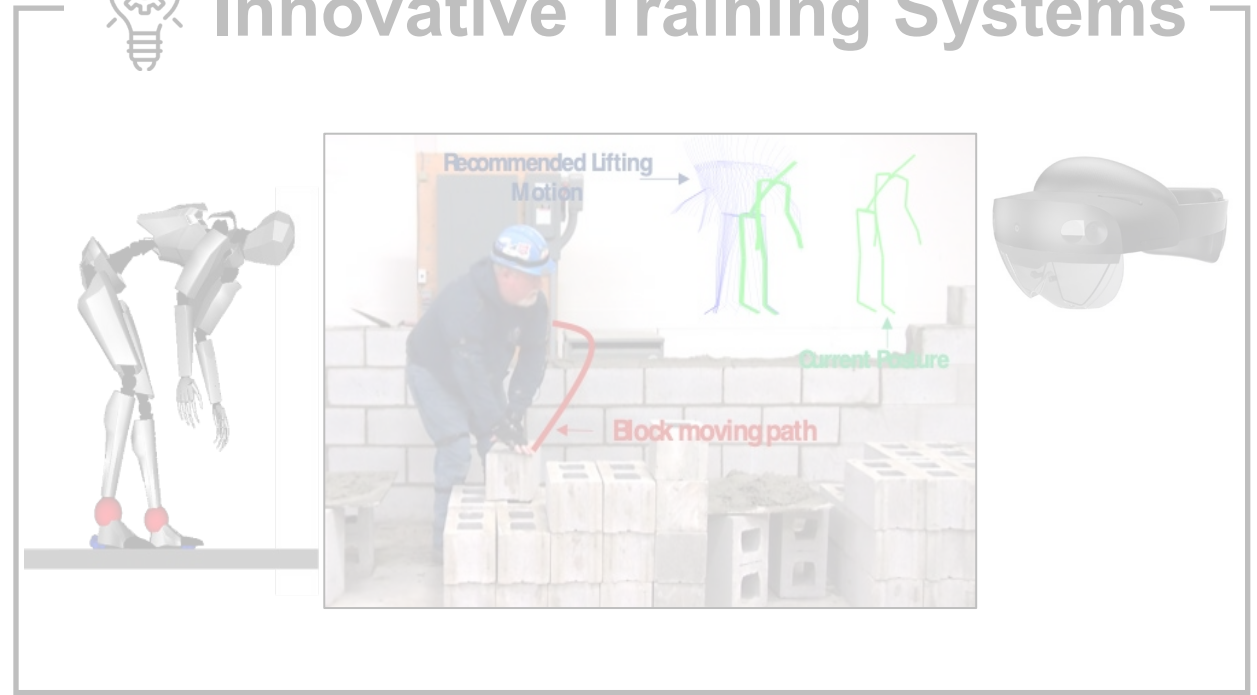
### Learning from Experts



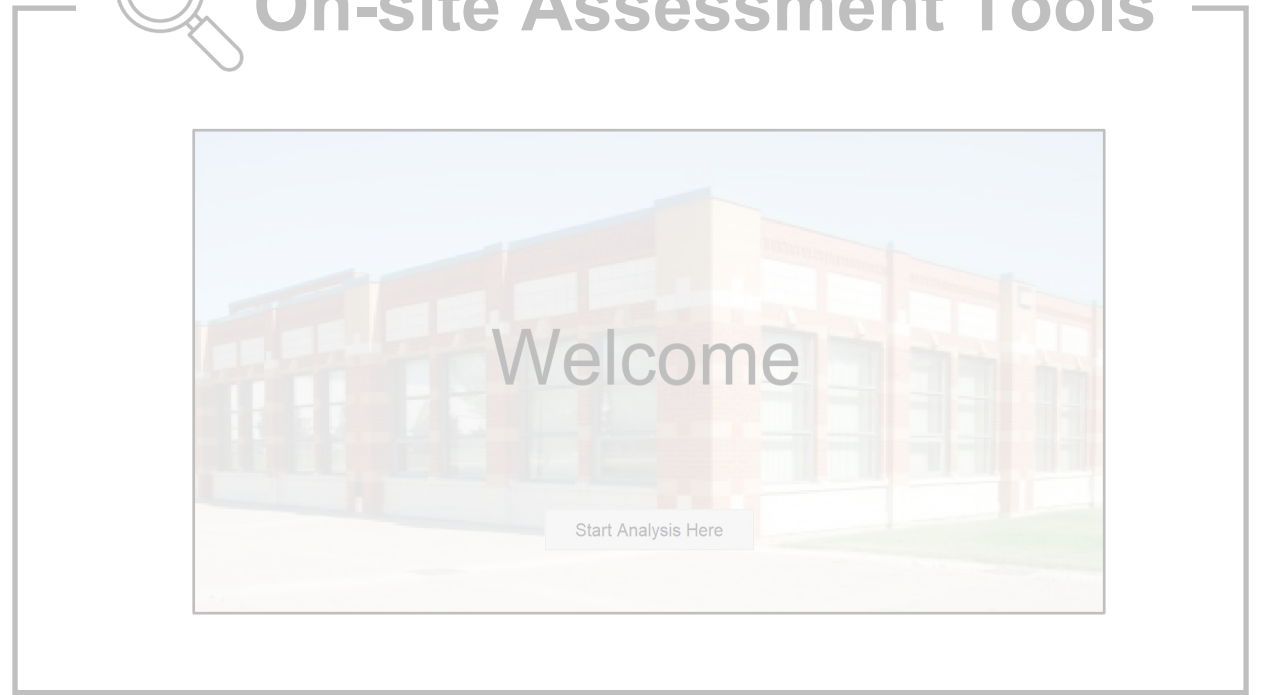
### Workplace Design



### Innovative Training Systems



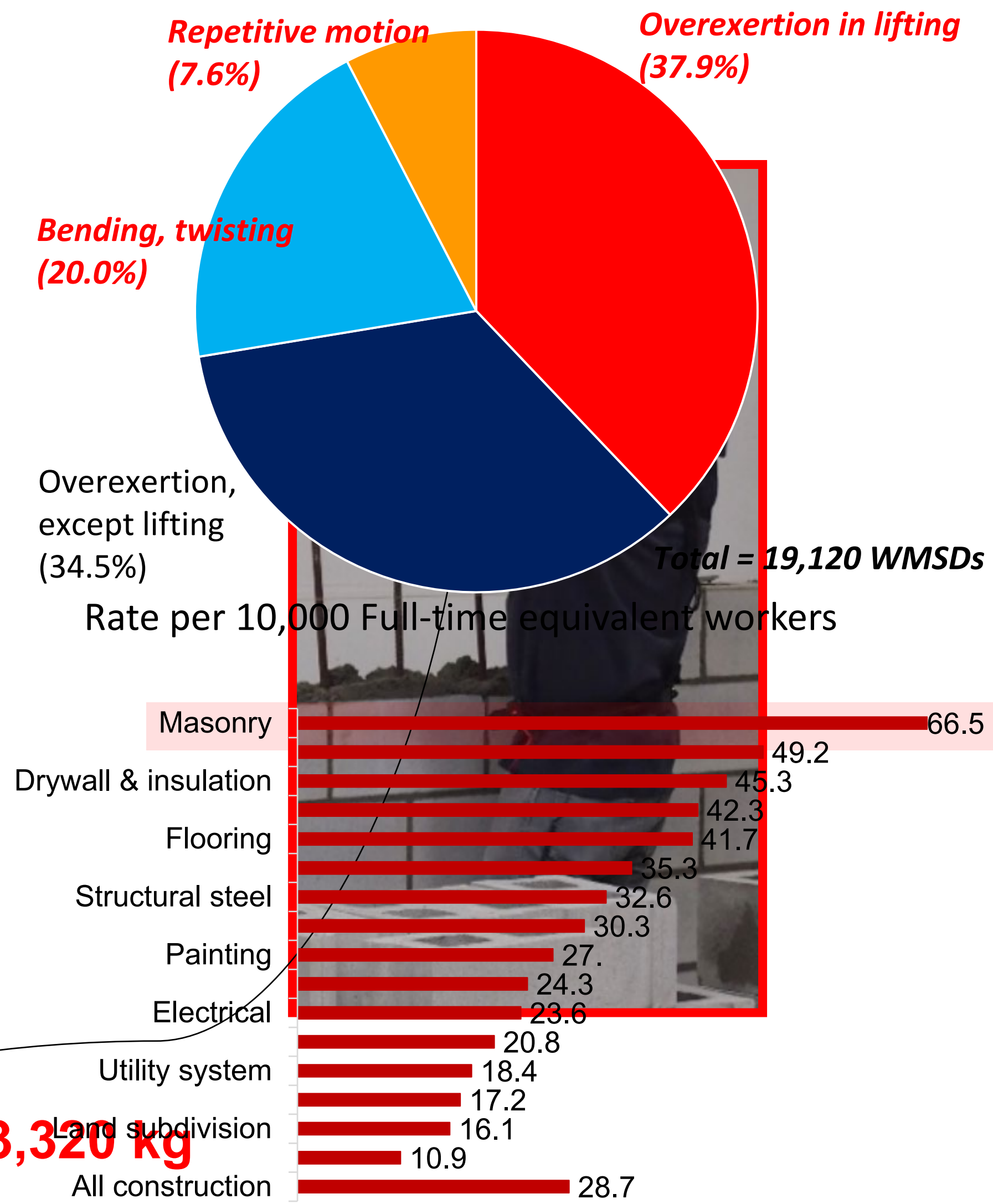
### On-site Assessment Tools







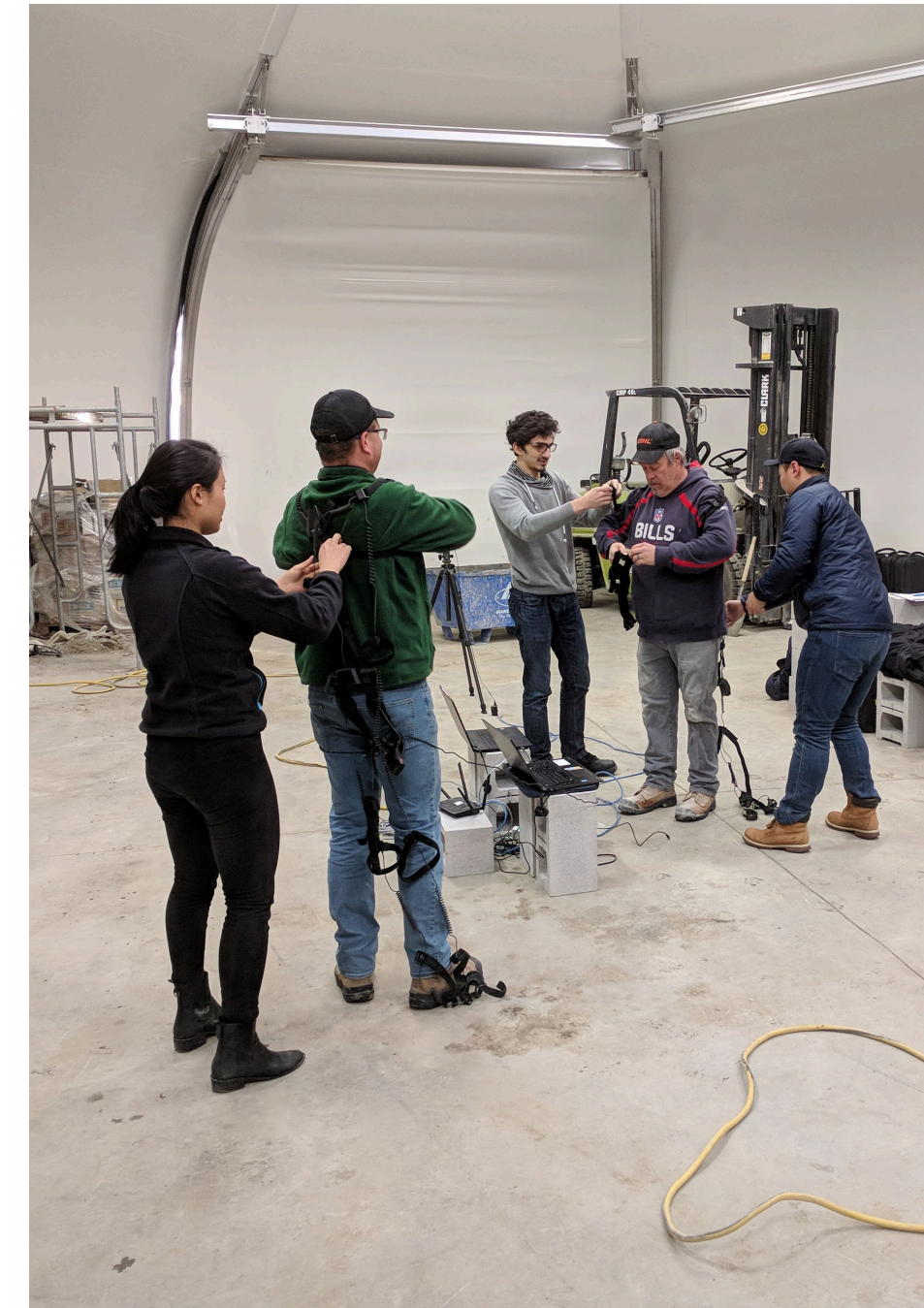
$16.6 \text{ kg} \times 200 \text{ CMUs} = 3,320 \text{ kg}$



1) Distribution of risk factors for WMSDs resulting in days away from work in construction, 2010 (CPWR 2013)  
2) Rate of overexertion injuries resulting in days away from work, selected construction subsectors, 2010 (CPWR 2013)



# Research Methods





# Data Collection: Participants



Experience group	Number of participants			Height (cm)		Weight (kg)	
	Conestoga College	CMDC	Total	Average	Std.	Average	Std.
Novice	5	12	17	182.9	6.9	86.1	13.8
One year	4	15	19	180.8	5.2	89.3	15.1
Three years	7	9	16	182.1	4.8	89.9	15.2
Journeymen	5	9	14	178.1	6.1	87.3	10.3
Total	21	45	66	181.0	5.8	88.1	13.6



# Data Collection: Experimental Setup



Experimental setup at CMDC



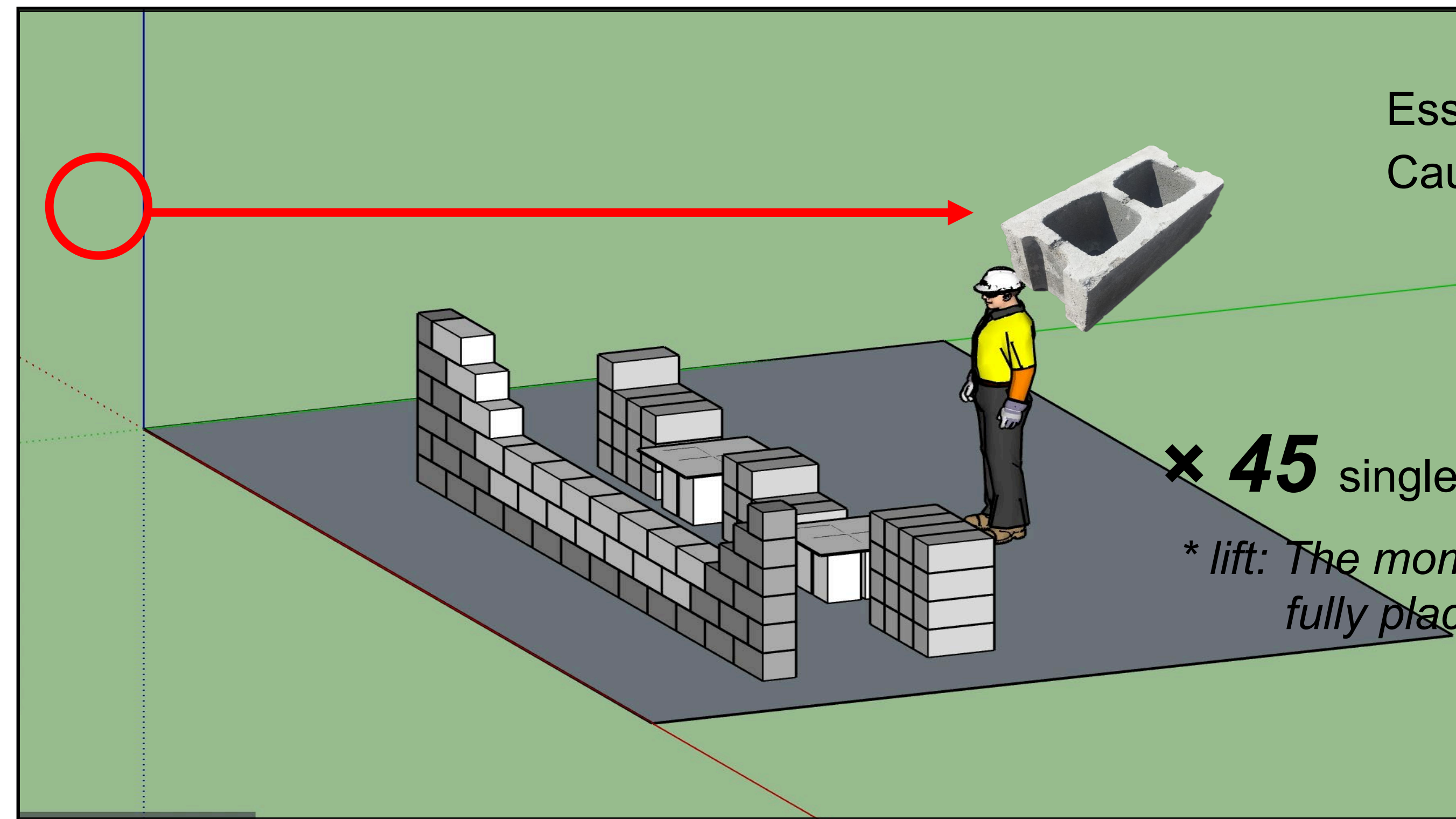
3-axes accelerometer

3-axes gyroscope

3-axes magnetometer

$\times 17$





Essential masonry-task part  
Cause cumulative stress injuries

**× 45** single CMU lifting motion files

*\* lift: The moment picks up the CMU to fully placed on the lead wall.*

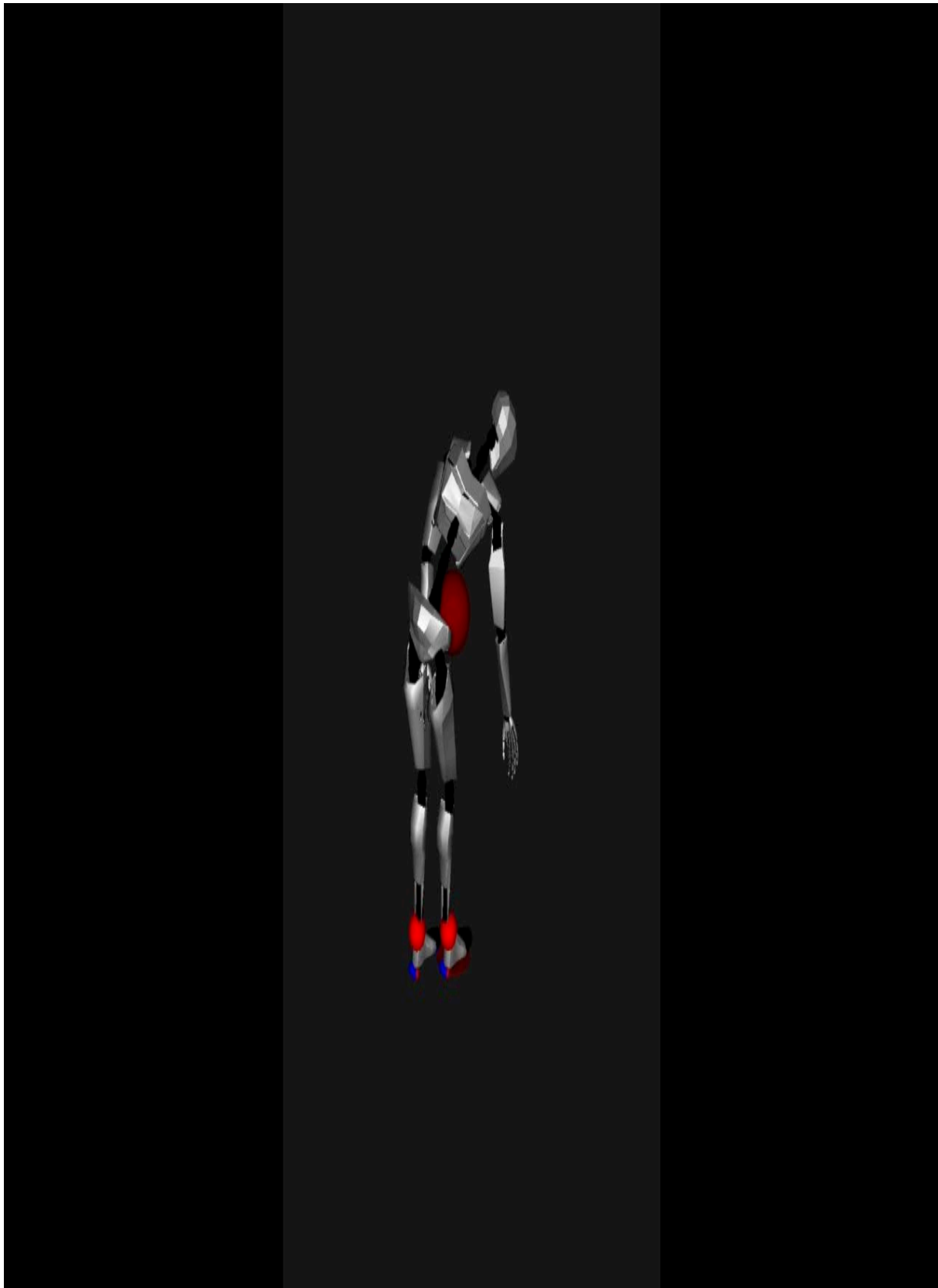


# Data Processing: Motion Data Extraction

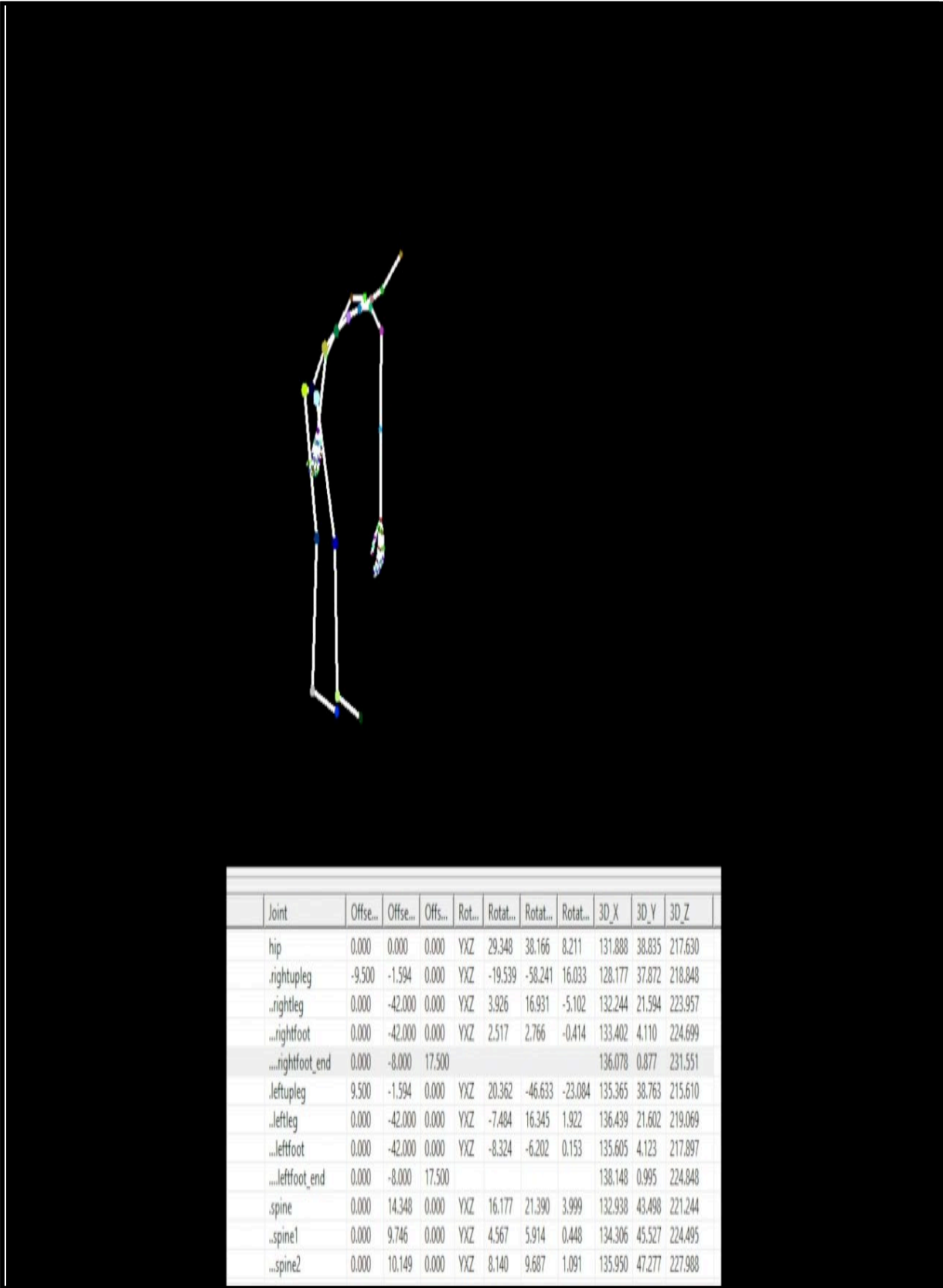
Video



Raw motion file

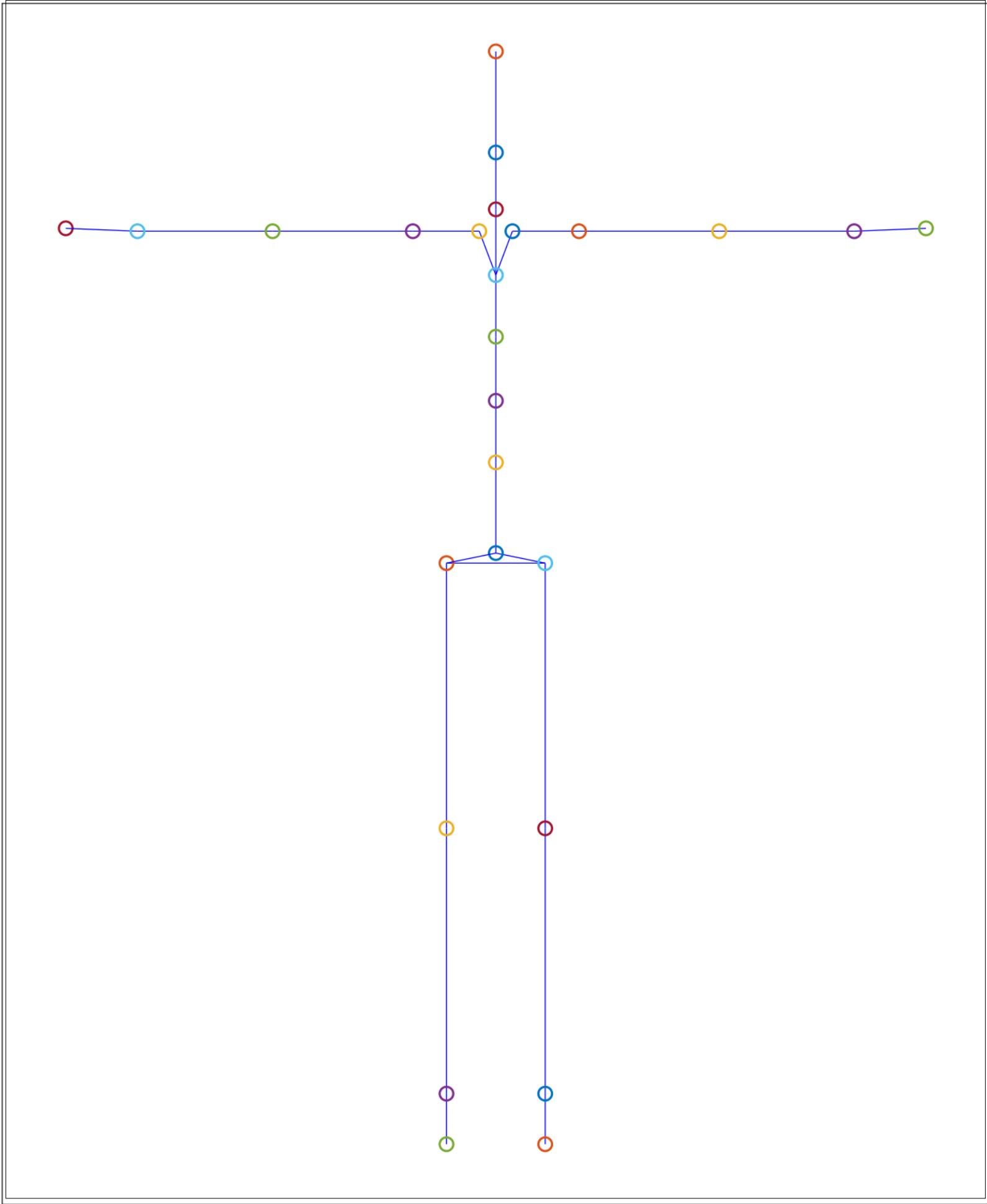


BVH motion file

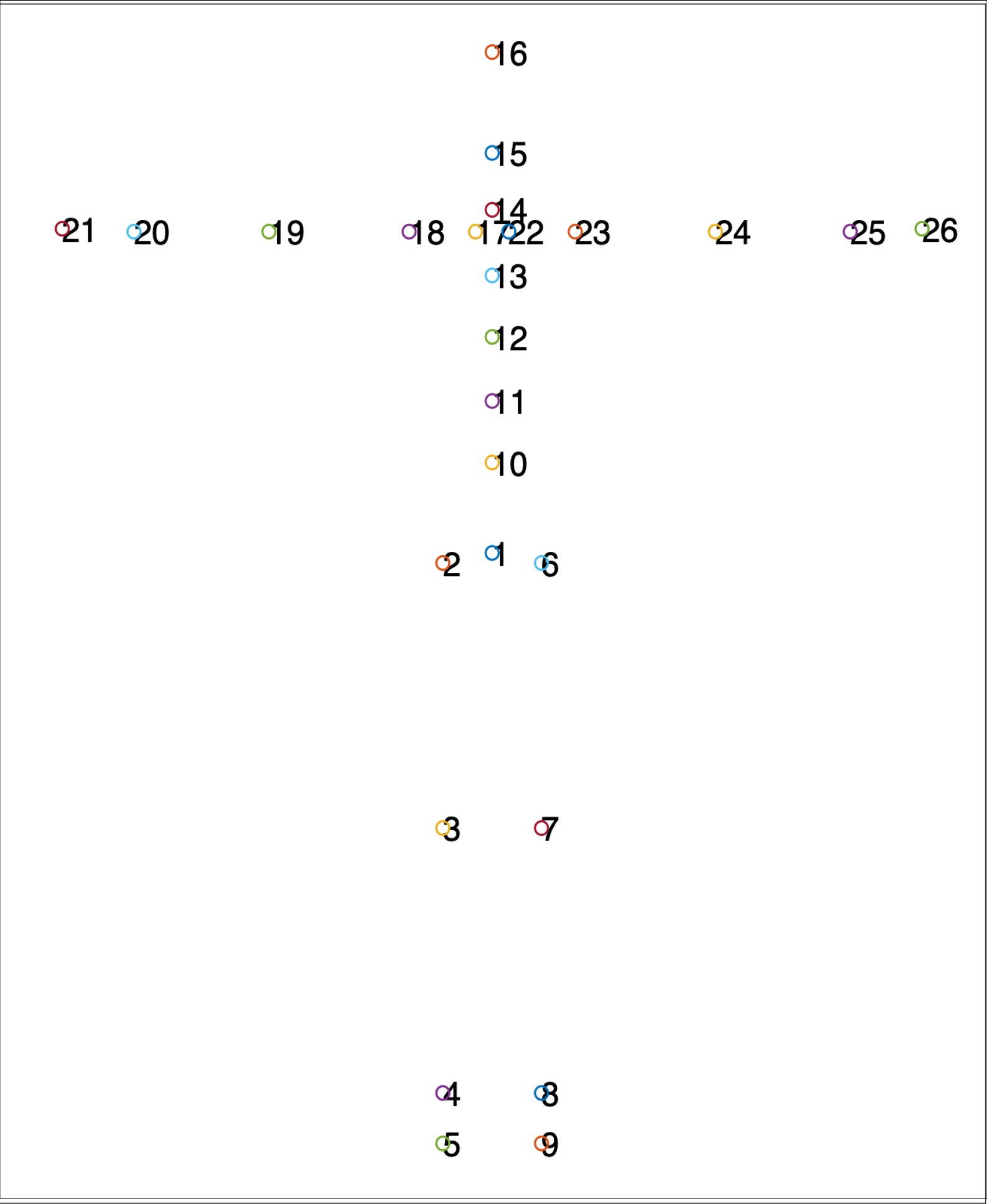


# Data Processing: 3D Joint Location

Skeletal model with T-pose



Joint locations with T-pose

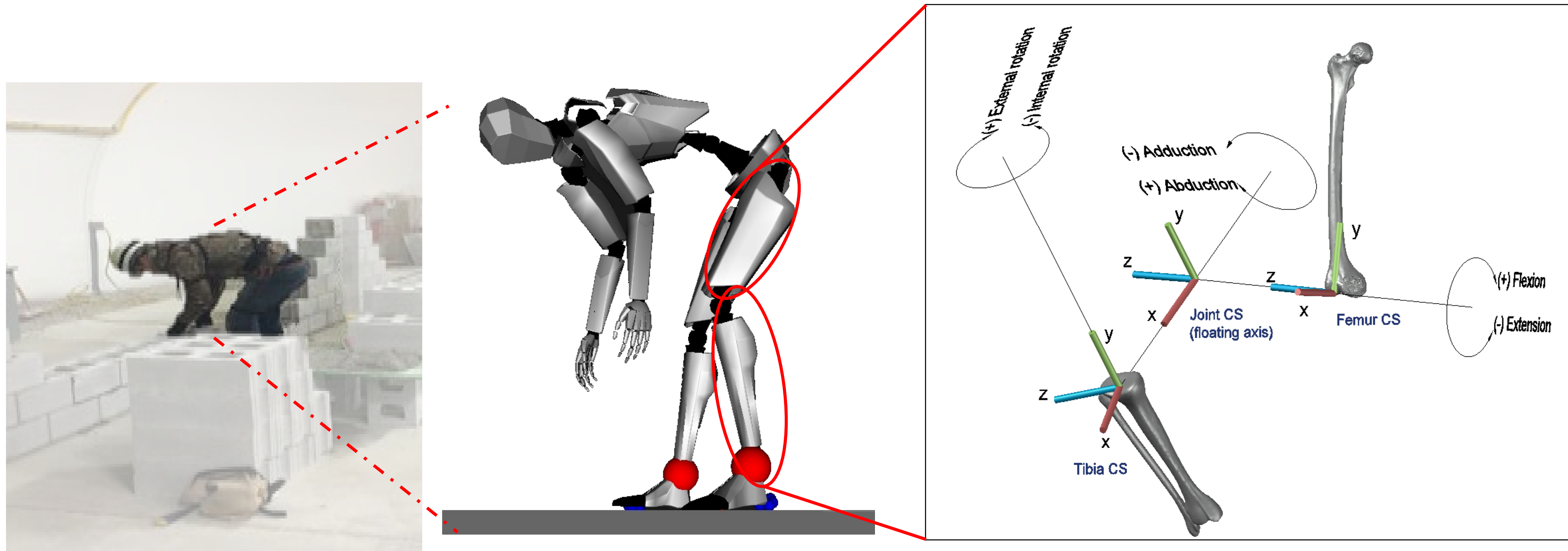


Joint No.	Joint Name
1	Hip
2	Right Hip
3	Right Knee
4	Right Ankle
5	Right Ball of Foot
6	Left Hip
7	Left Knee
8	Left Ankle
9	Left Ball of Foot
10	Spine
11	Spine
12	Spine
13	Sternoclavicular Joint
14	C7/T1
15	Head Origin
16	Head End
17	Right Pre-shoulder
18	Right Shoulder
19	Right Elbow
20	Right Wrist
21	Right Grip Center
22	Left Pre-shoulder
23	Left Shoulder
24	Left Elbow
25	Left Wrist
26	Left Grip Center



# Data Processing: Joint Angle Estimation

- Joint angle estimation
  - International Society of Biomechanics (ISB) standards

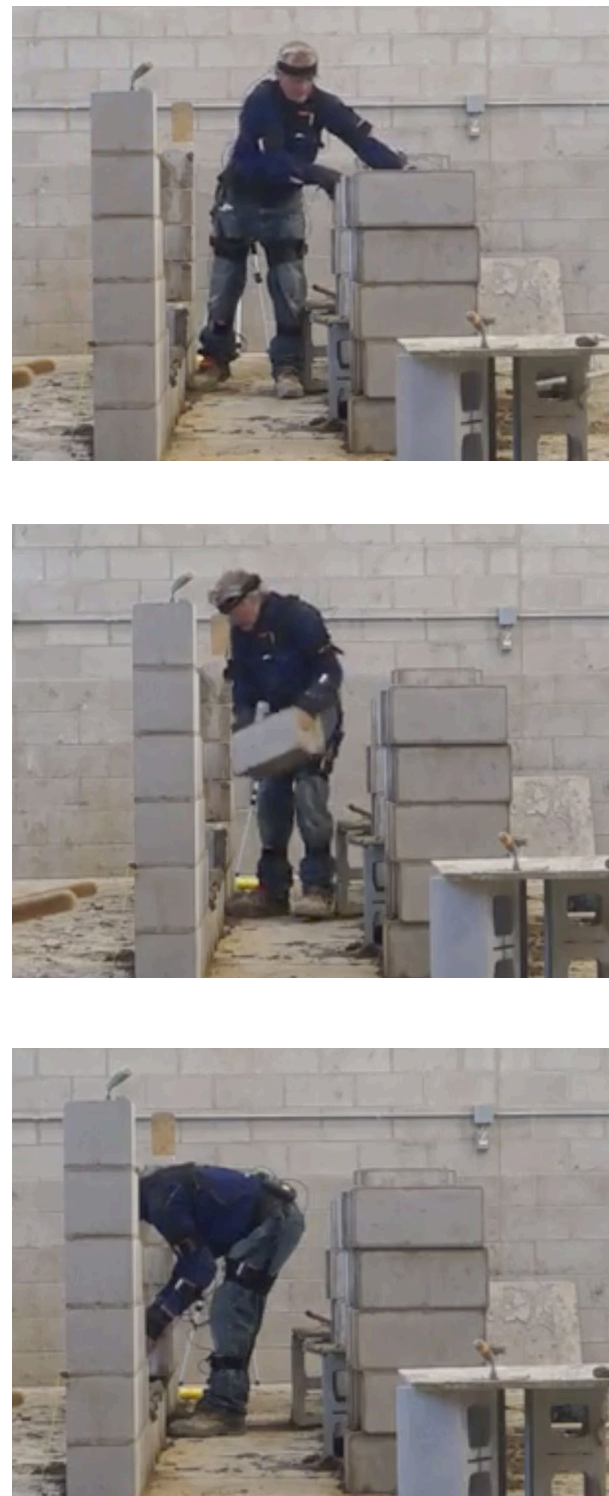


Example of calculating knee angles (Grood & Suntay, 1983)

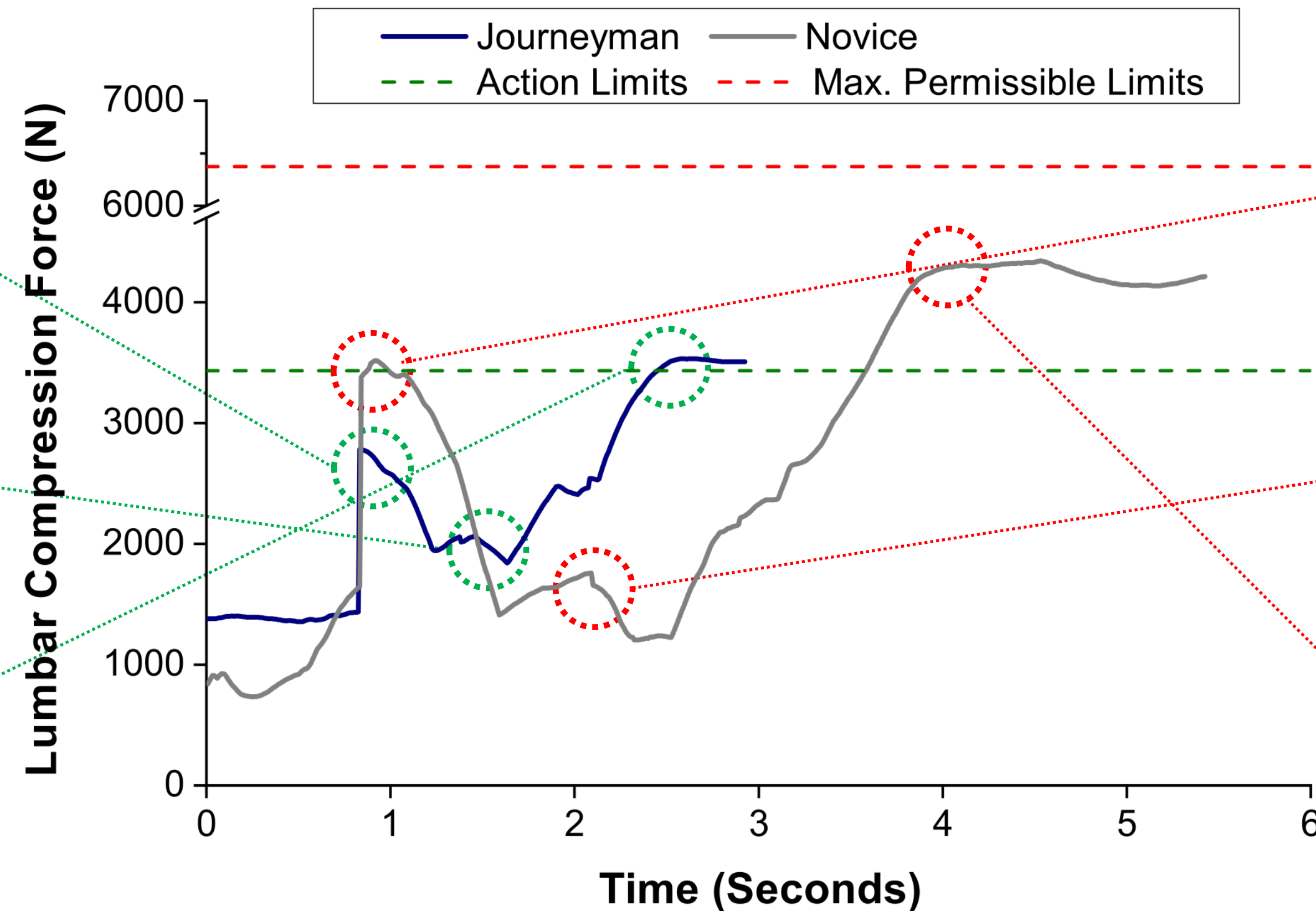


- Joint loads (compression forces and moments) at major joints
  - Low-back at lumbar disc (L4/L5), elbow, shoulder, hip, and knee joints

**Journeyman Lift**



**Novice Lift**

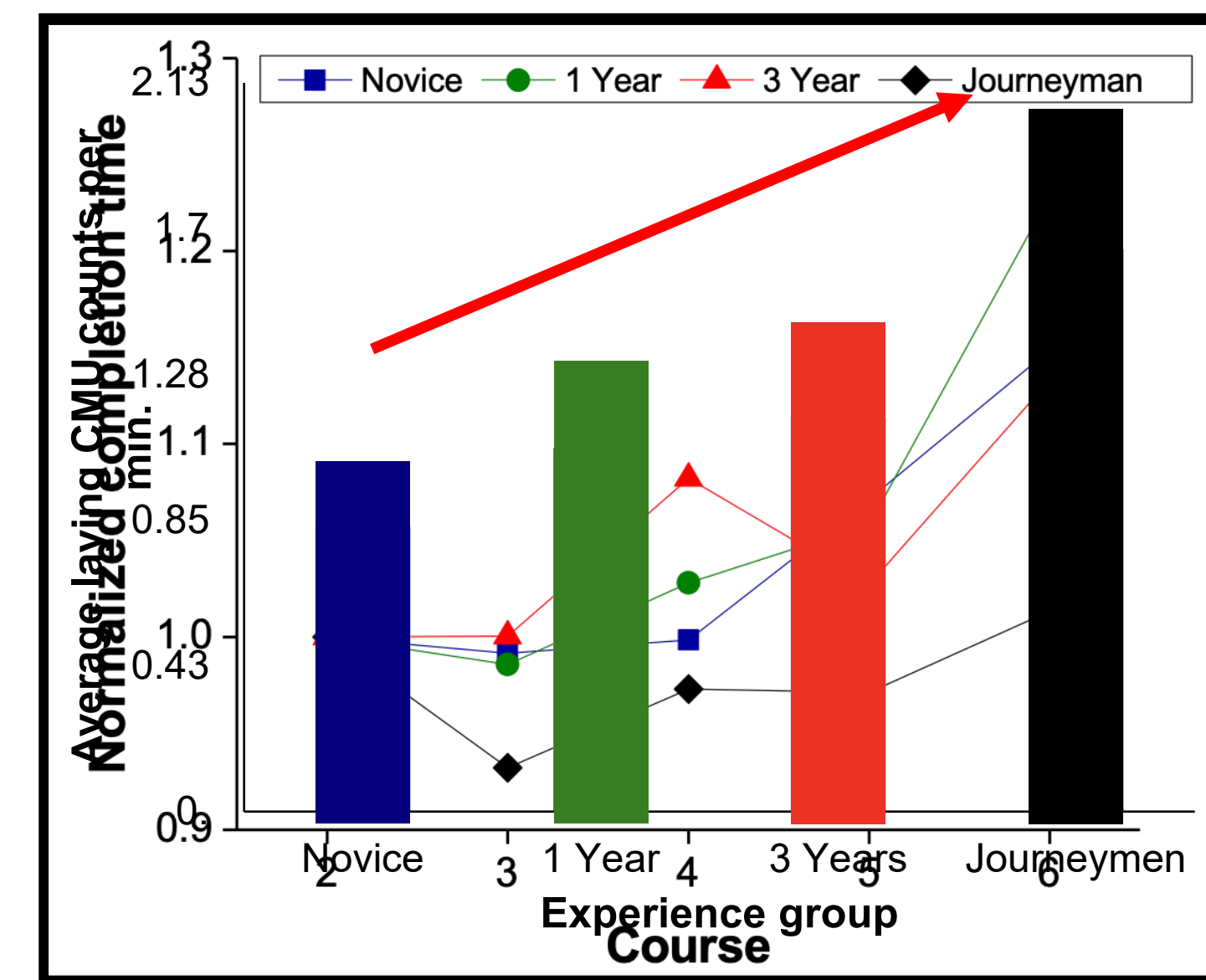
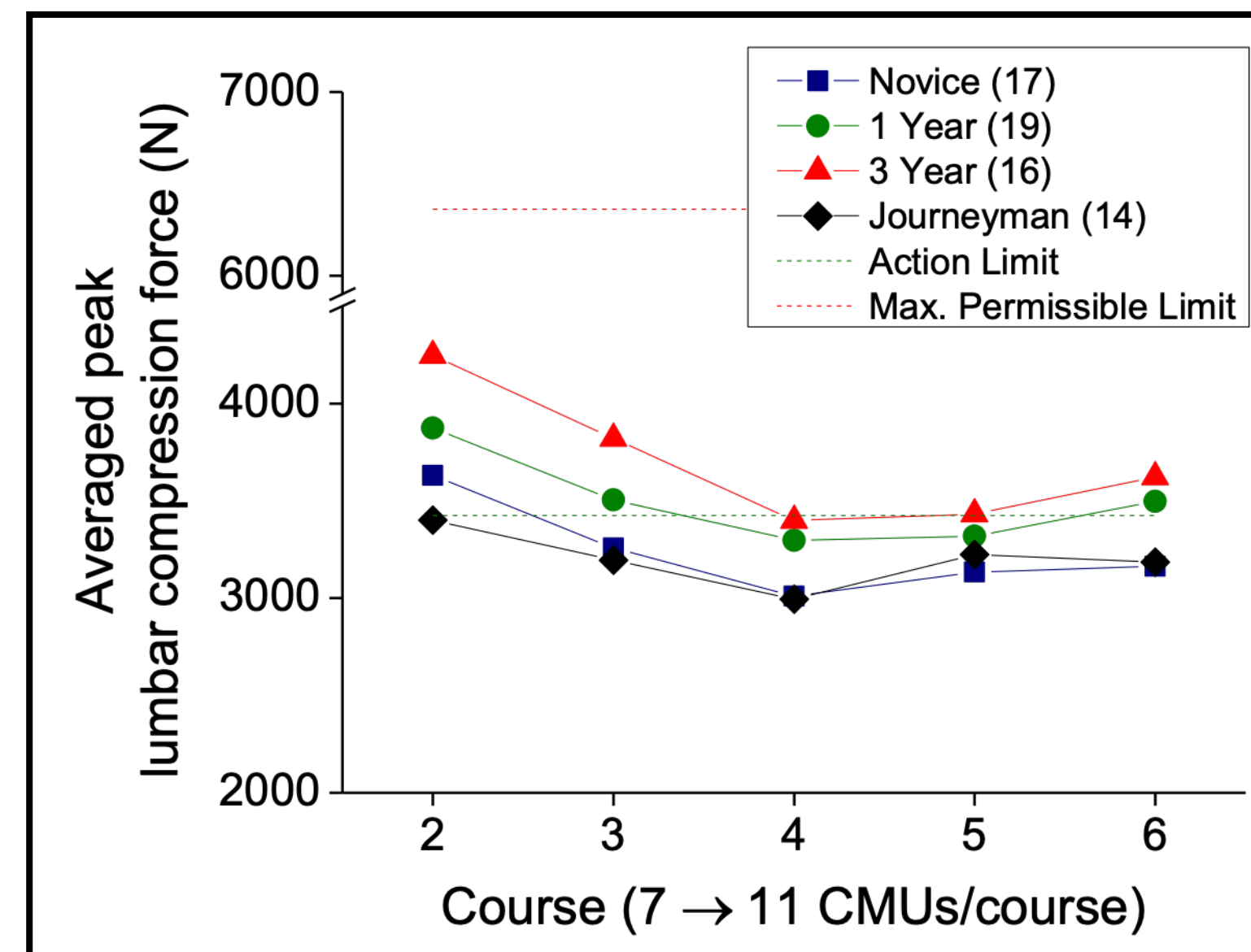
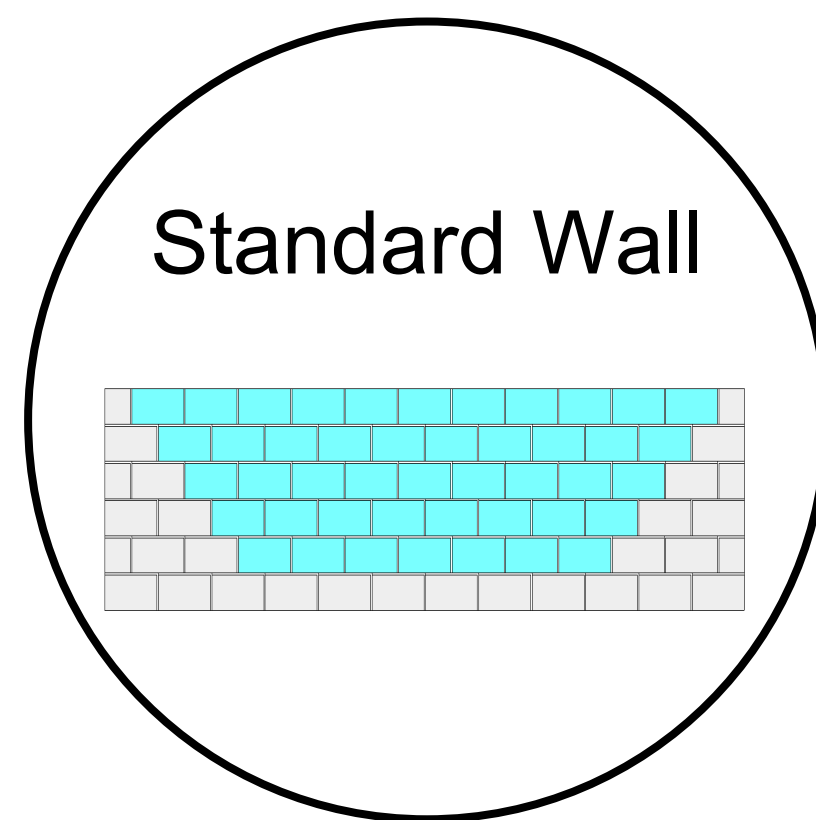


# Overcome the Novice Mason's Risk Hump

“Analysis of Relationships Between Body Load and Training, Work Methods, and Work Rate: Overcoming the Novice Mason's Risk Hump”, *Journal of Construction Engineering and Management* (2020)

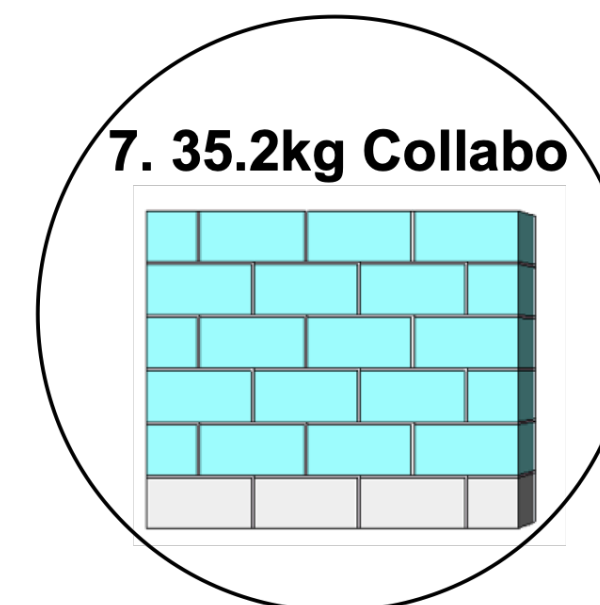
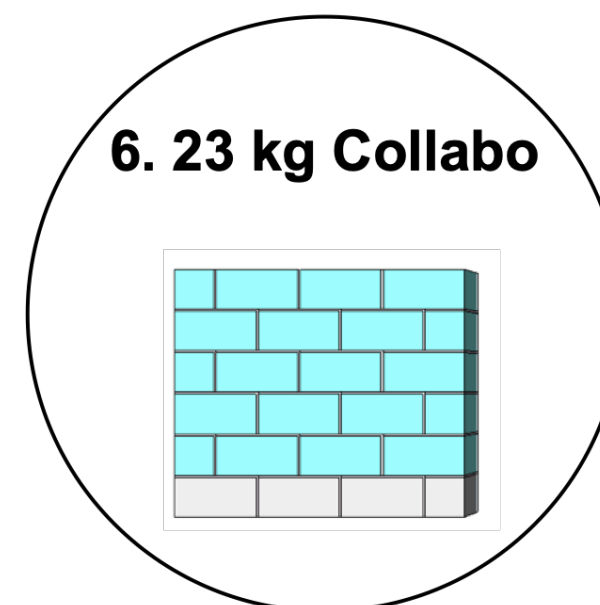
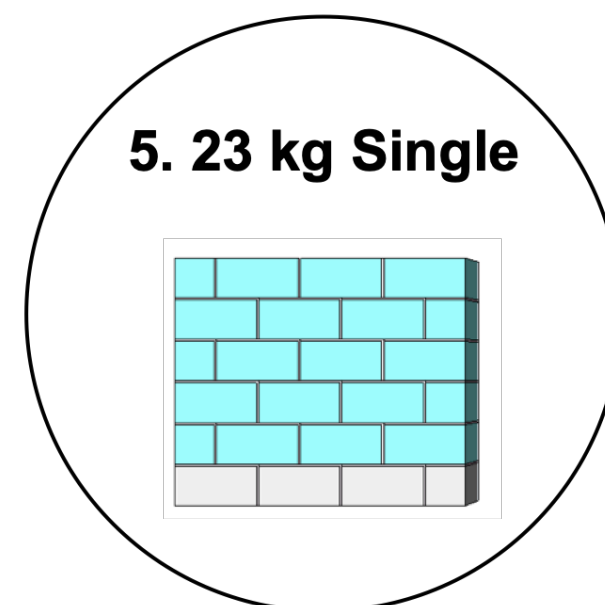
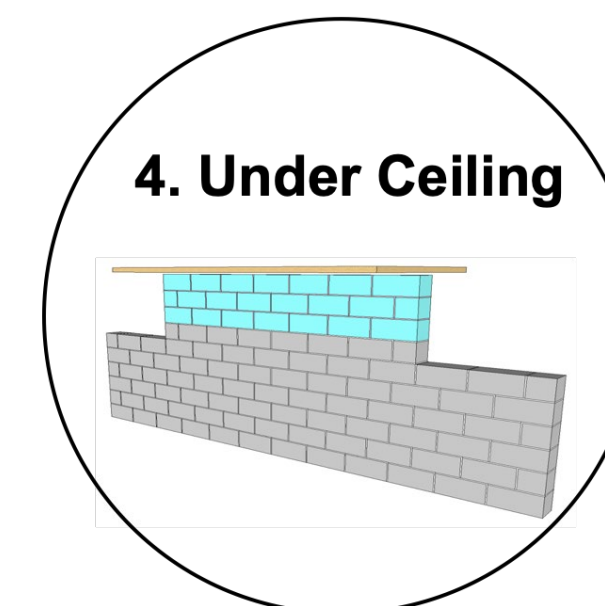
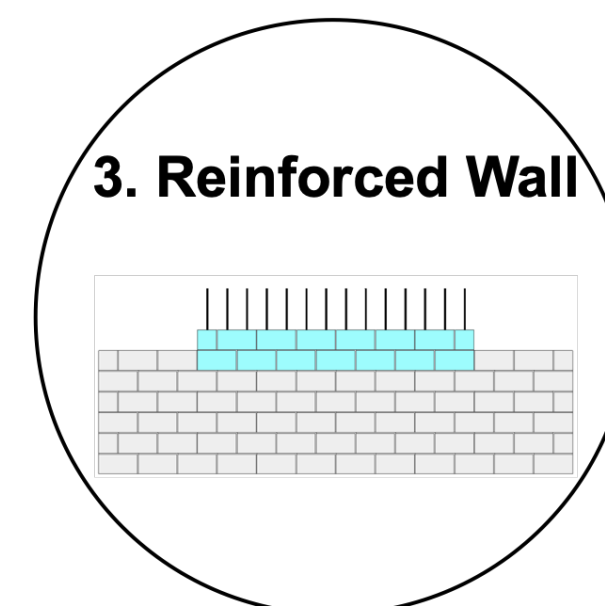
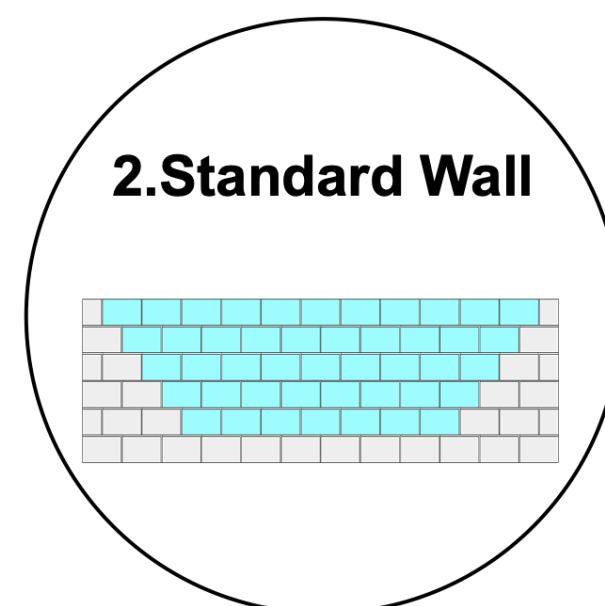
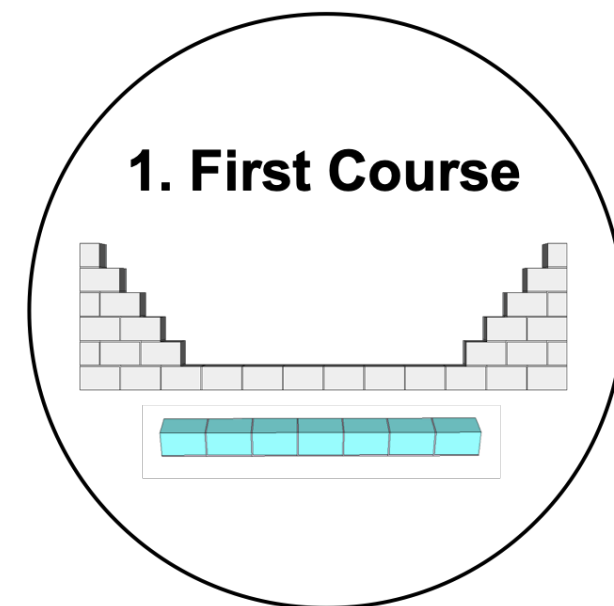


- Analyzed relationship between body loads, experience, and work methods
  - 66 masons; 4 experience groups; 45 CMUs on standard wall
- **Journeyman = Fastest & Safest**
- Novices = Slow but often safe
- 3-year apprentices = Fast but least safe





- Evaluate body load in 7 masonry activities performed by experts
  - Representative of standard activities
  - Masons may encounter awkward postures or elevated risk exposure





# Expert Masons' Ergonomic Characteristics

“Ergonomic Characteristics of Expert Masons”, *Journal of Construction Engineering and Management* (2022)



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  - Representative of standard activities
  - Masons may encounter awkward postures or elevated risk exposure



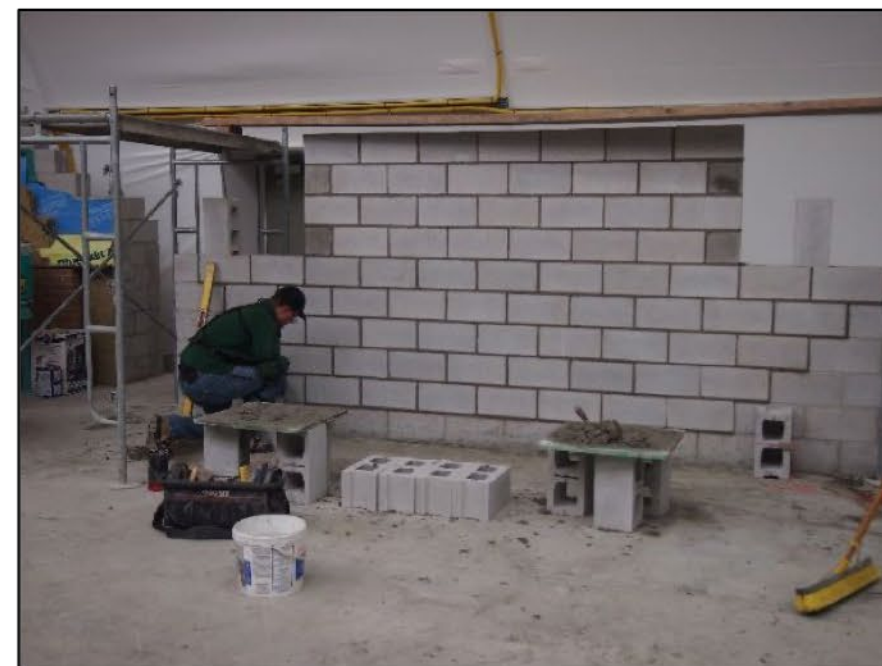
(a)



(b)



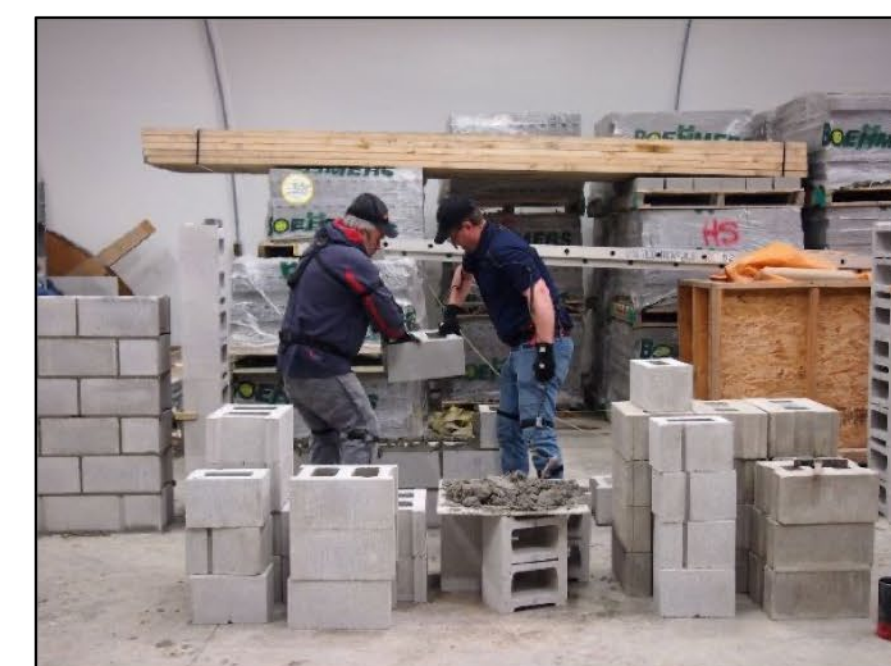
(c)



(d)



(e)

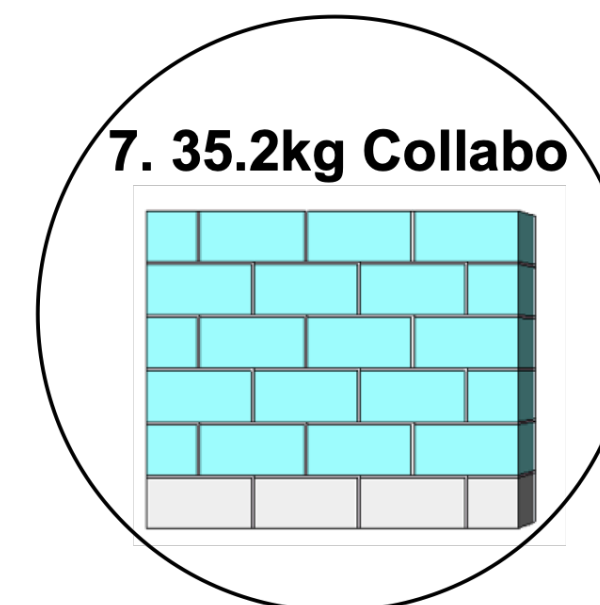
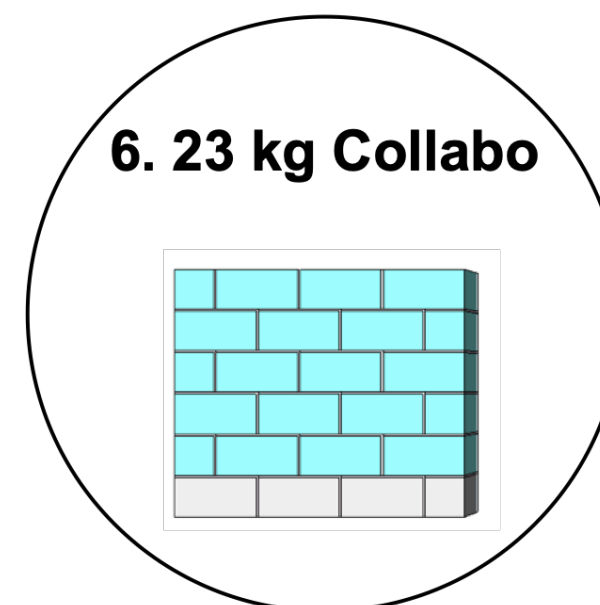
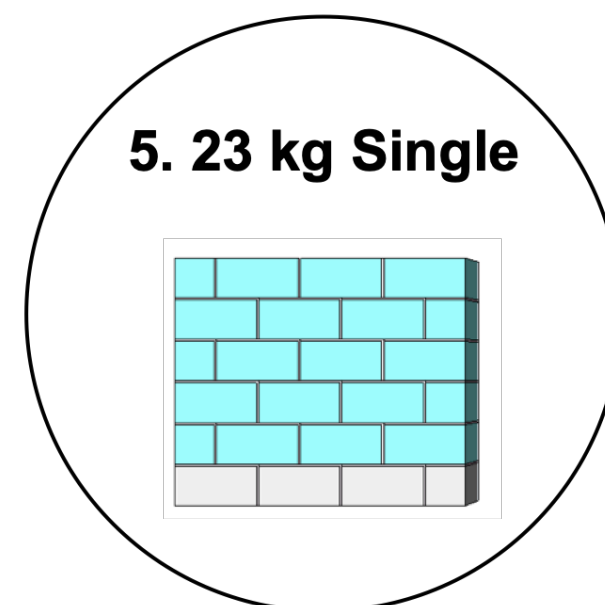
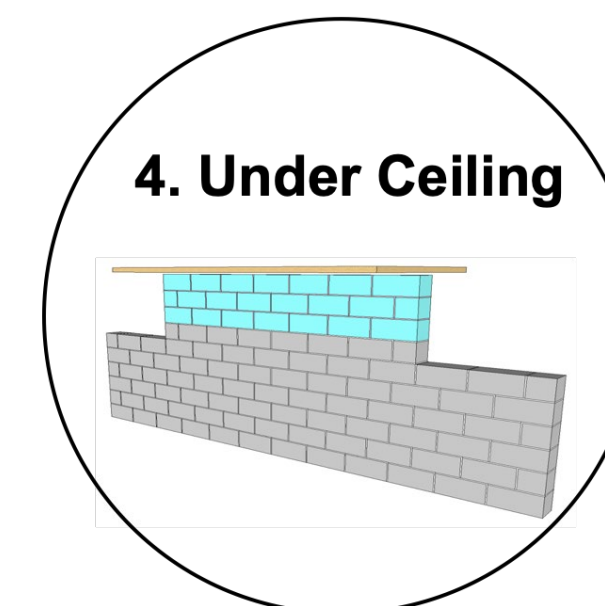
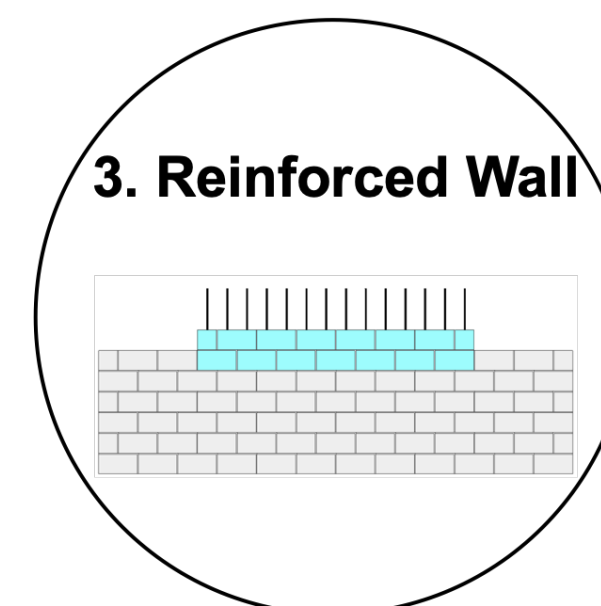
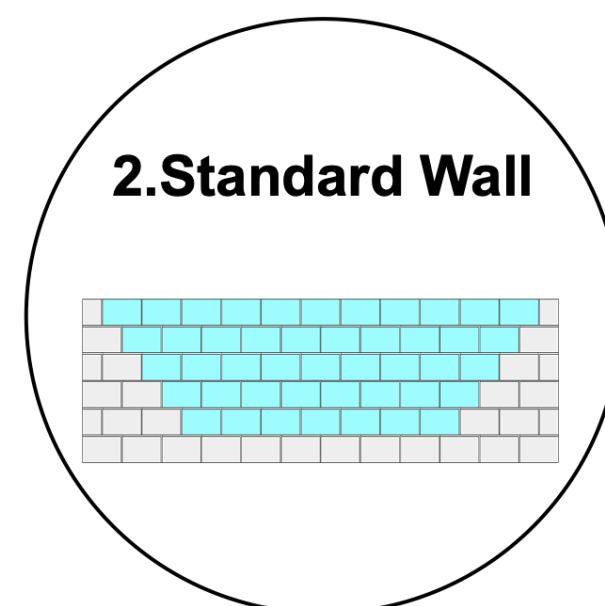
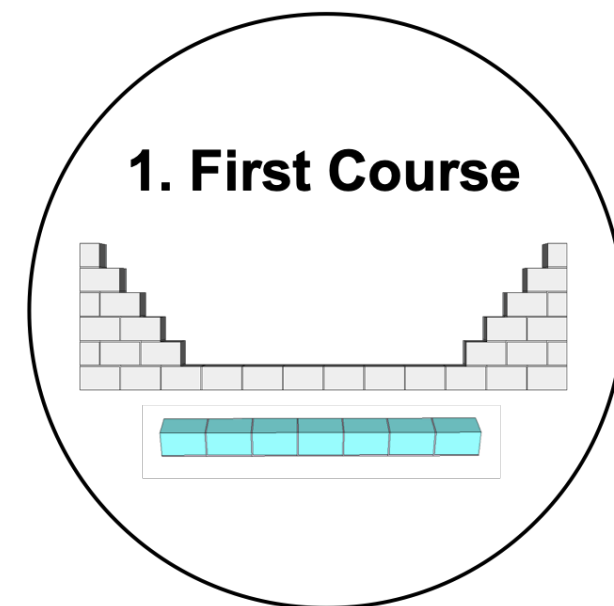


(f)



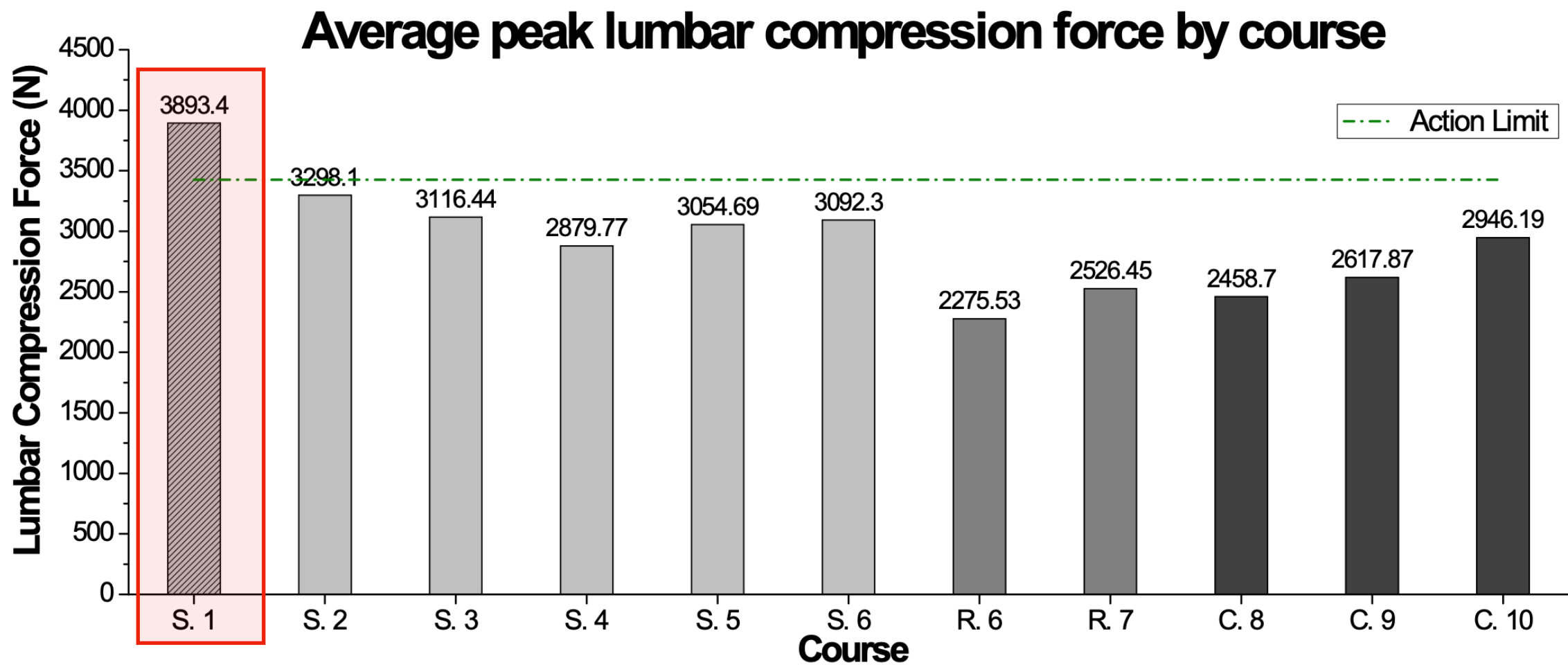
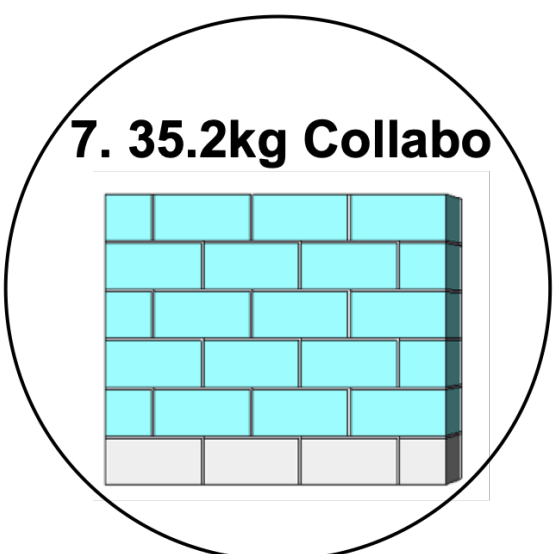
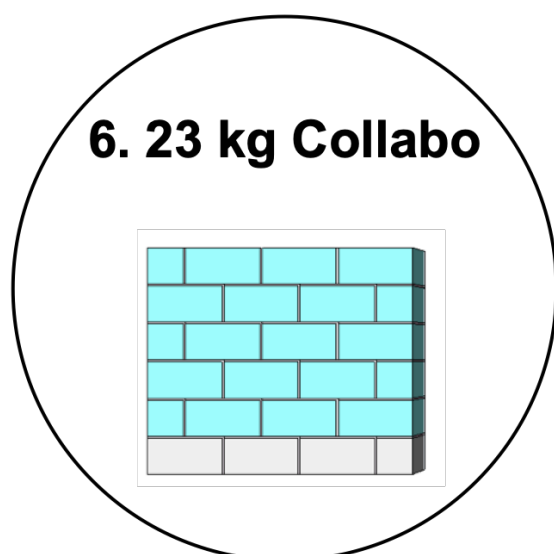
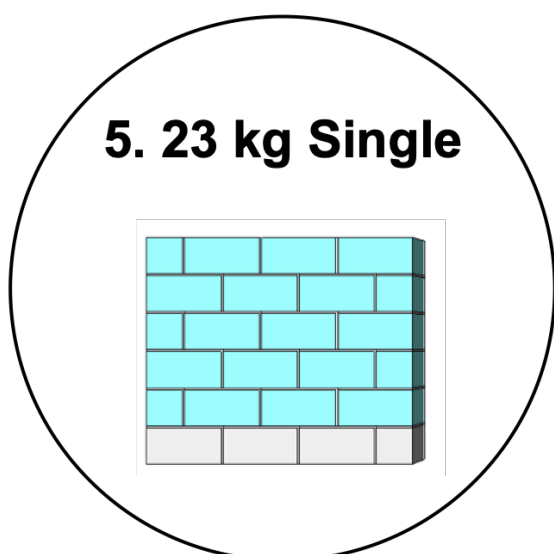
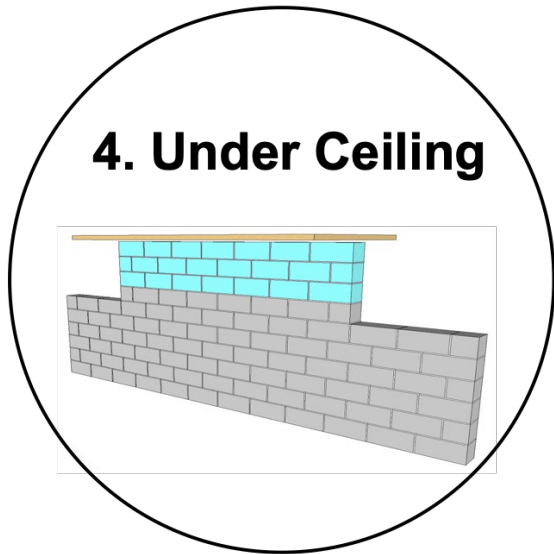
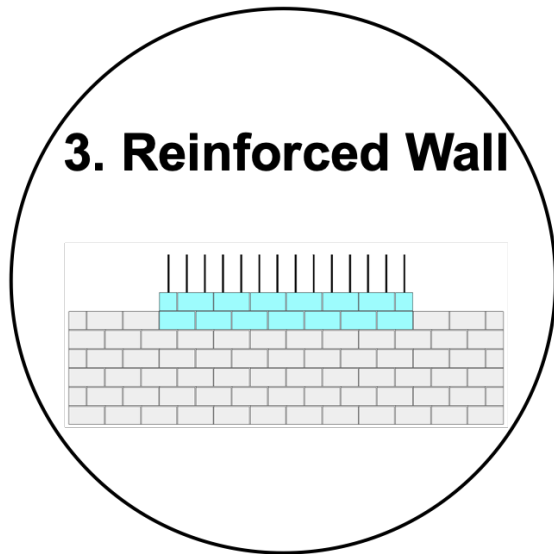
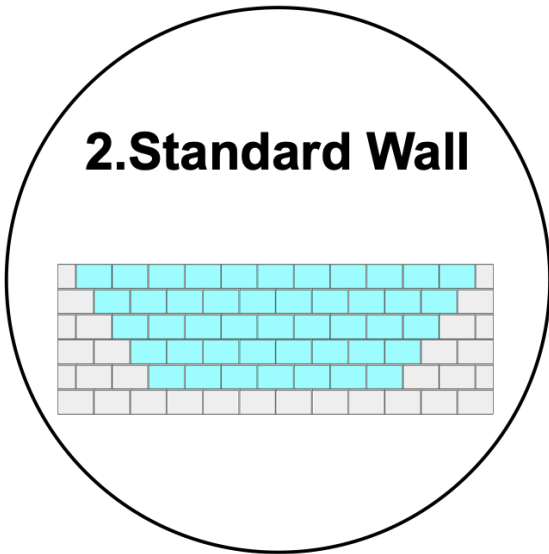
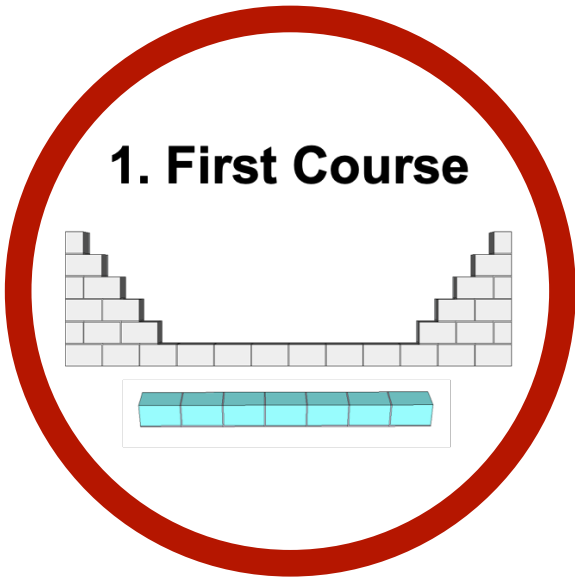


- Evaluate body load in 7 masonry activities performed by experts
  - Representative of standard activities
  - Masons may encounter awkward postures or elevated risk exposure

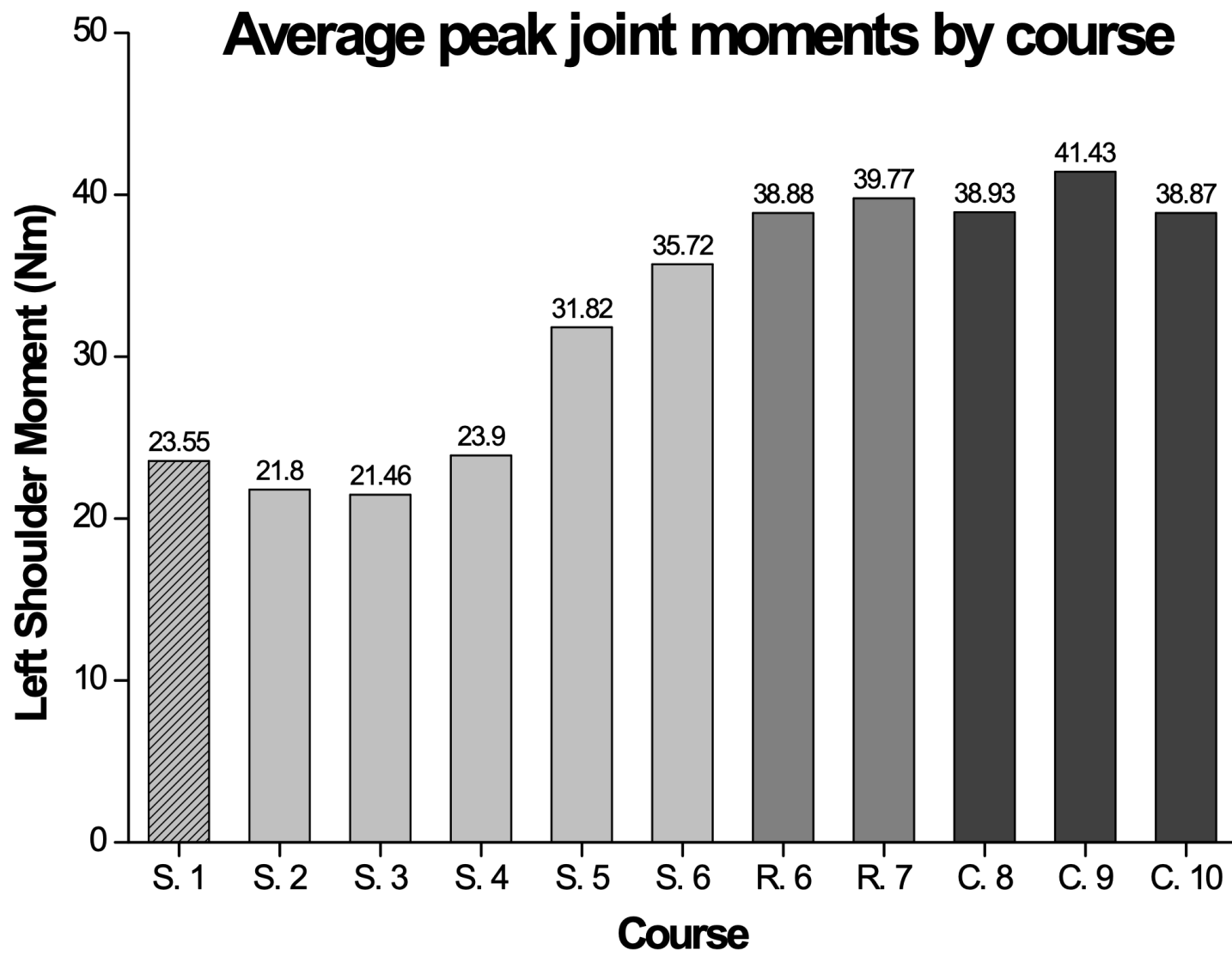




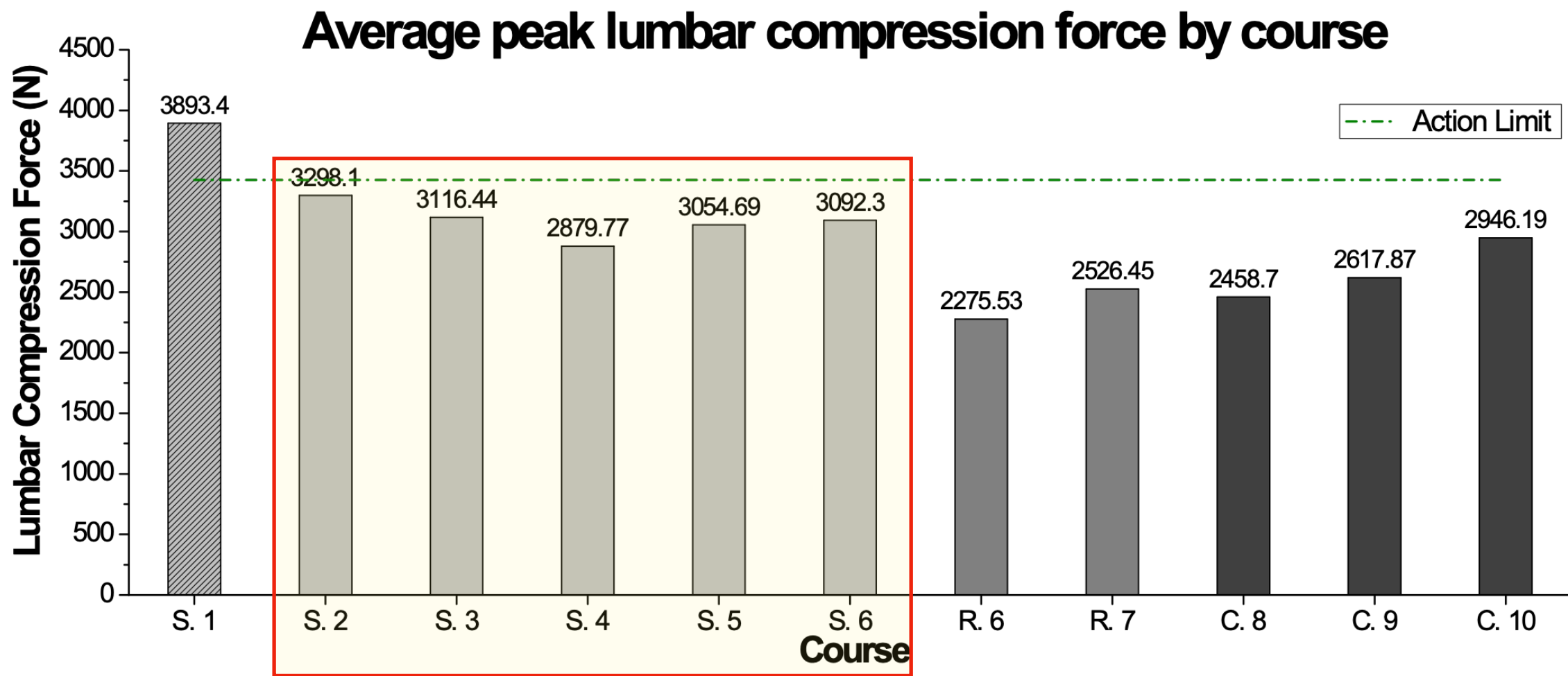
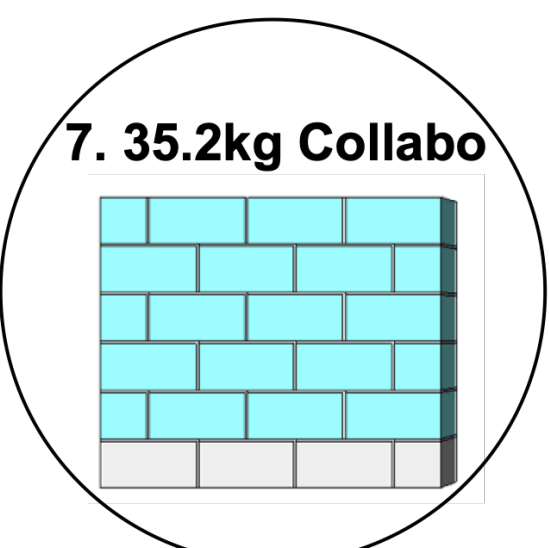
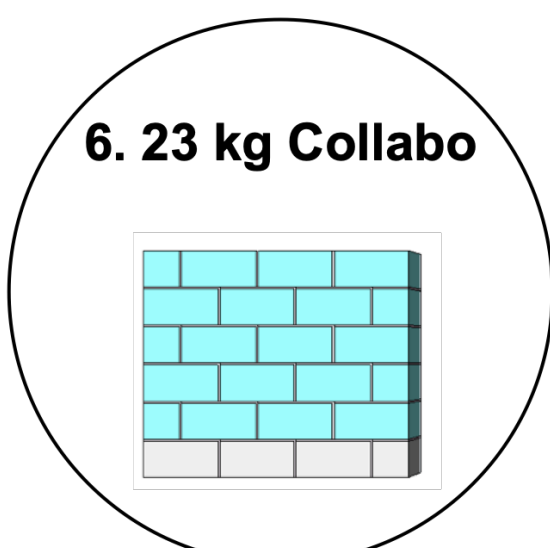
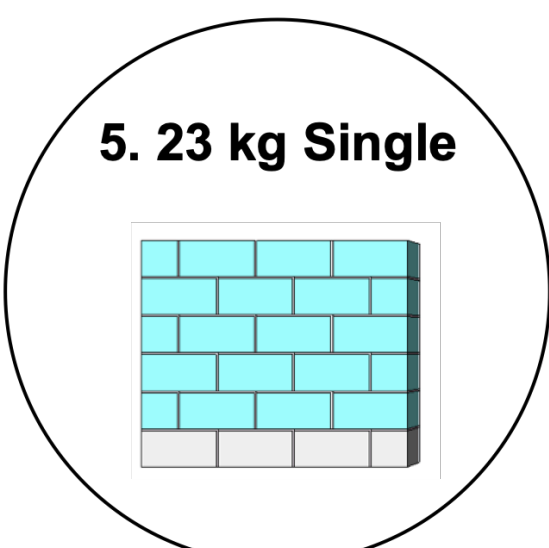
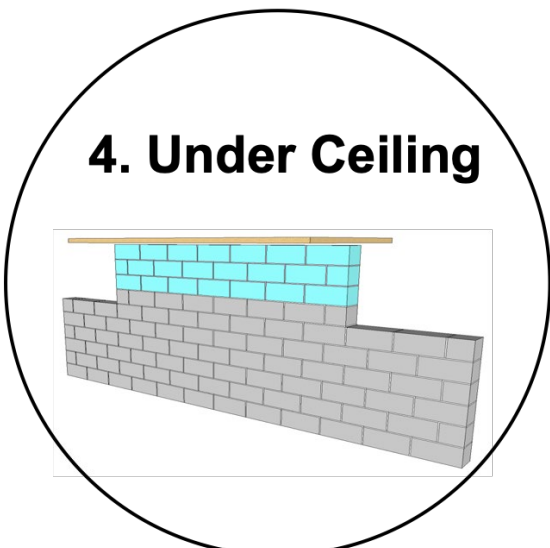
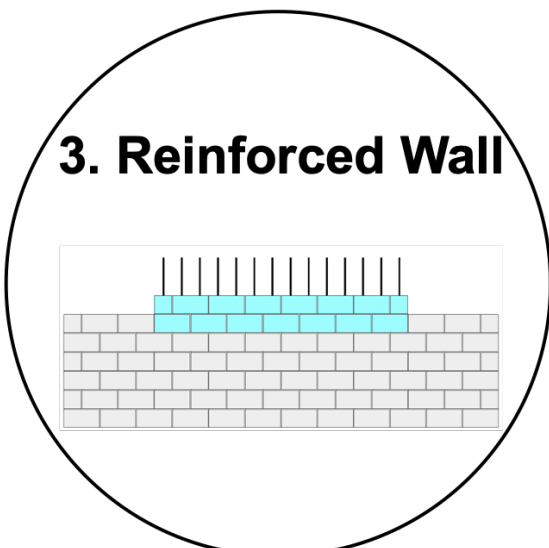
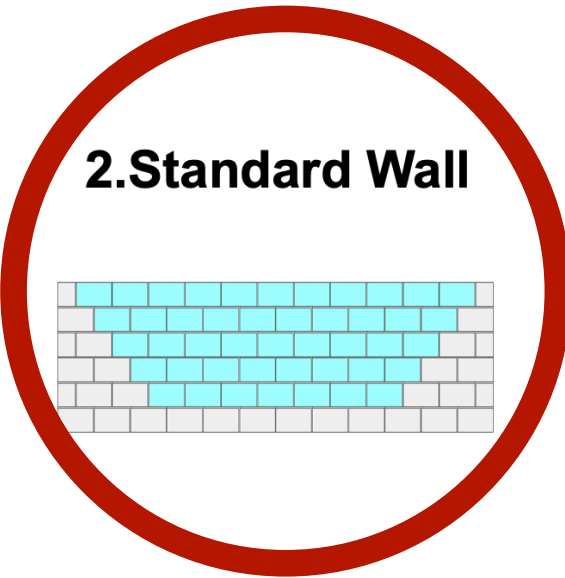
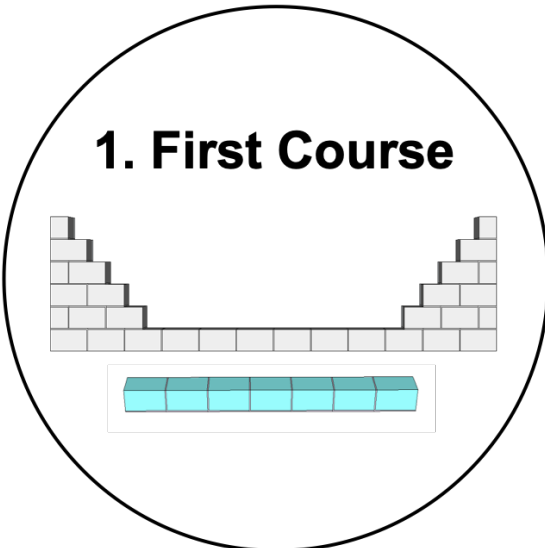
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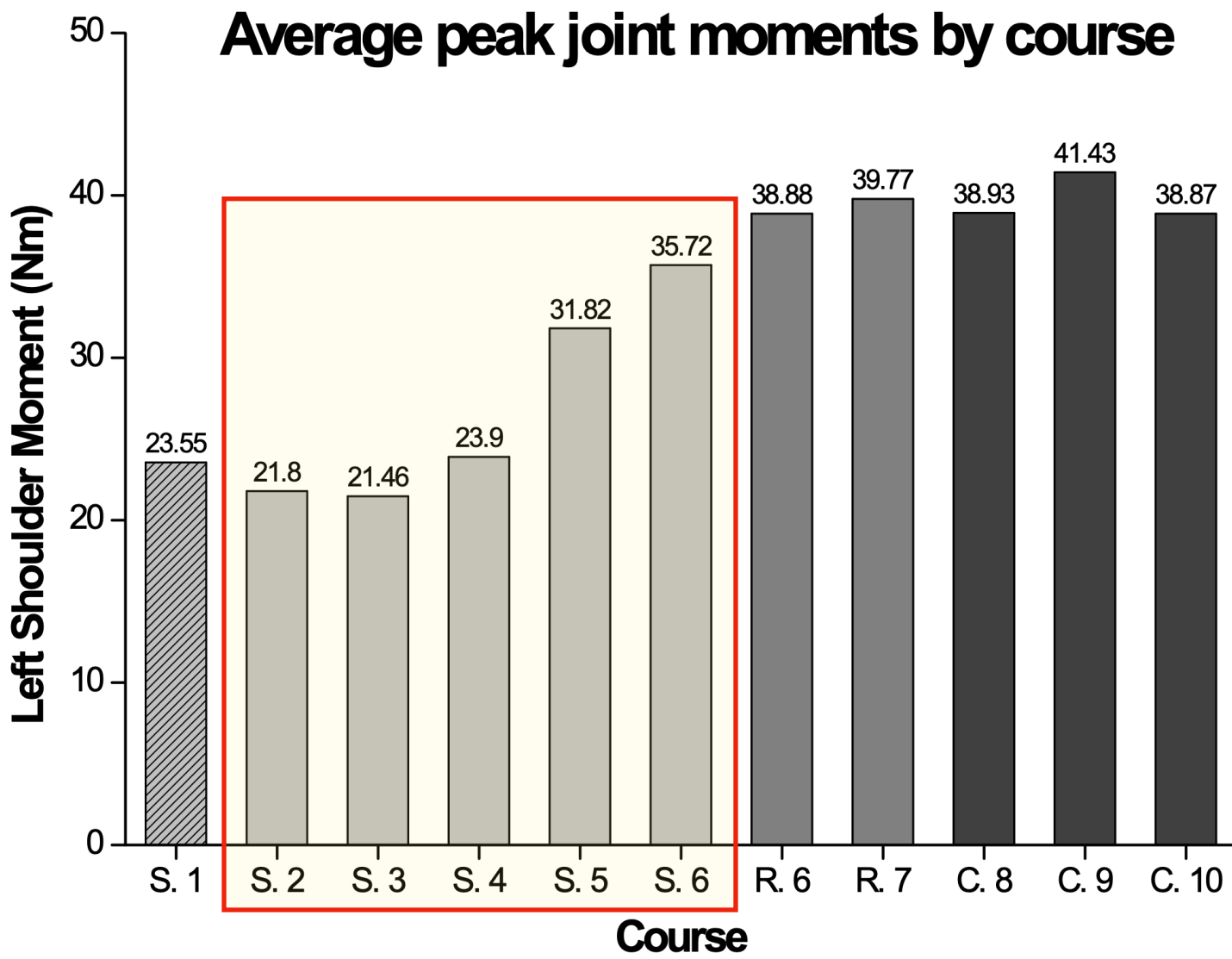
\* S: Standard Wall/ R: Reinforced Wall/ C: Constraint Space (Under Ceiling)



- Evaluate body load in 7 masonry activities performed by experts

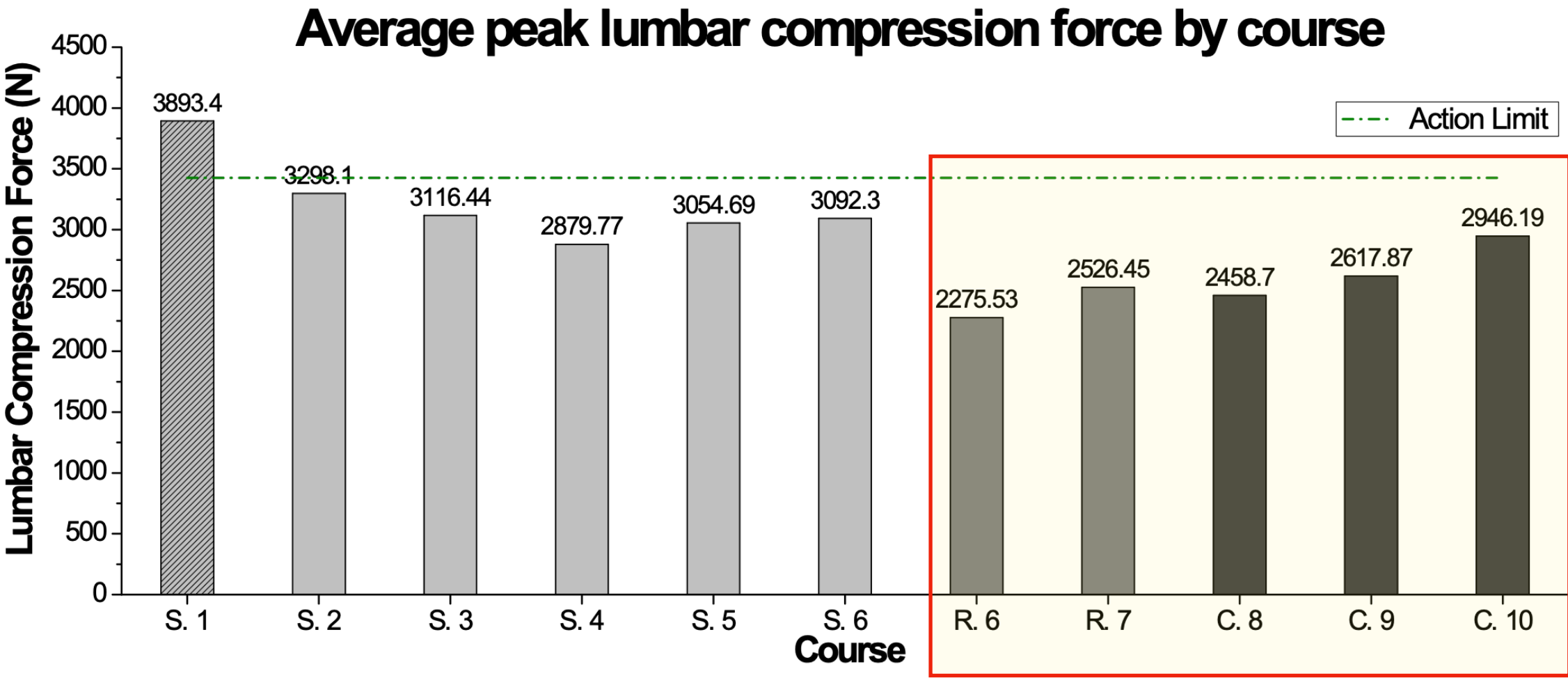
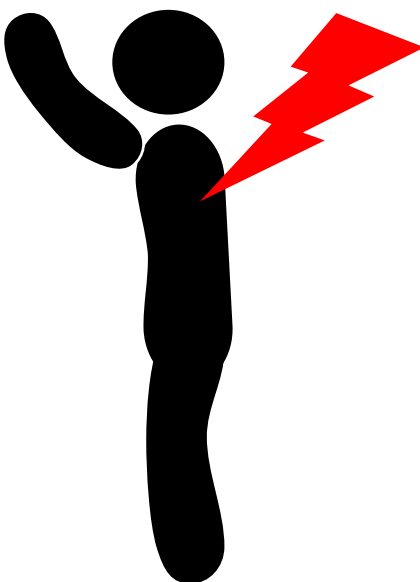
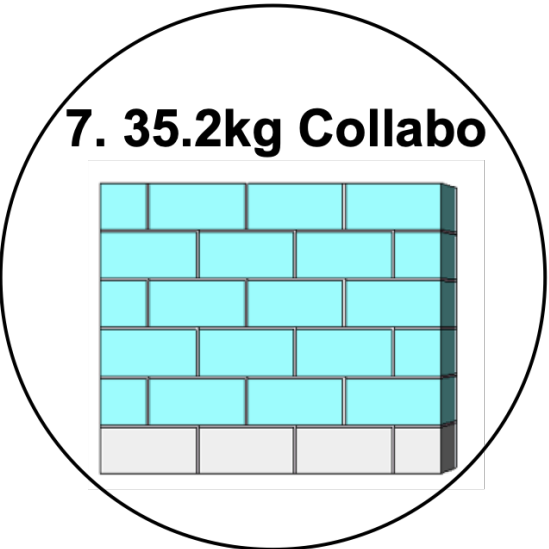
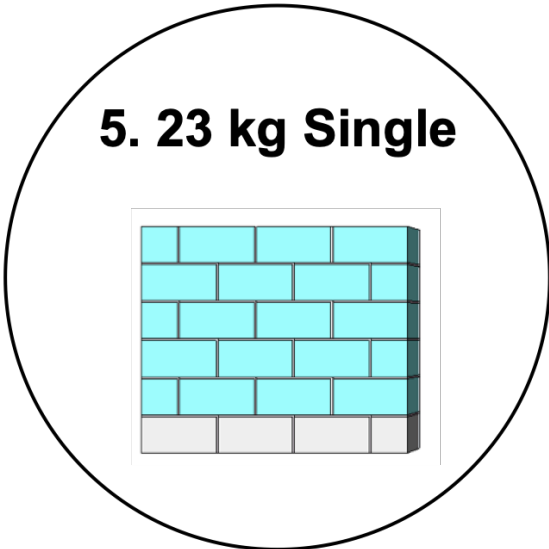
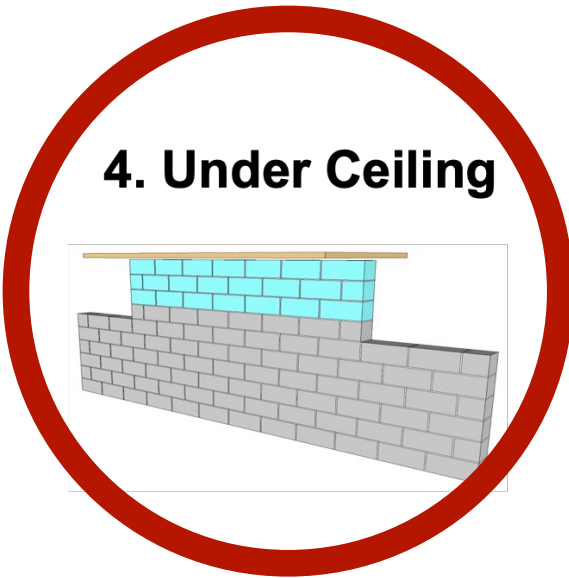
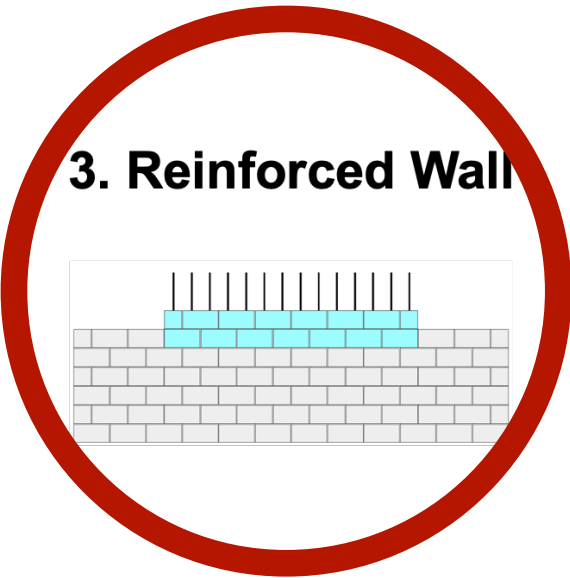
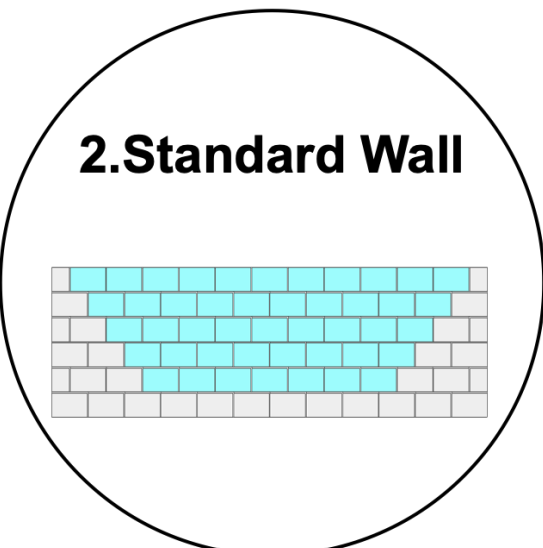
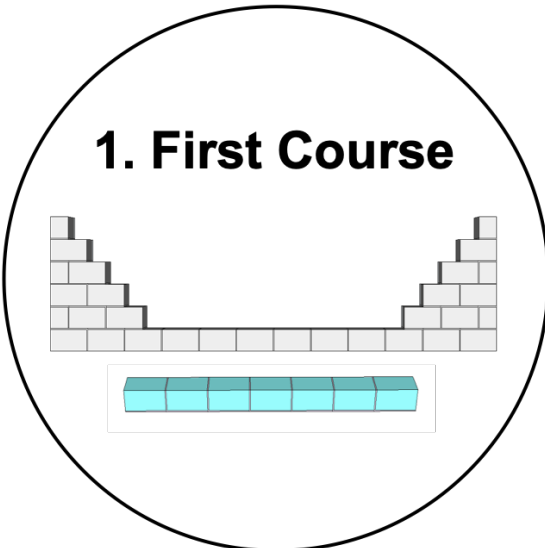


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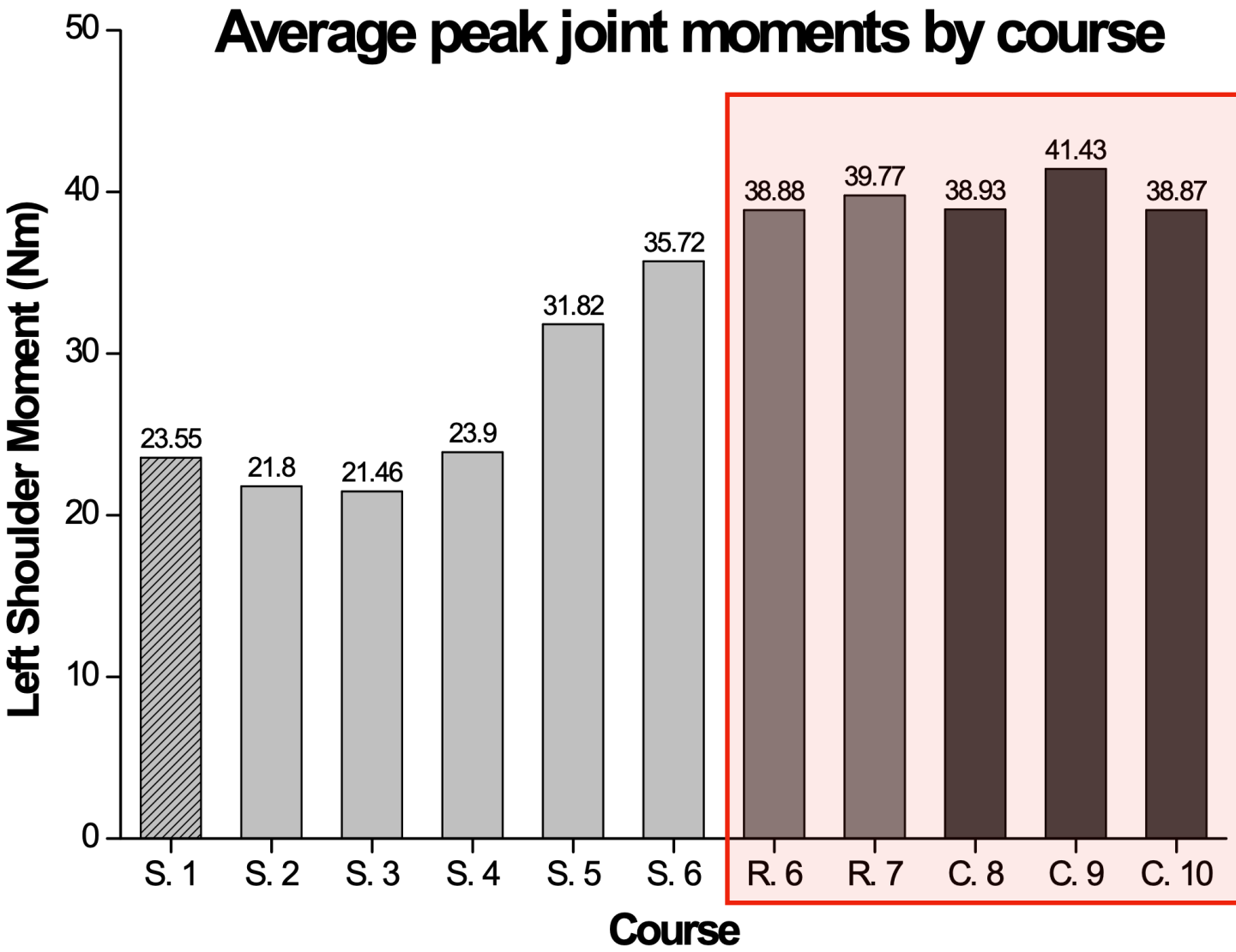




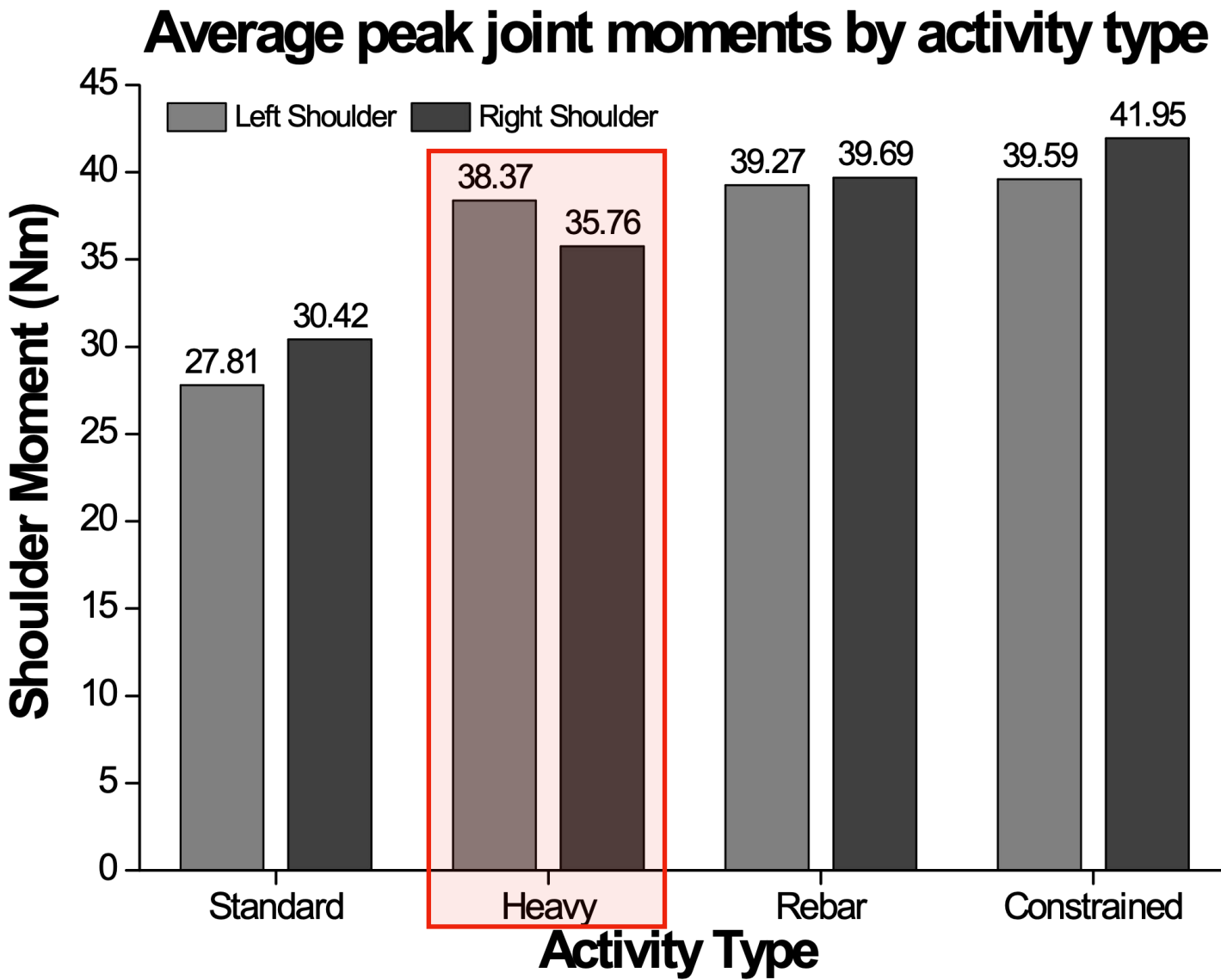
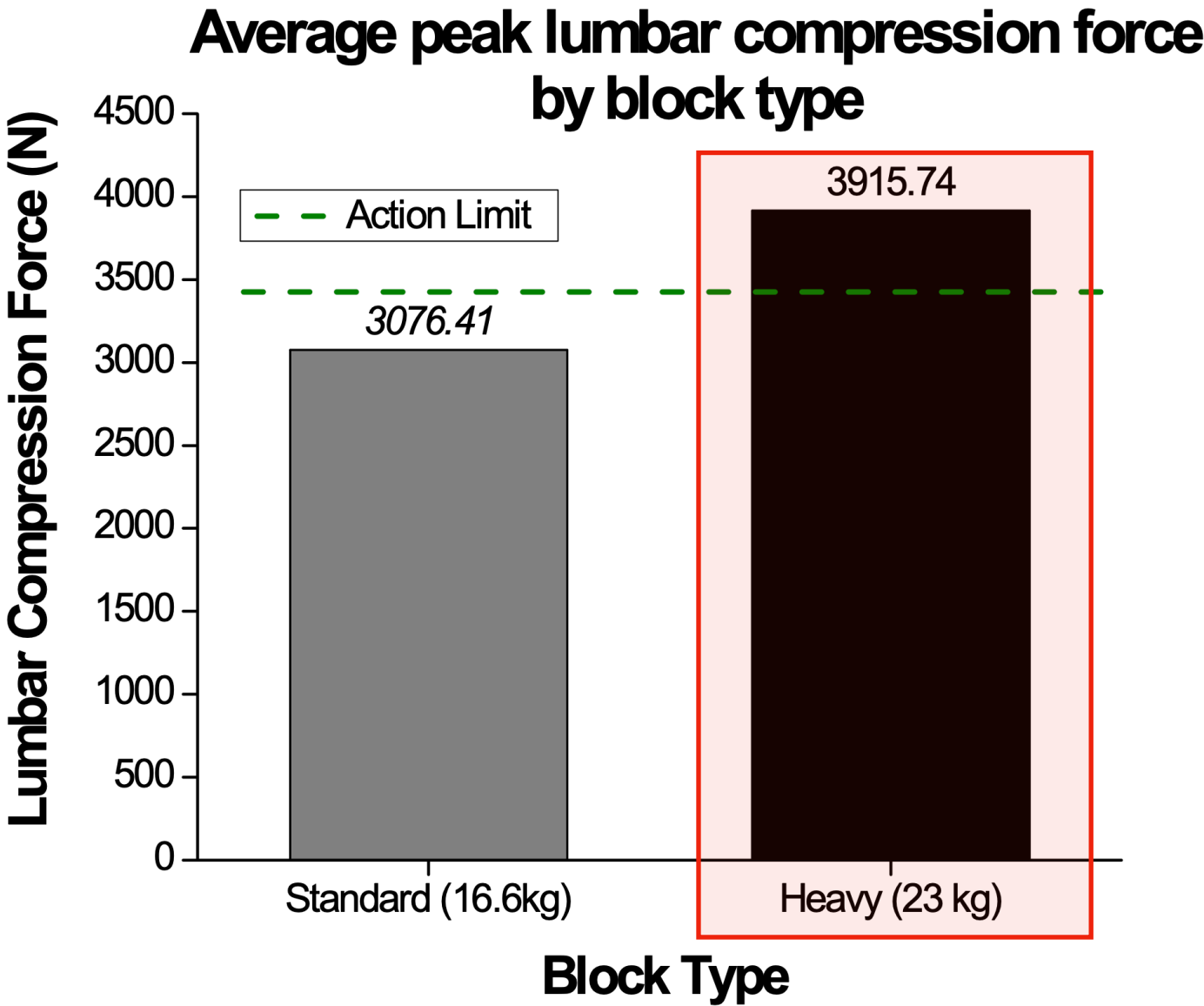
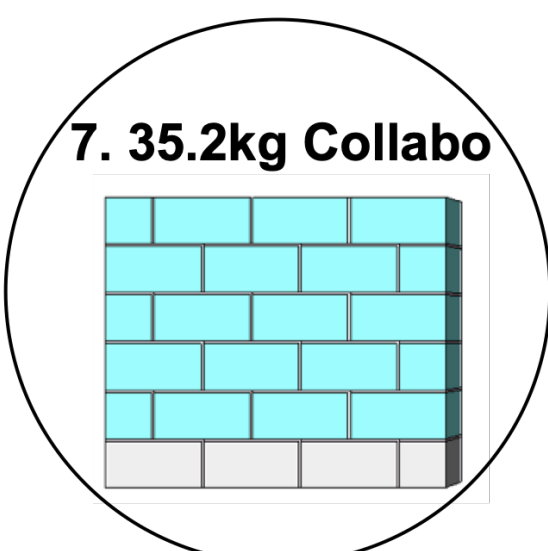
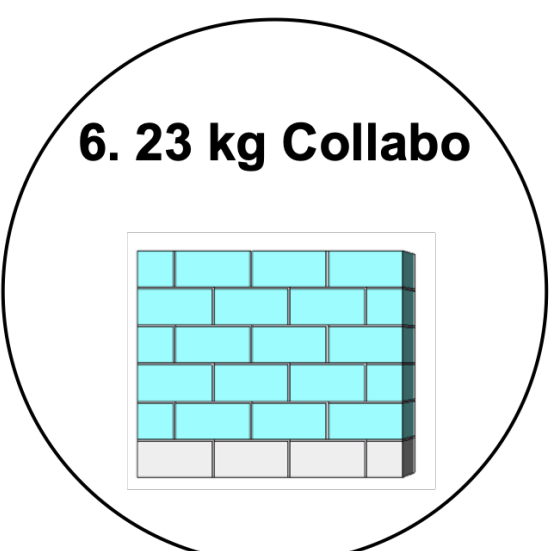
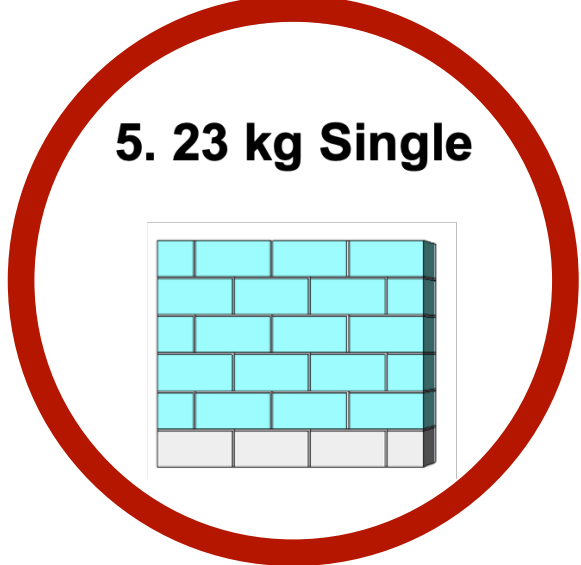
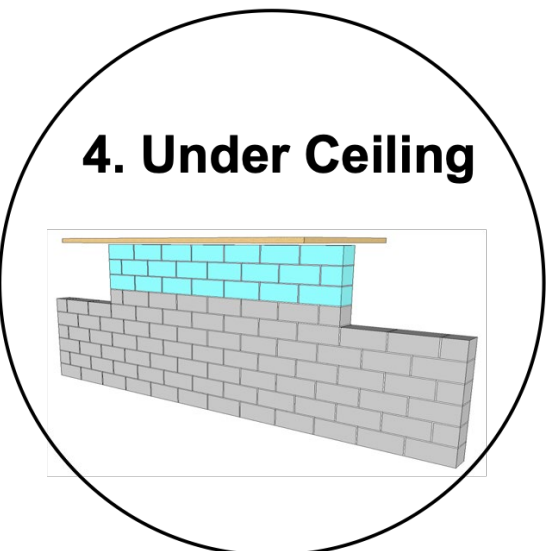
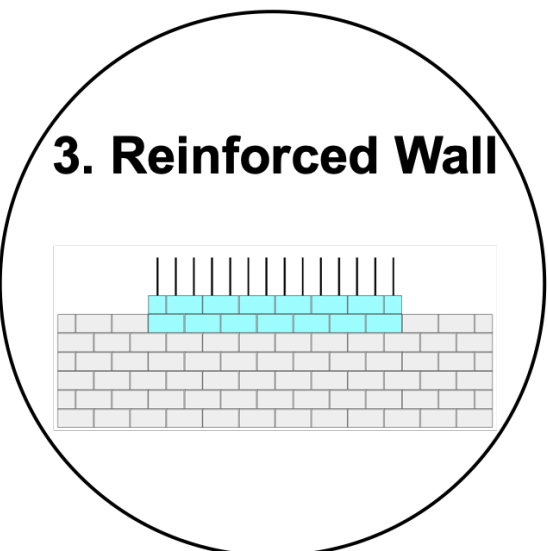
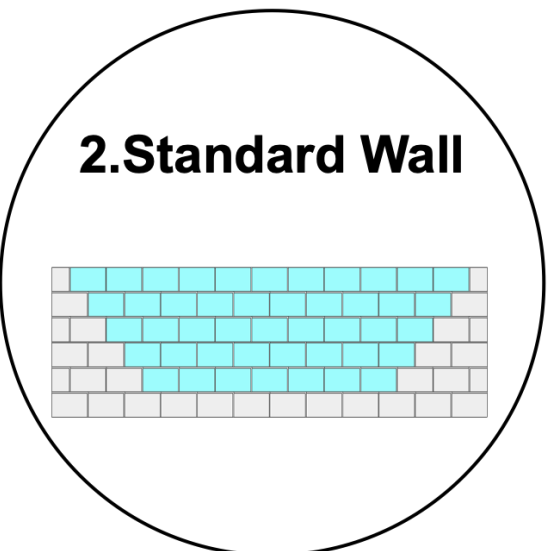
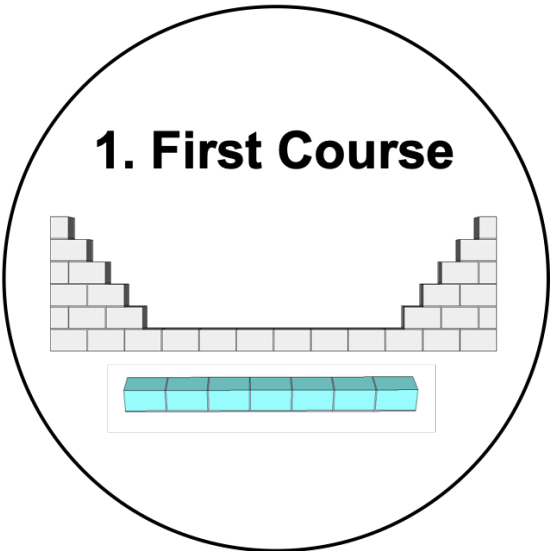
- Evaluate body load in 7 masonry activities performed by experts



\* S: Standard Wall/ R: Reinforced Wall/ C: Constraint Space (Under Ceiling)



- Evaluate body load in 7 masonry activities performed by experts

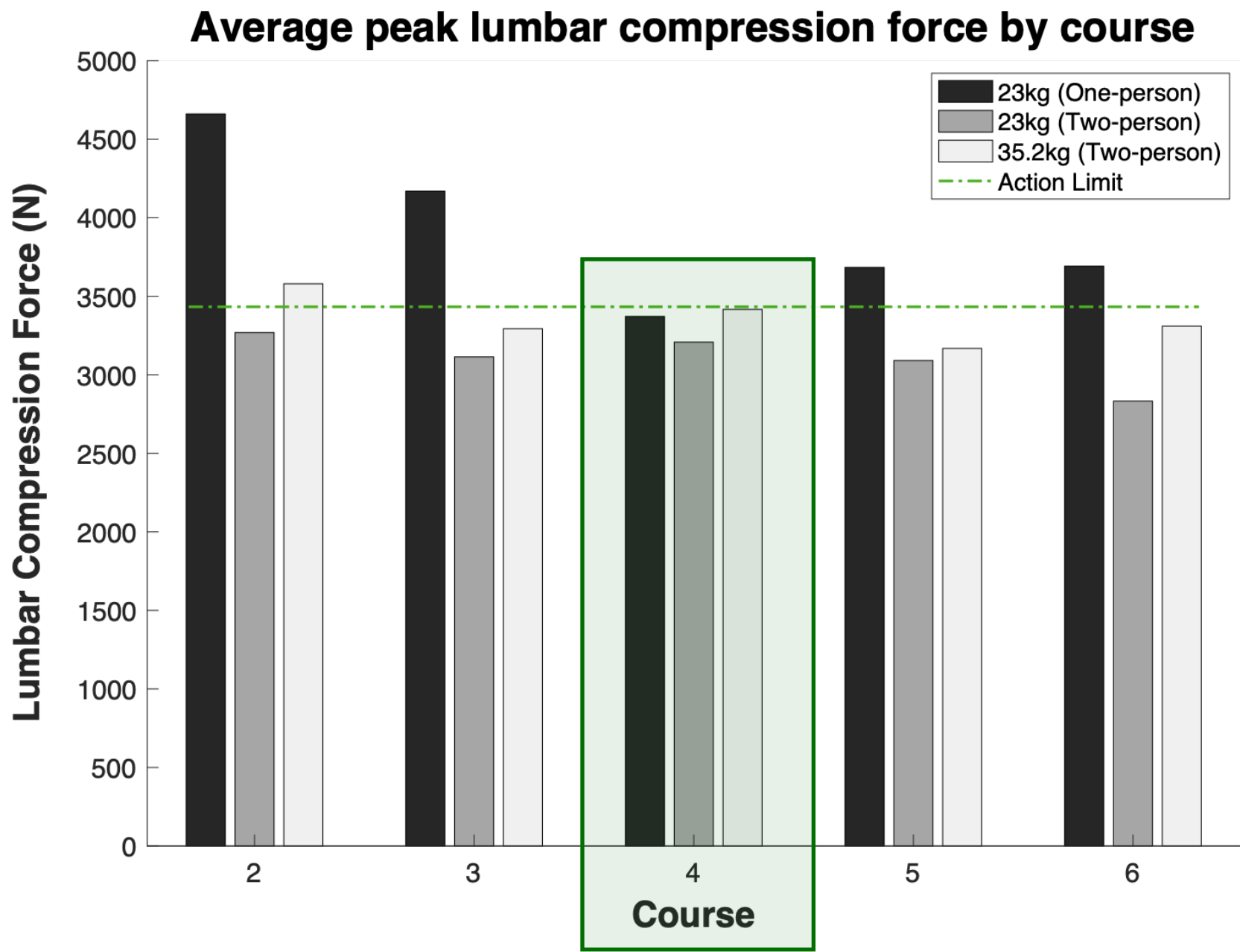
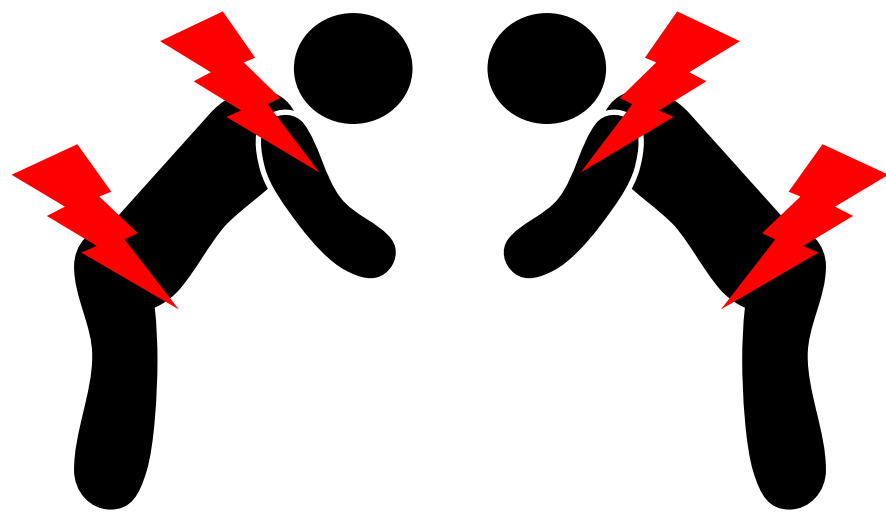
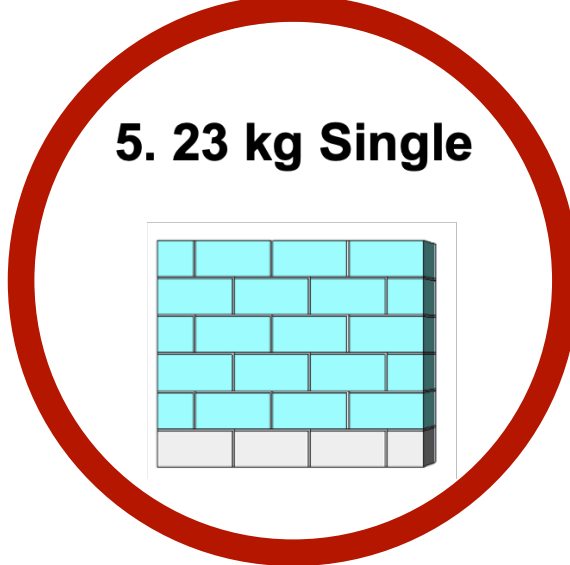
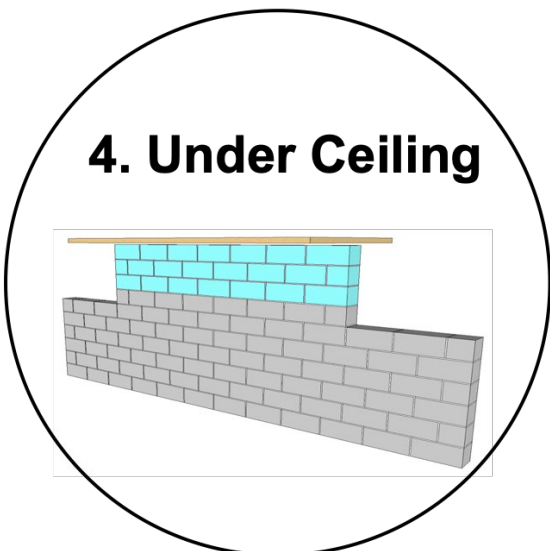
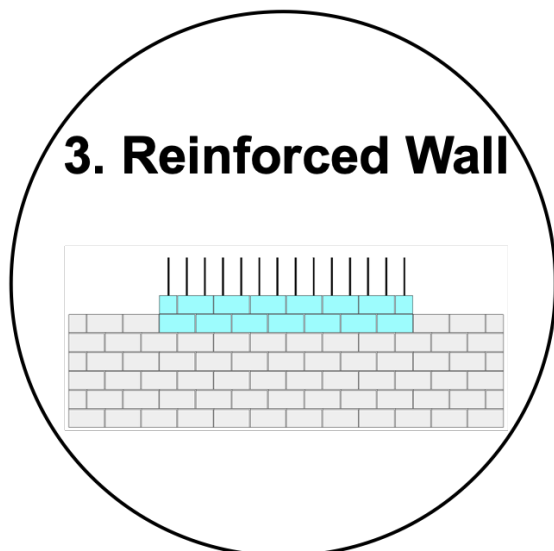
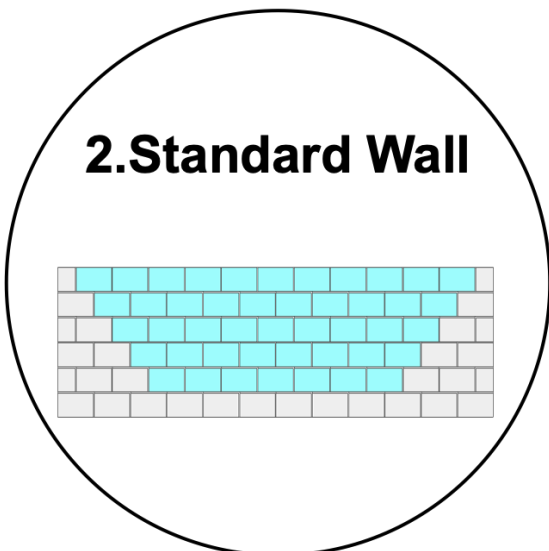
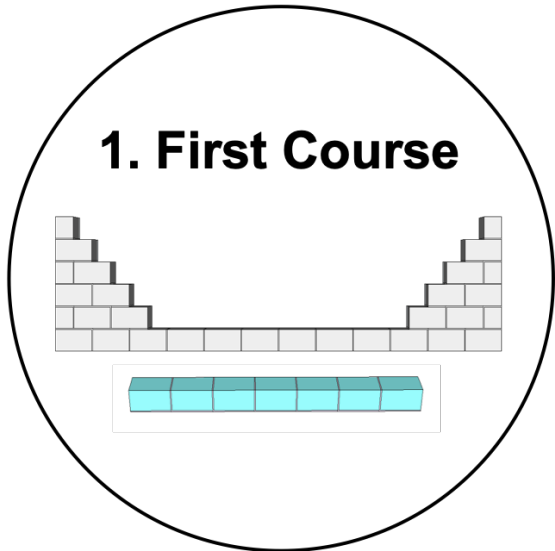


# Expert Masons' Ergonomic Characteristics

“Ergonomic Characteristics of Expert Masons”, *Journal of Construction Engineering and Management* (2022)

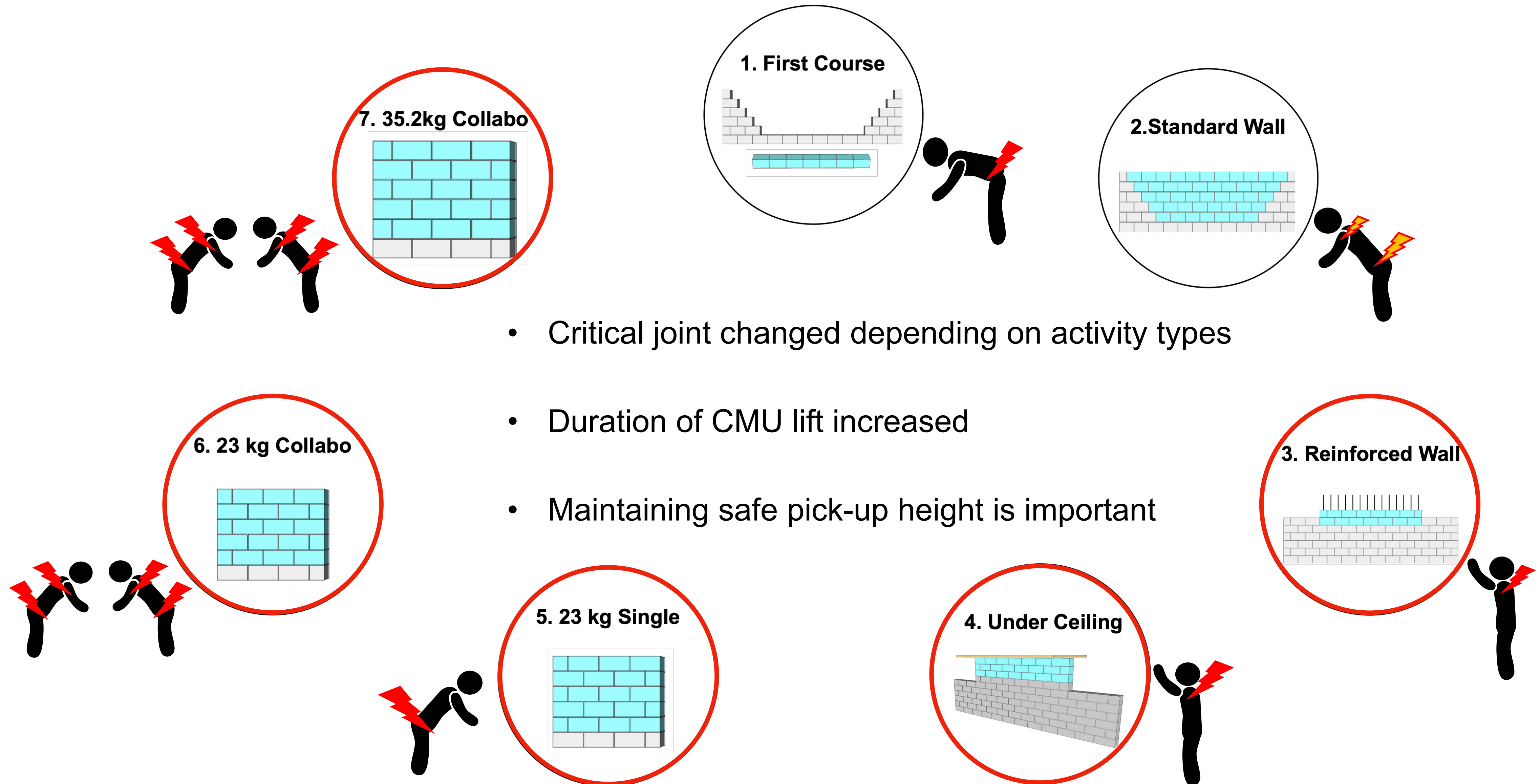


- Evaluate body load in 7 masonry activities performed by experts





# Biomechanical Work Strategies



# Semi-Automated Work Systems: Human-Automation-Robots

“Health and productivity impact of semi-automated work systems in construction”, *Automation in Construction* (2020)



- Adoption of full automation in construction
  - Bricklaying robots (SAM 100 and In-situ-Fabricator)
  - Challenges: dynamics changes in workplaces, worker interventions, and regulations
- **Inevitable:** Collaboration among robots, machines, and workers



SAM 100 (Construction Robotics)



Mobile robotic fabrication (Gifftthaler et al. 2017)

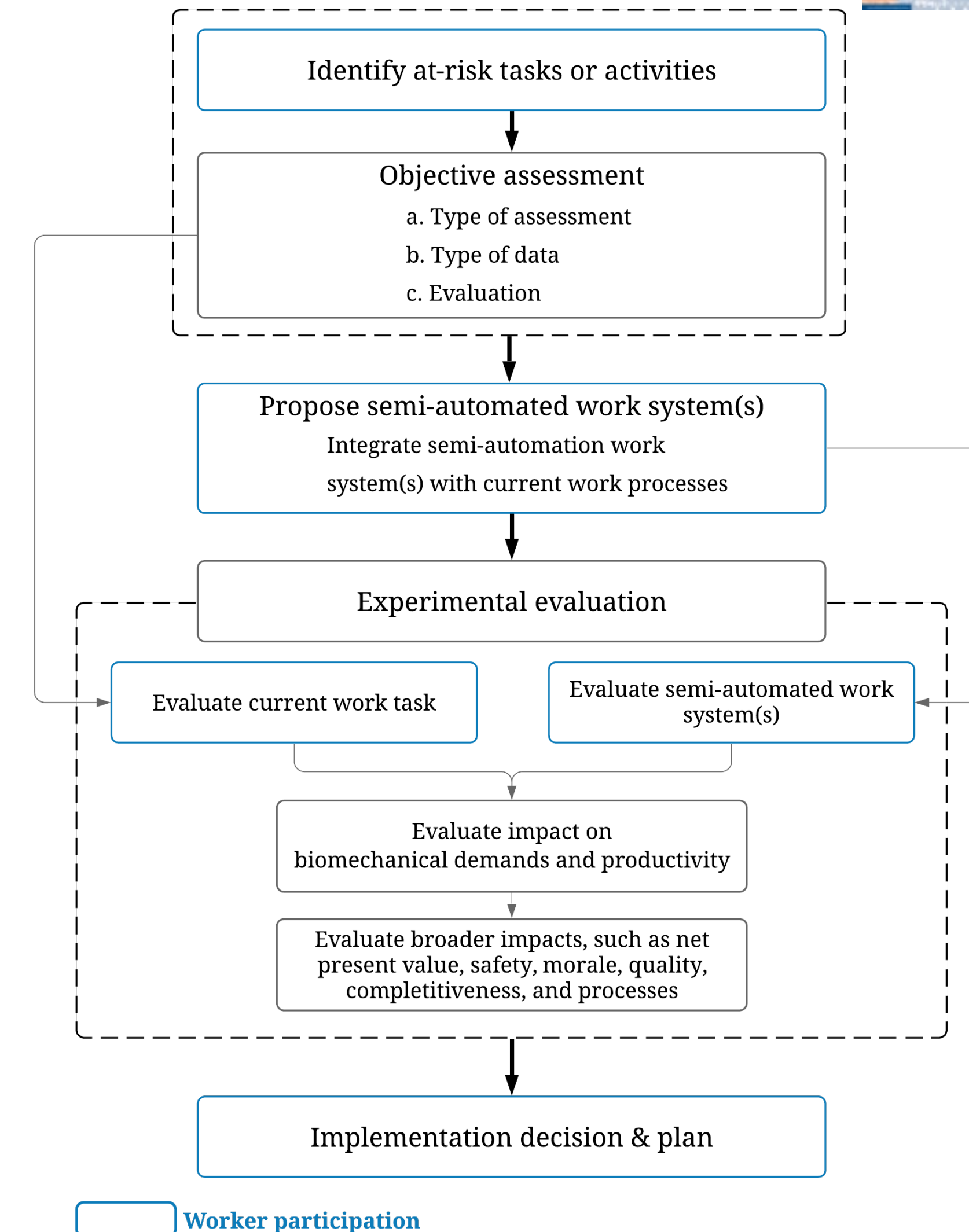




# Semi-Automated Work Systems: Human-Automation-Robots

- Semi-automated work systems
  - Critical to estimate the anticipated effectiveness
- A systematic and objective methodology
  - Evaluate their value and impact in construction context

“Health and productivity impact of semi-automated work systems in construction”, *Automation in Construction* (2020)



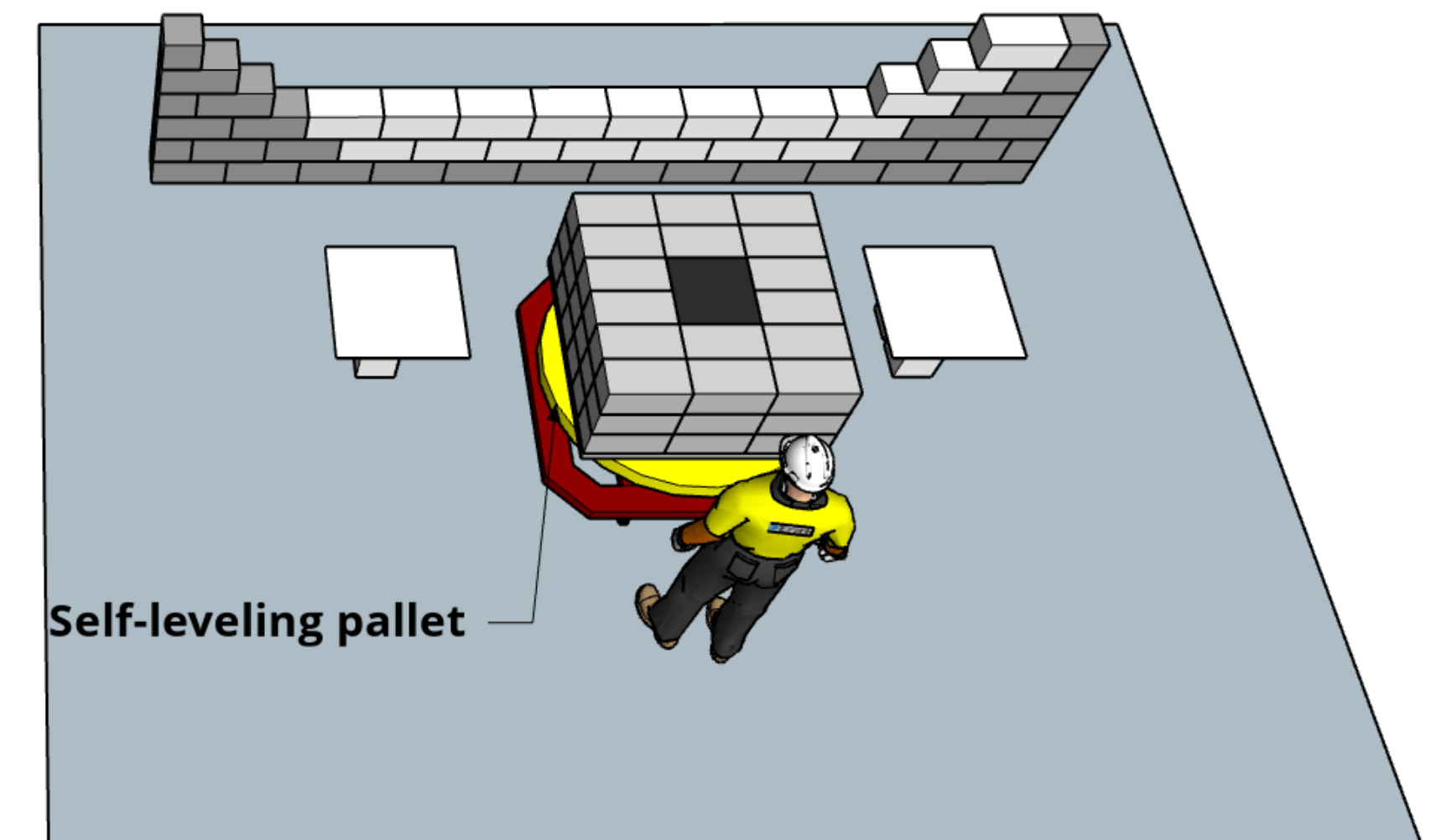
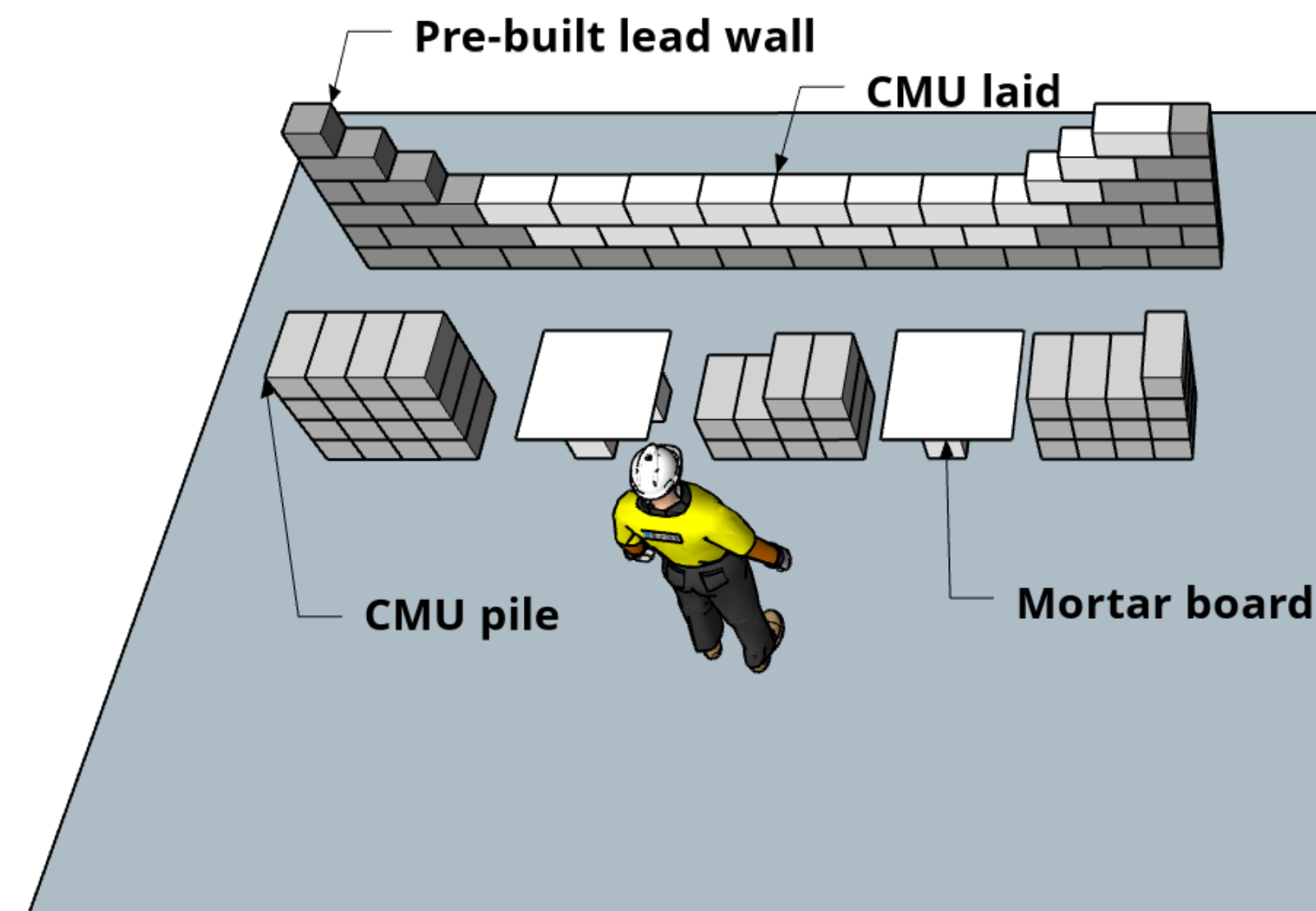


# Strategies to Improve Laying CMUs

“Health and productivity impact of semi-automated work systems in construction”, *Automation in Construction* (2020)

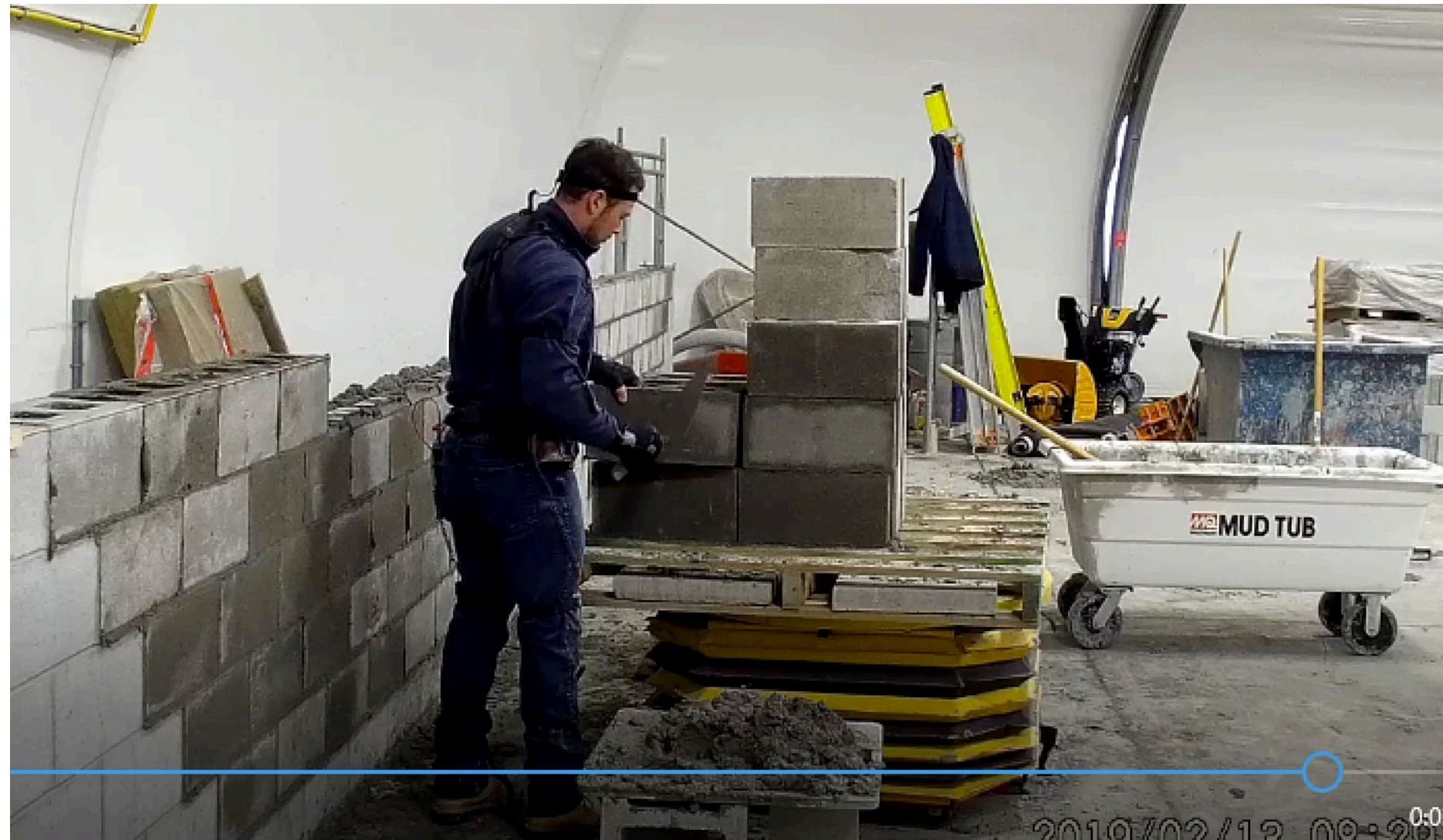
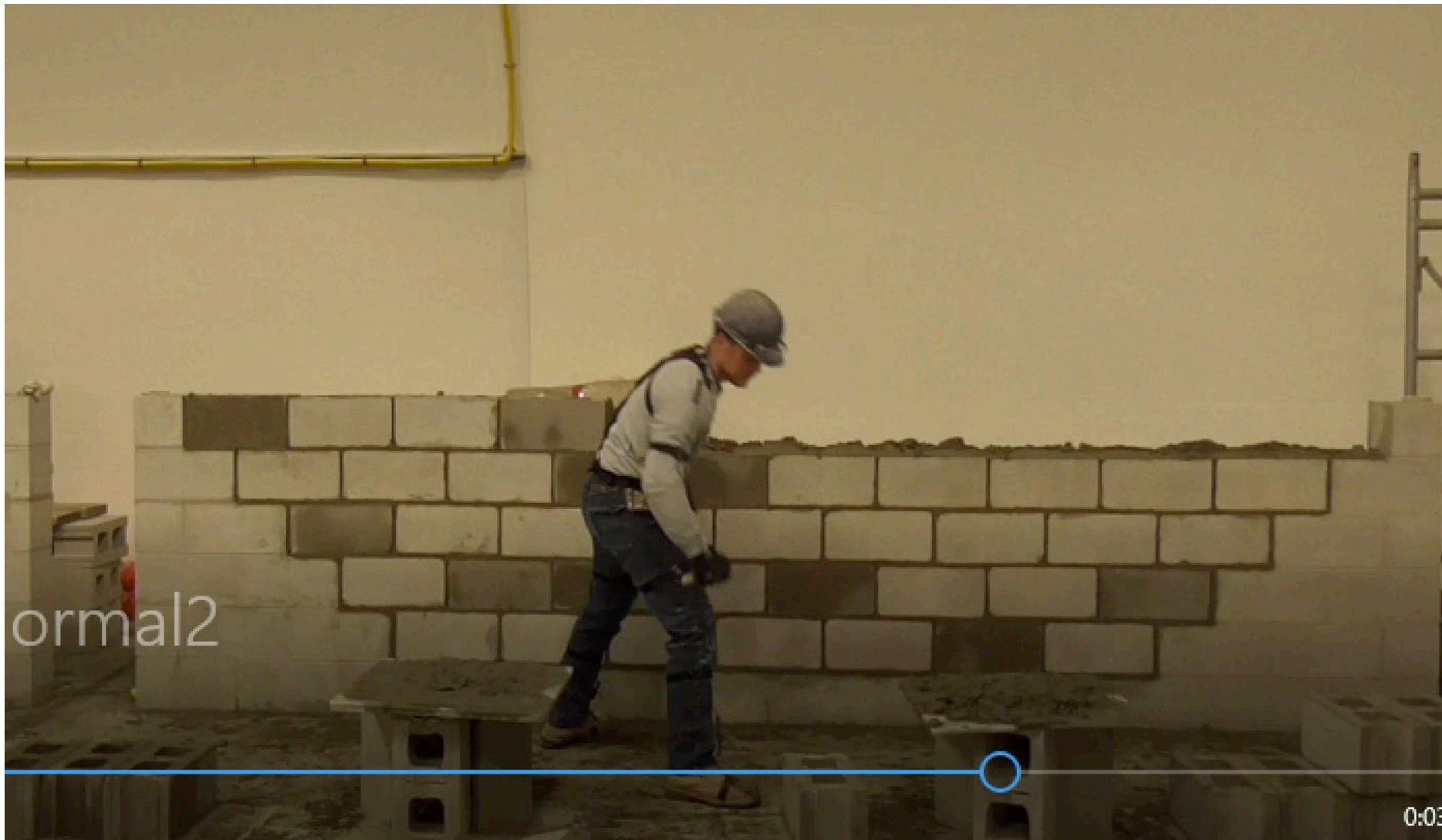


- Semi-automated work systems
  - Critical to estimate the anticipated effectiveness
- A systematic and objective methodology
  - Evaluate their value and impact in construction context
- **Self-leveling pallet**





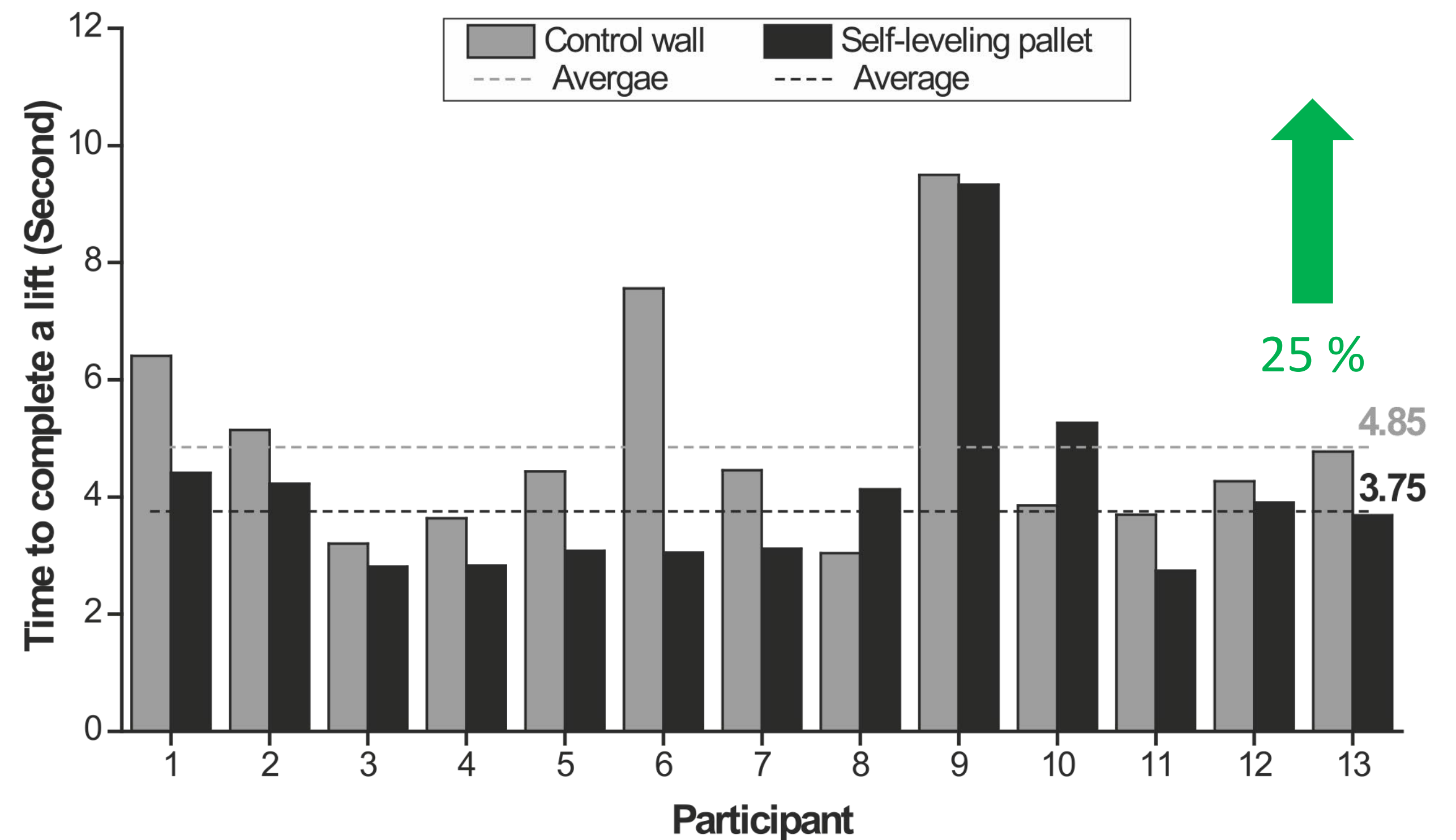
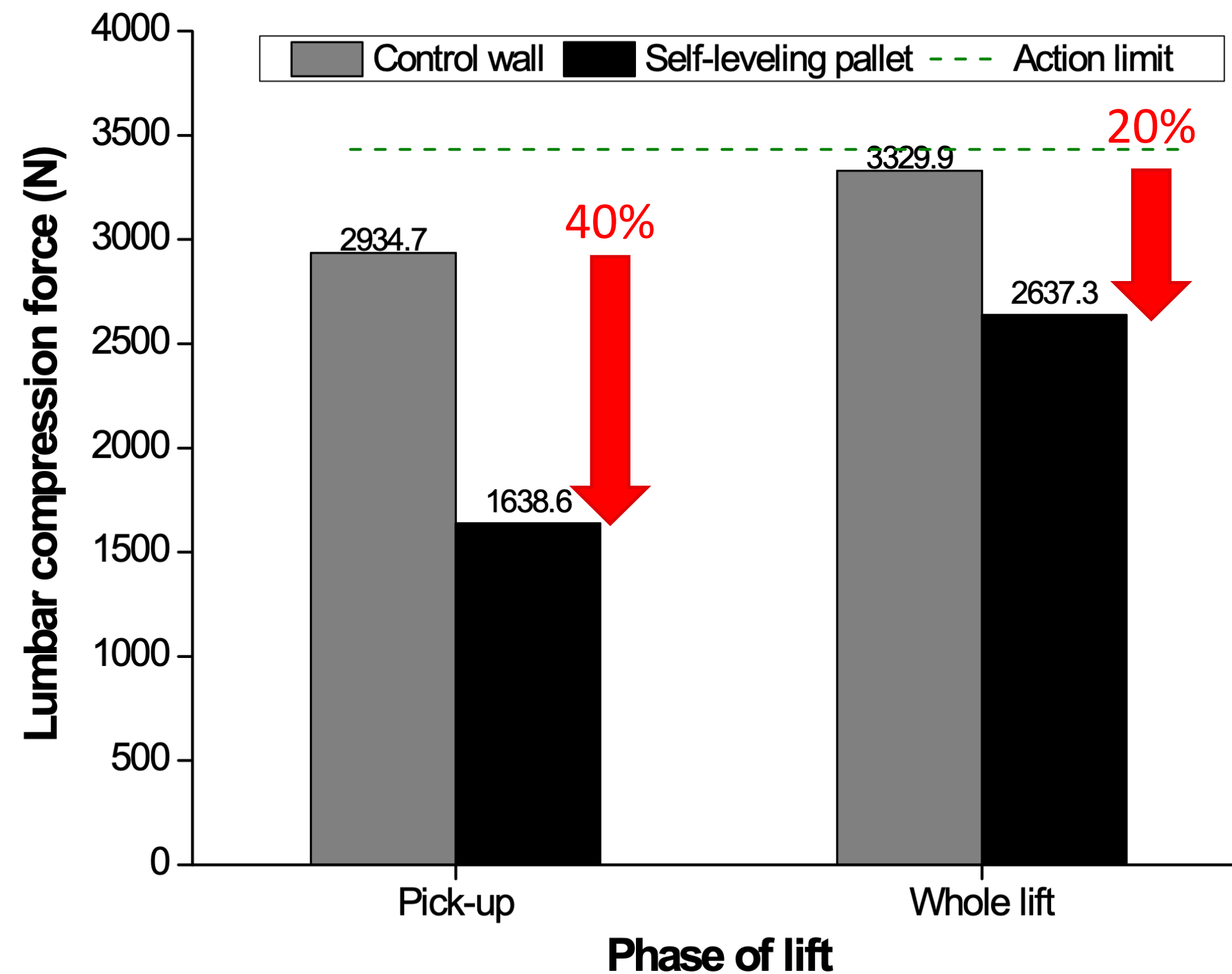
# Self-leveling Pallet - Motion Comparison





# Safety & Productivity Impact

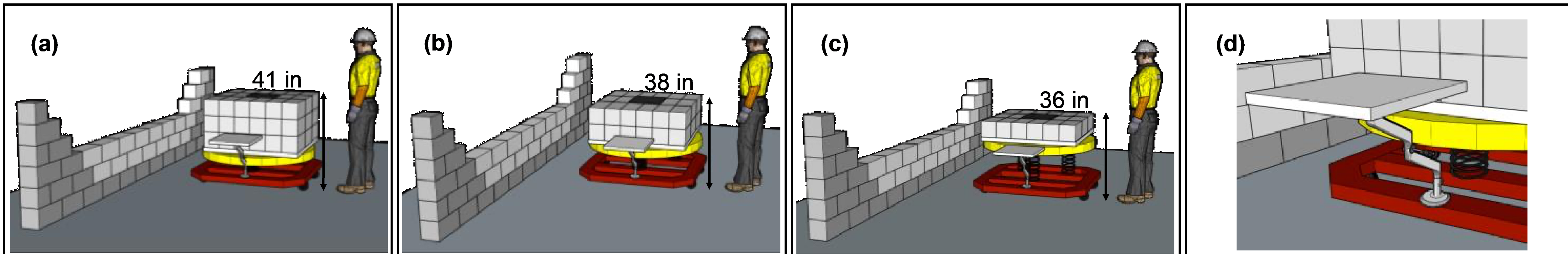
- Reduce stress contributions
  - On average reduced peak stress of picking up the unit by 40% and whole lift phase by 20%
- Productivity impacts
  - Noticeable increase in speed of construction (~10%) due to average drop in lift time (~25%)



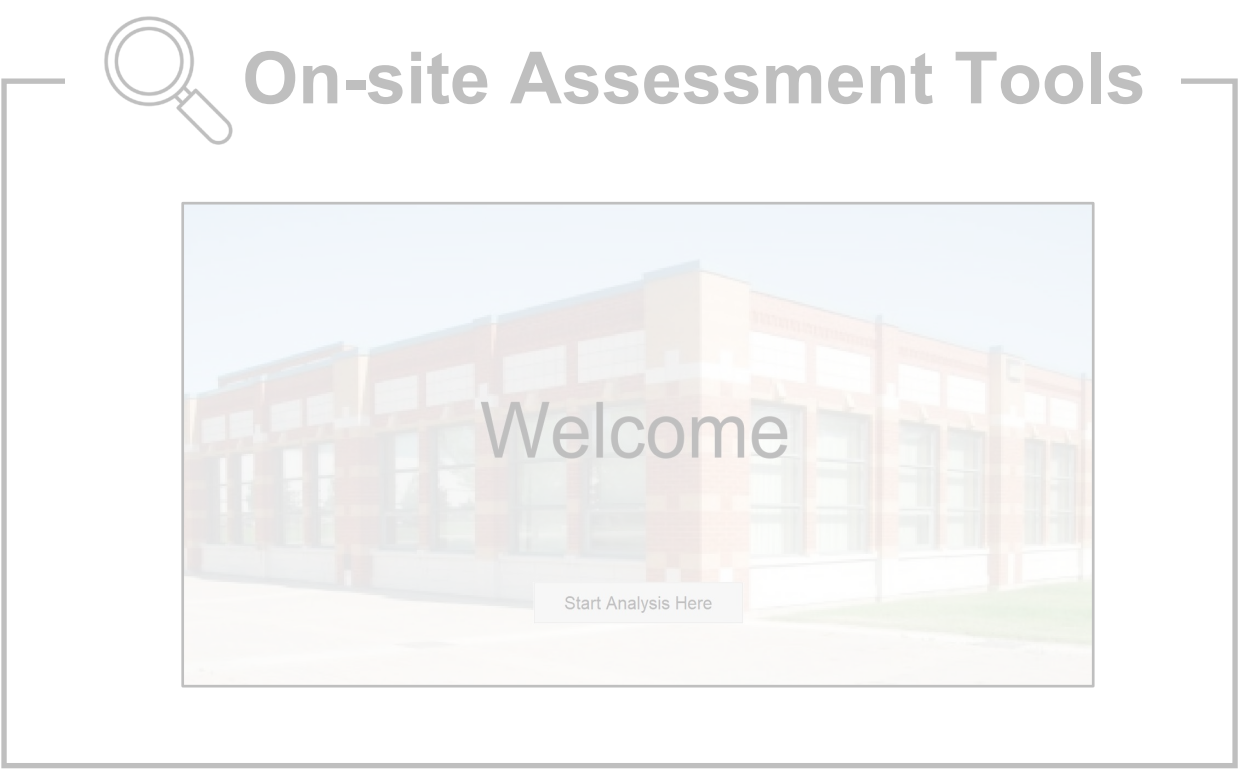
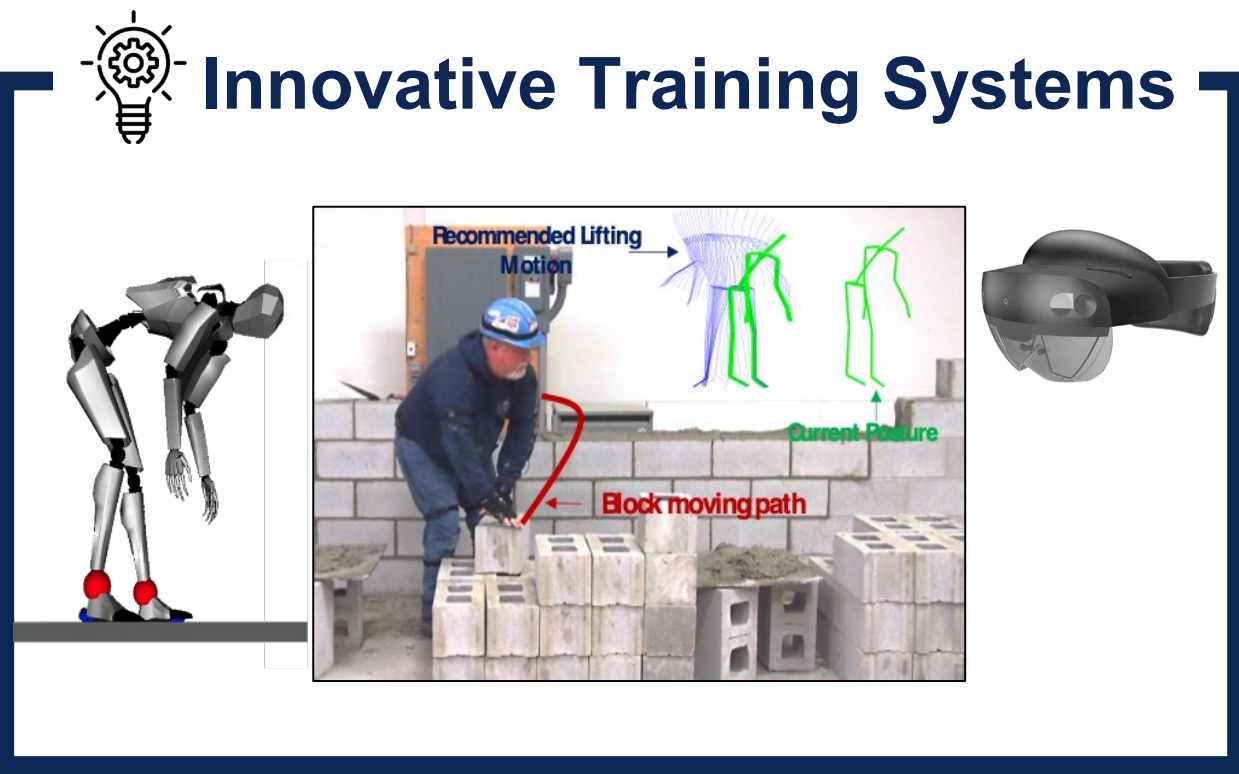
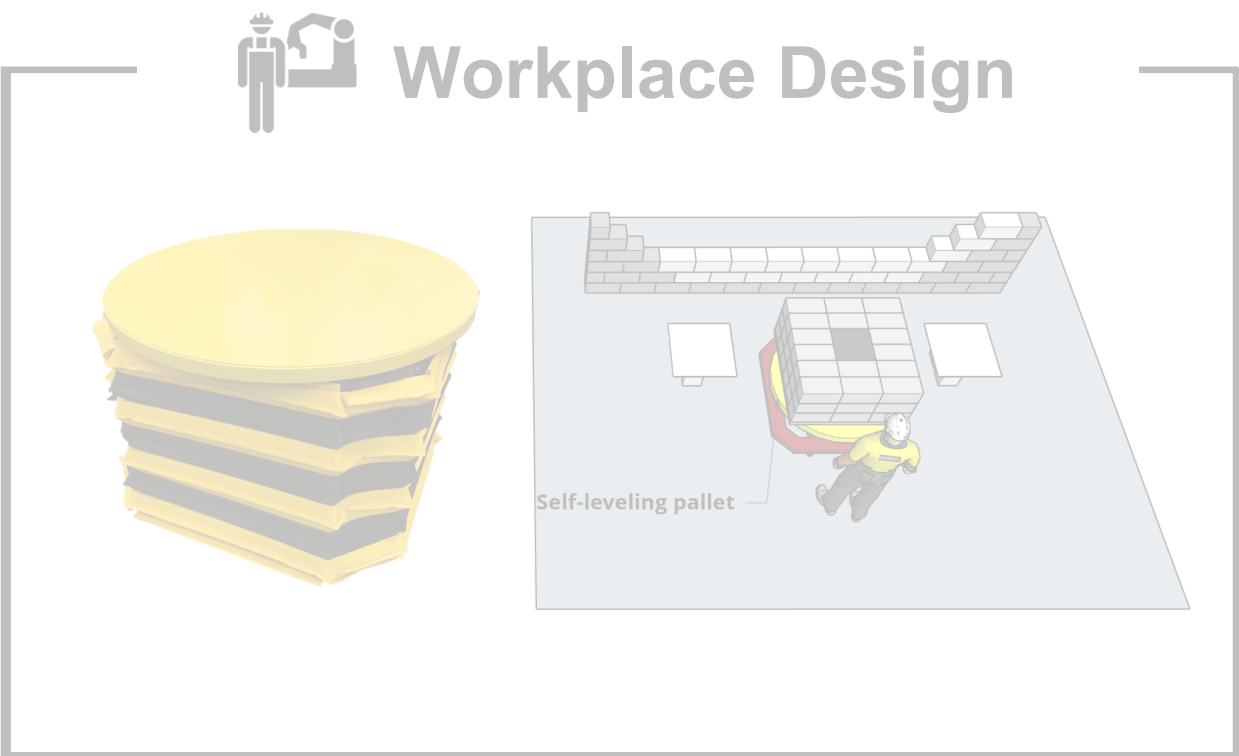


# Self-leveling Work Platform (Pending Proposal, NIOSH R21)

- Evaluate and improve a self-leveling masonry work platform
  - Assembly mortar plate and calibrate optimal lifting zone layout (biomechanical analysis)
  - Laboratory assessment of the work platform
    - Different types of CMUs and Motion capture system,
- An evidence-based intervention readily for use by the masonry trade



## Research Thrusts



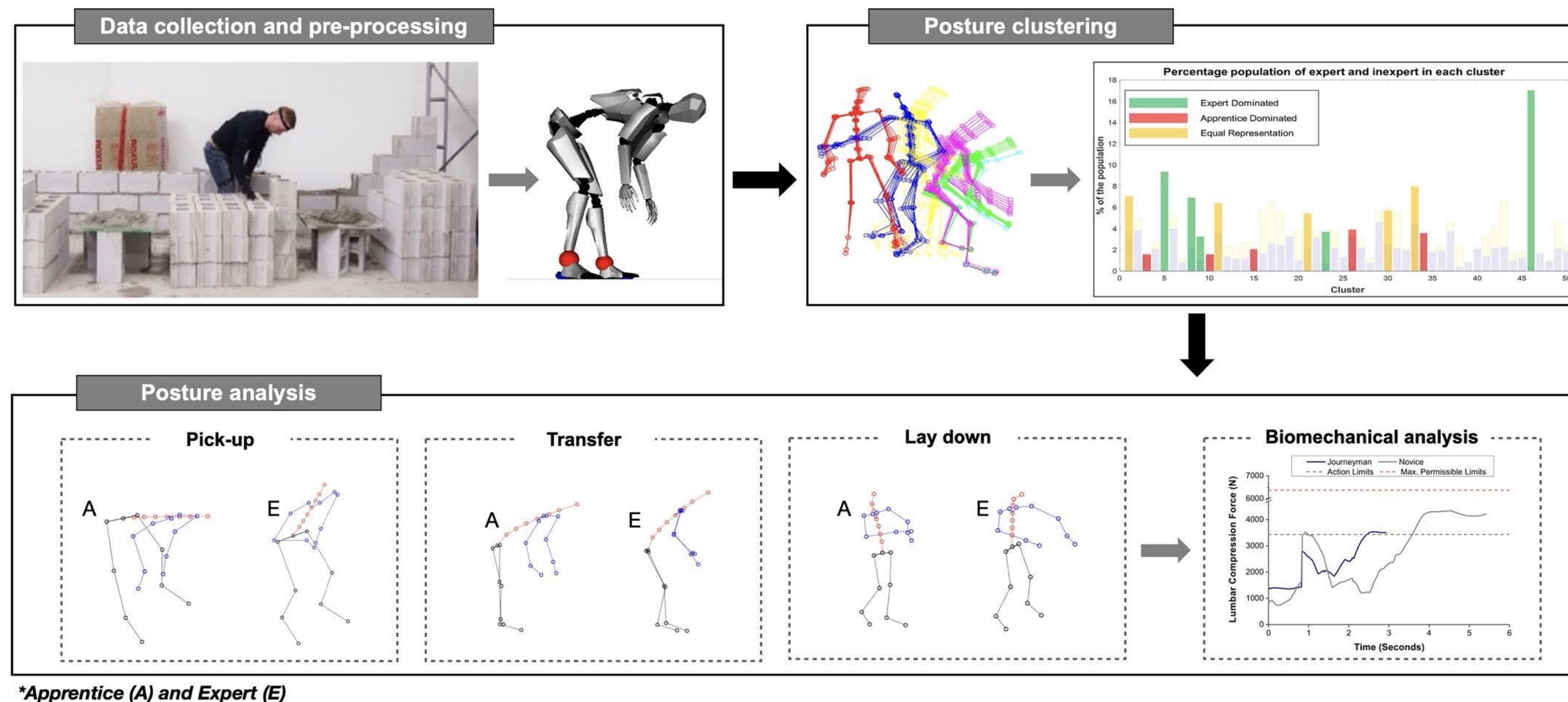


# Expert Posture Identification

“Automated Clustering of Proper Working Postures for Phases of Movement”, *Automation in Construction* (2022)



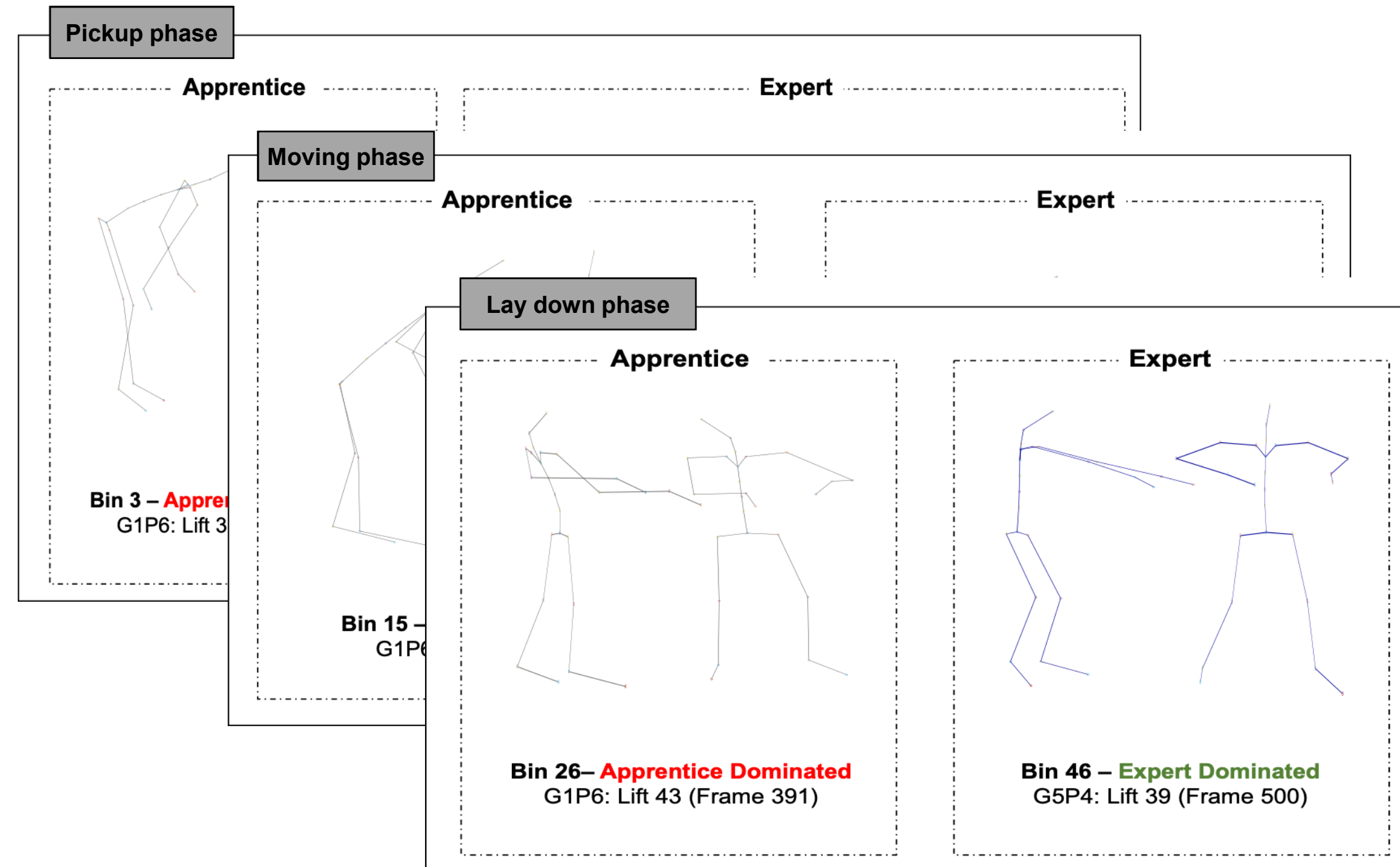
- Identified the proper postures as workers develop as they gain experience
- Automated posture clustering algorithms
  - Whole-body 26 joint locations in x, y, and z-axis
  - *k*-means clustering



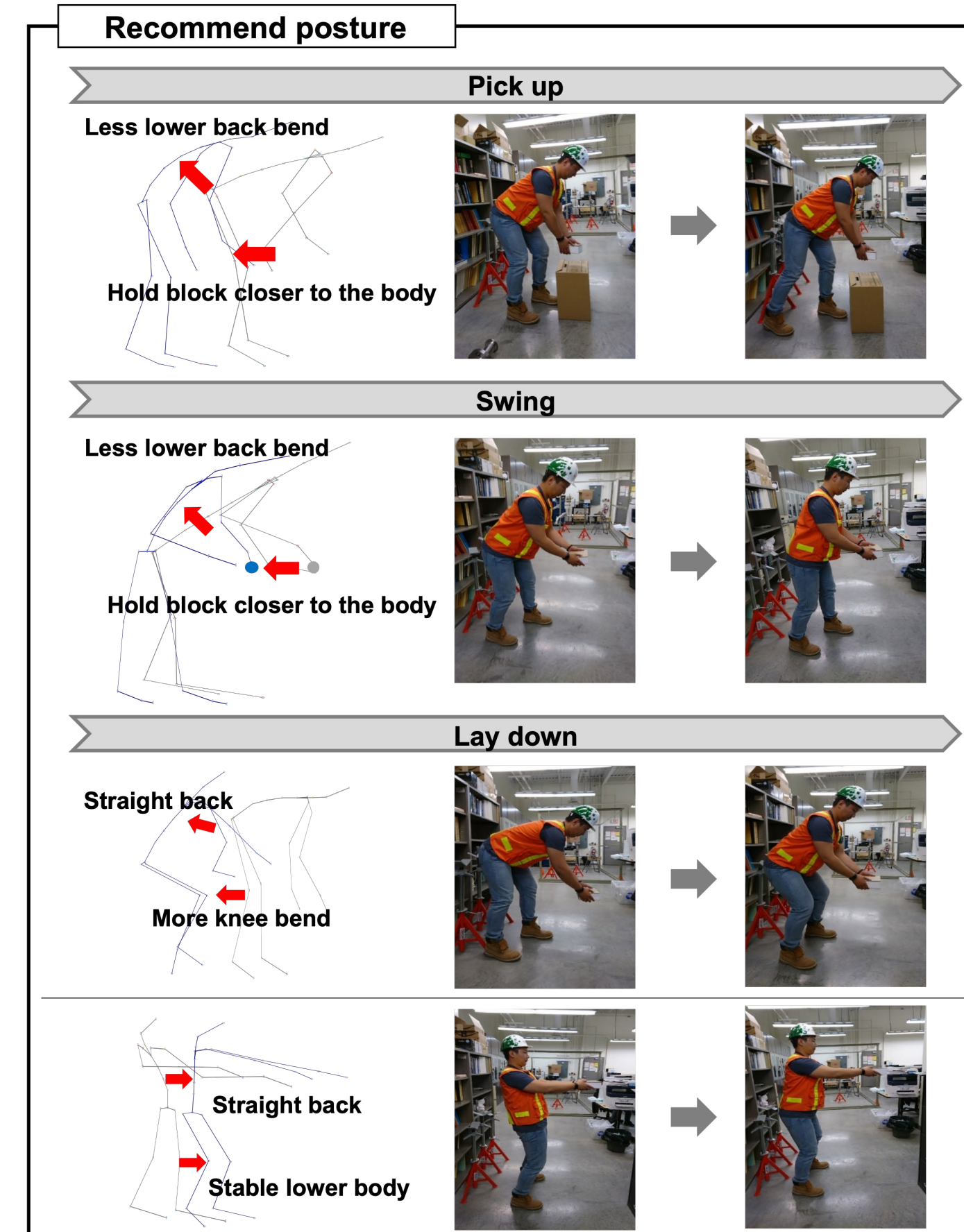


# Posture Comparison

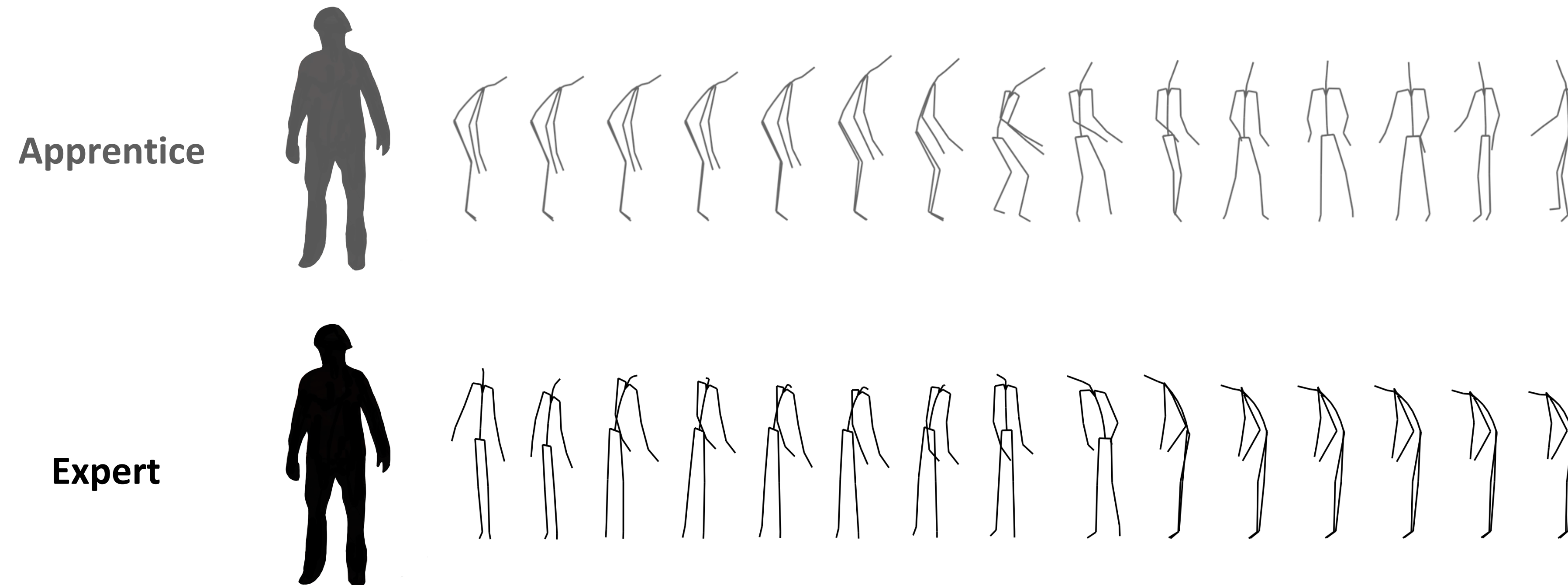
- Label posture into three CMU lift phases: pick up, moving, lay down



Advanced Masonry Work Systems Analysis  
(Frequent posture comparison)



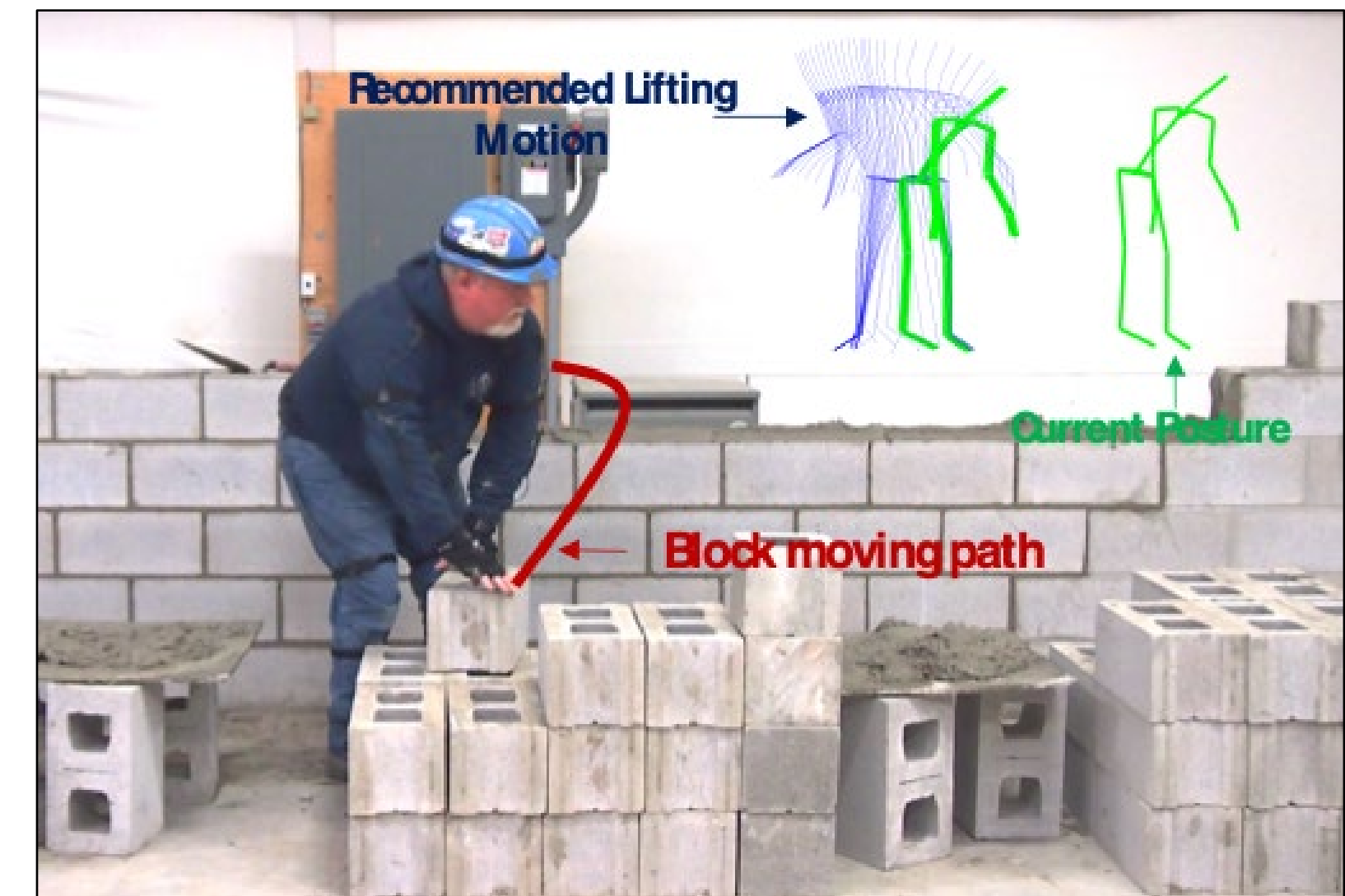
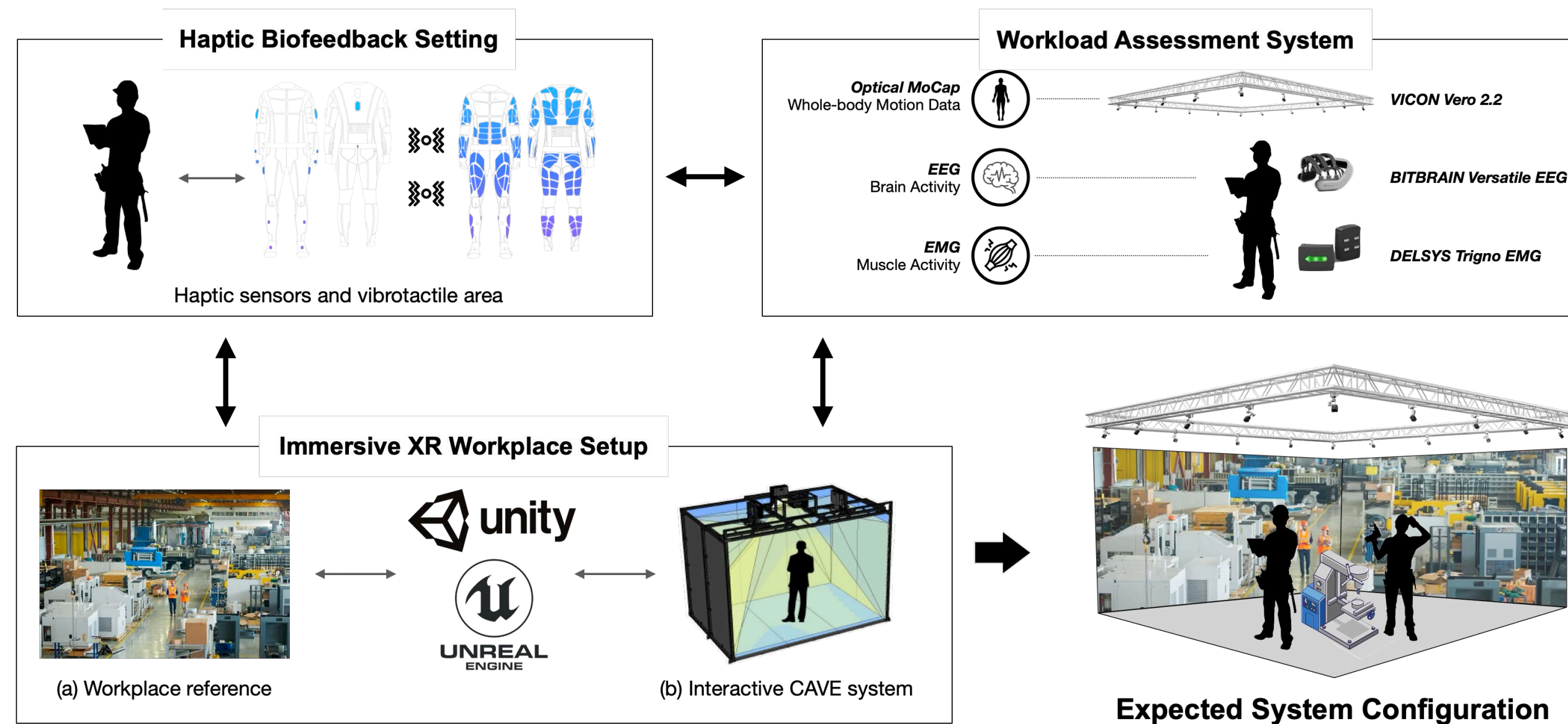
- Translate experts' postures, and effective motions into functional learning
  - Generate experts' motion sequence using motion engine





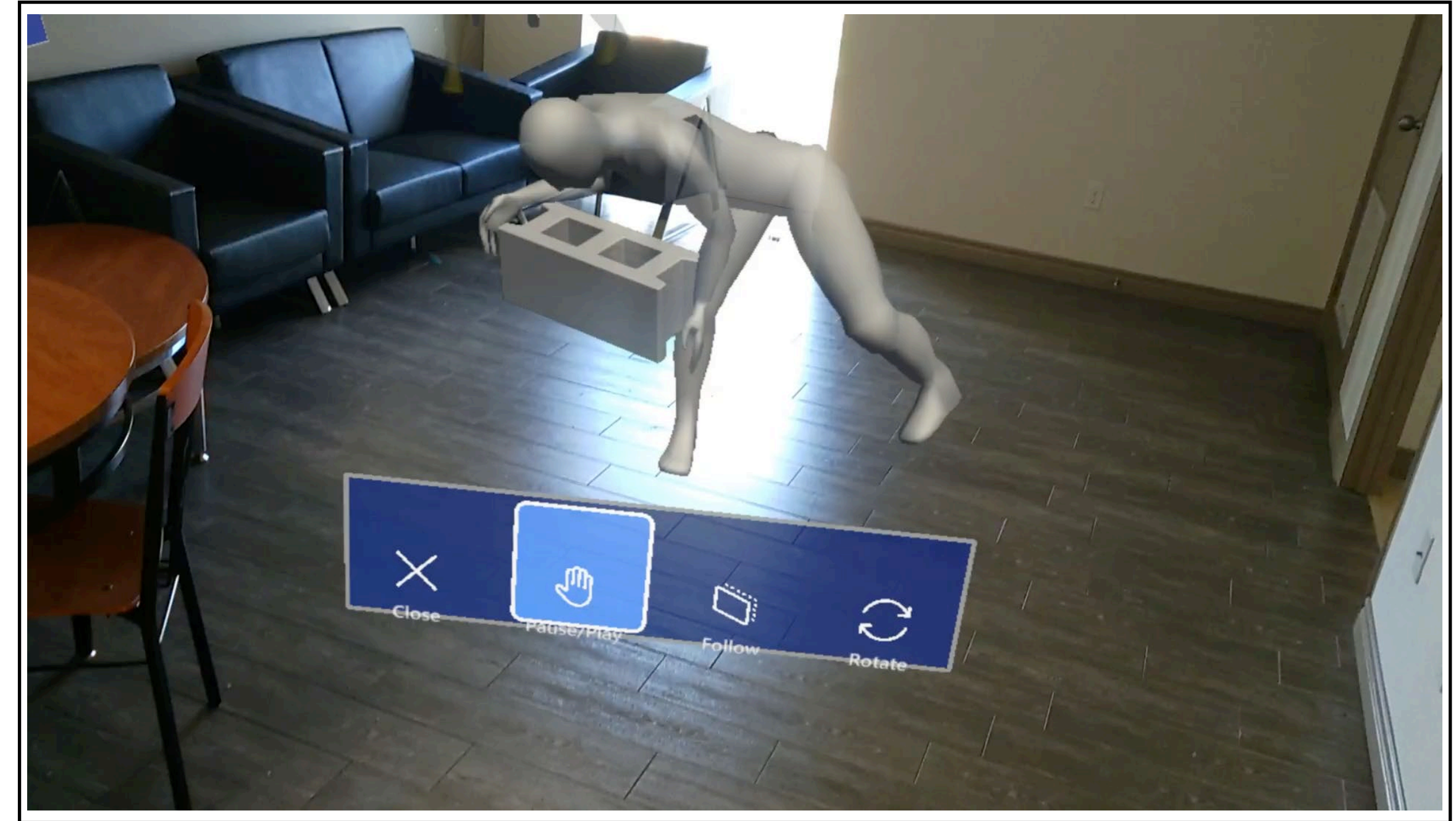
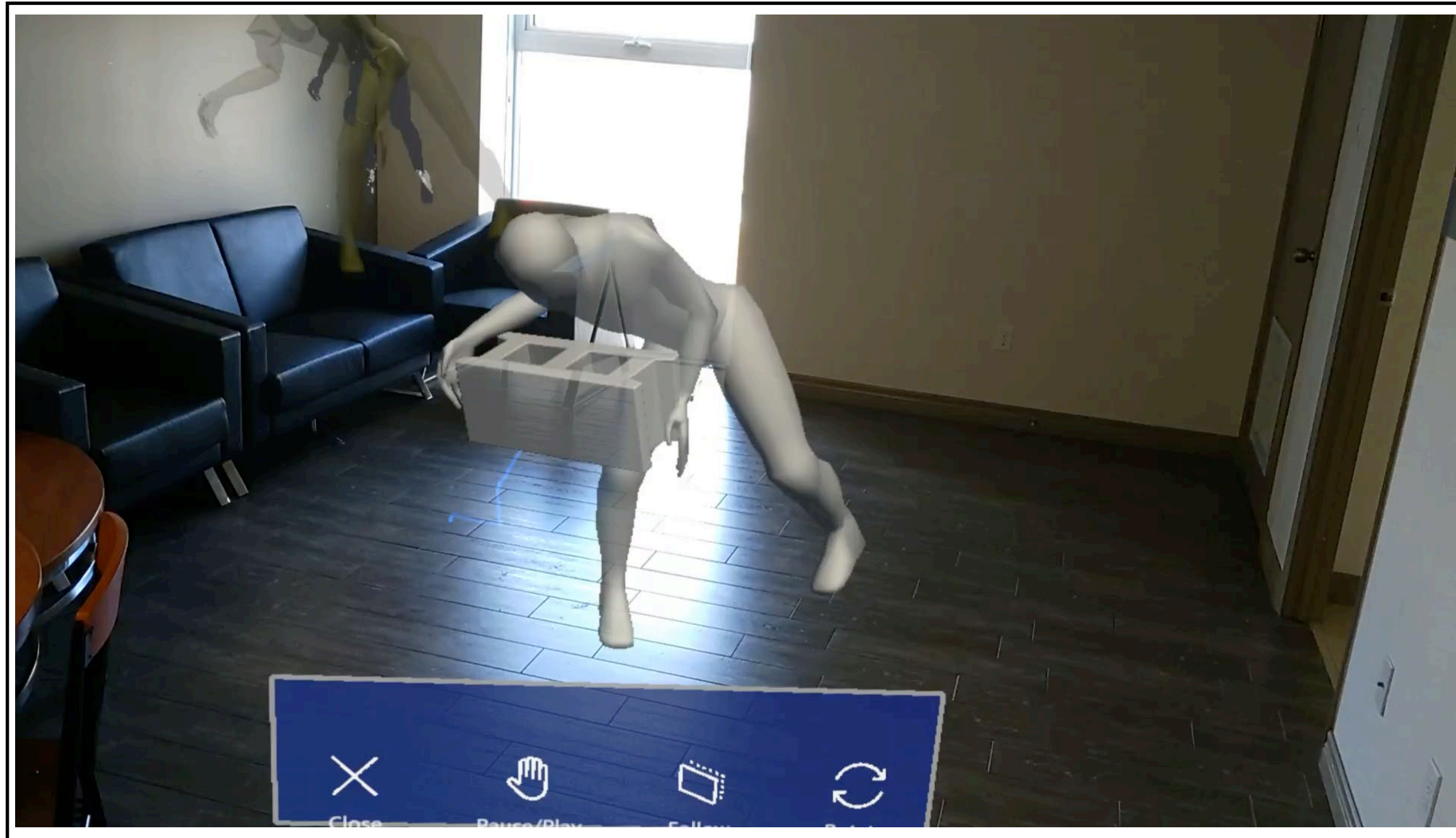
# XR-based Biofeedback-Enabled Workforce Training (Pending Proposal, NSF)

- Translate experts' postures, and effective motions into functional learning
  - Generate experts' motion sequence using motion engine
- Integrating Extended Reality (XR) and Biofeedback
  - Overlay real view with virtual contents in training system
  - Apprentices observe and follow 3D animations of expert's motion on XR display



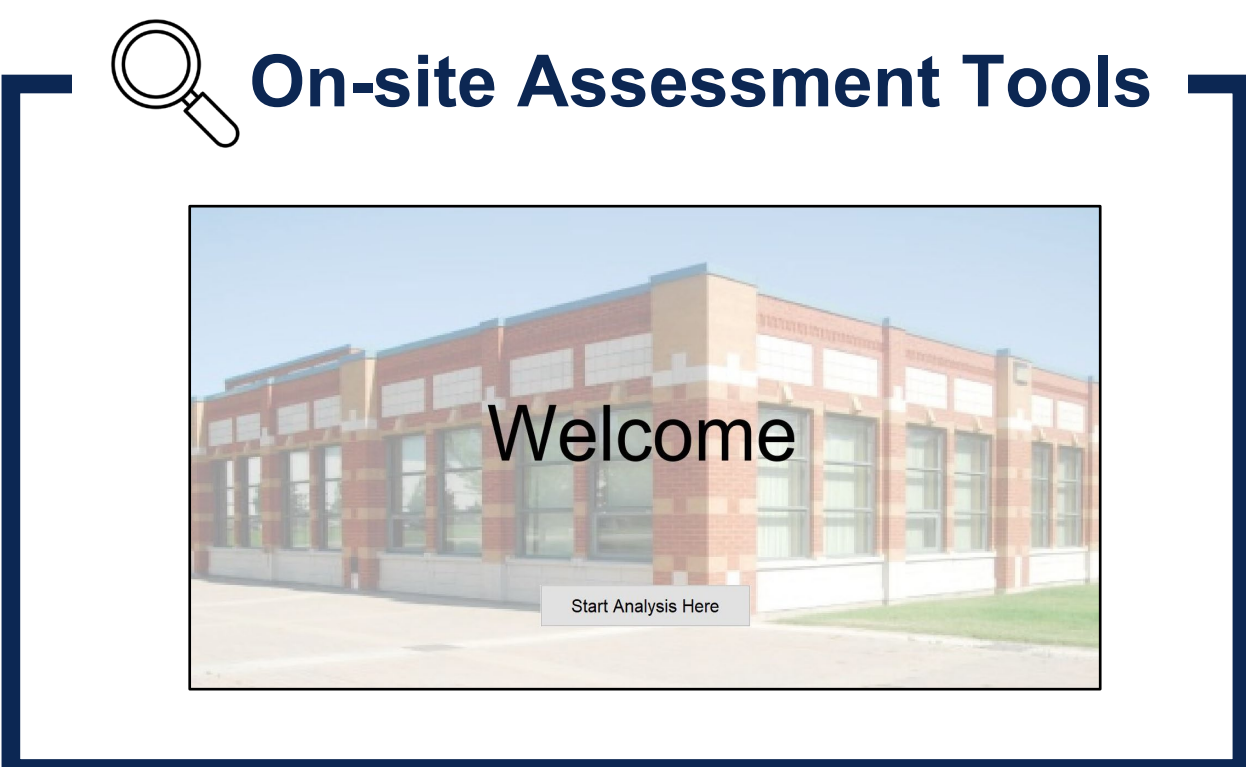
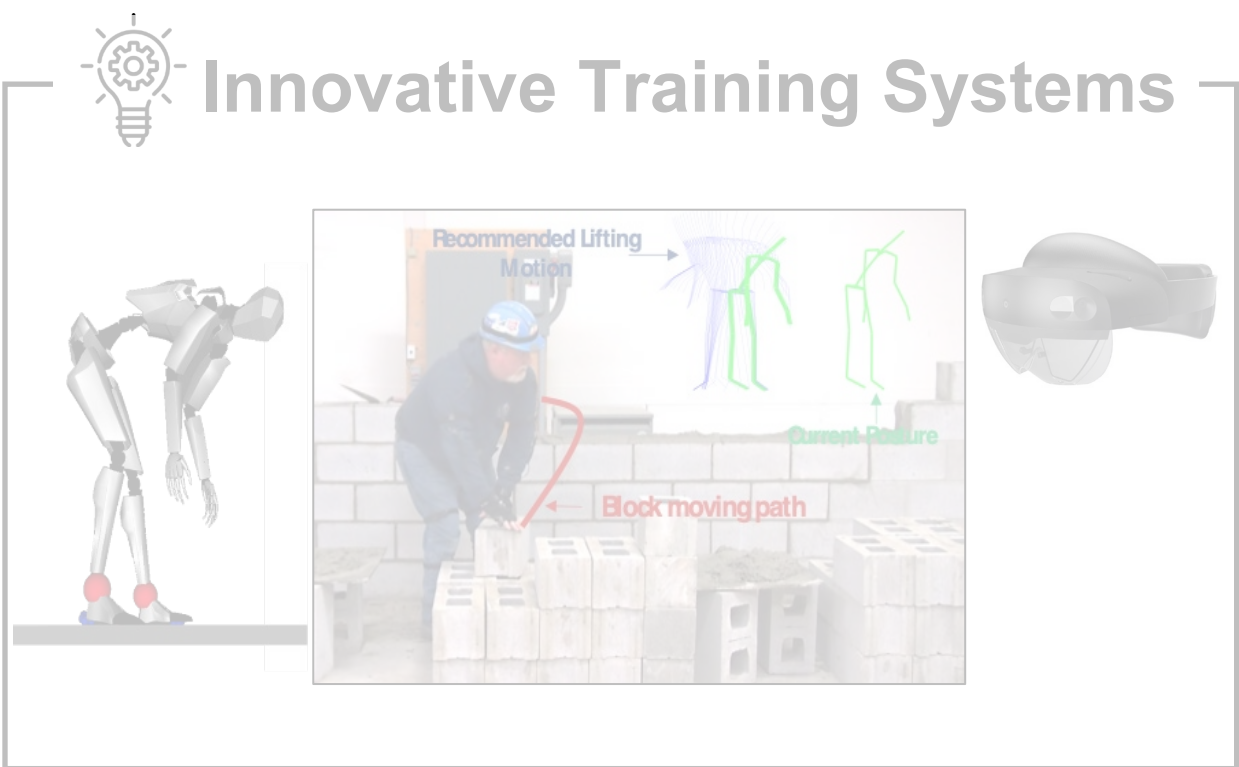


# XR-based Biofeedback-Enabled Workforce Training (Prototype Videos)



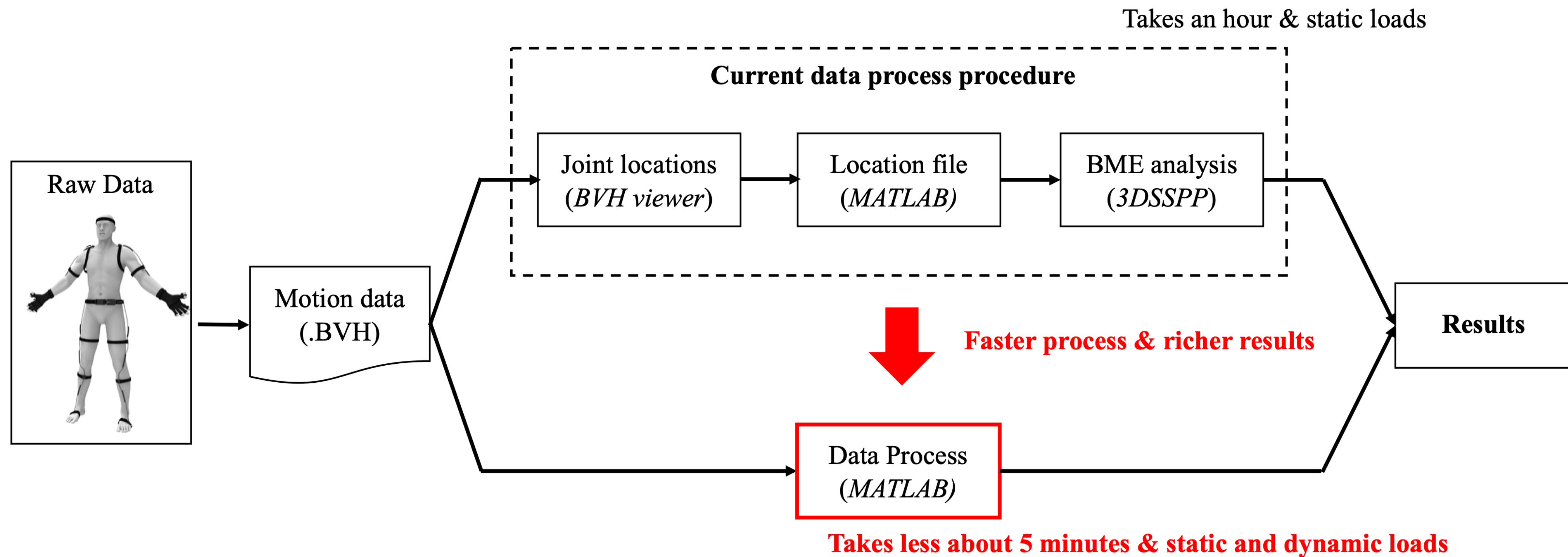
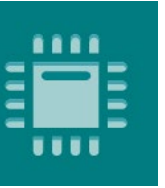


## Research Thrusts



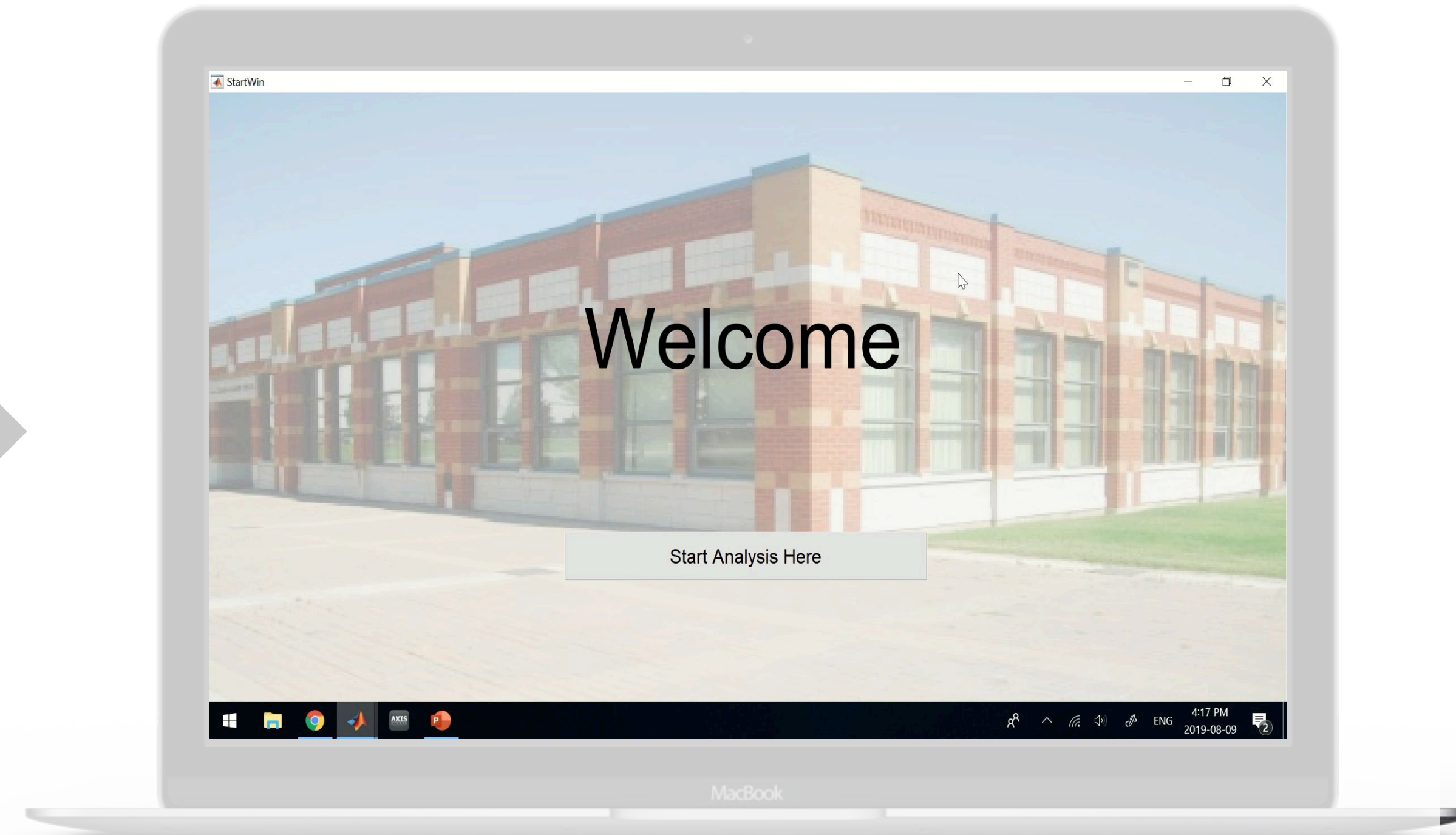
# Simplified Biomechanical Assessment using Inverse Dynamics Model

“Inertial motion capture-based whole-body inverse dynamics”, *Sensors* (2021)





# On-site Ergonomic Assessment Tool

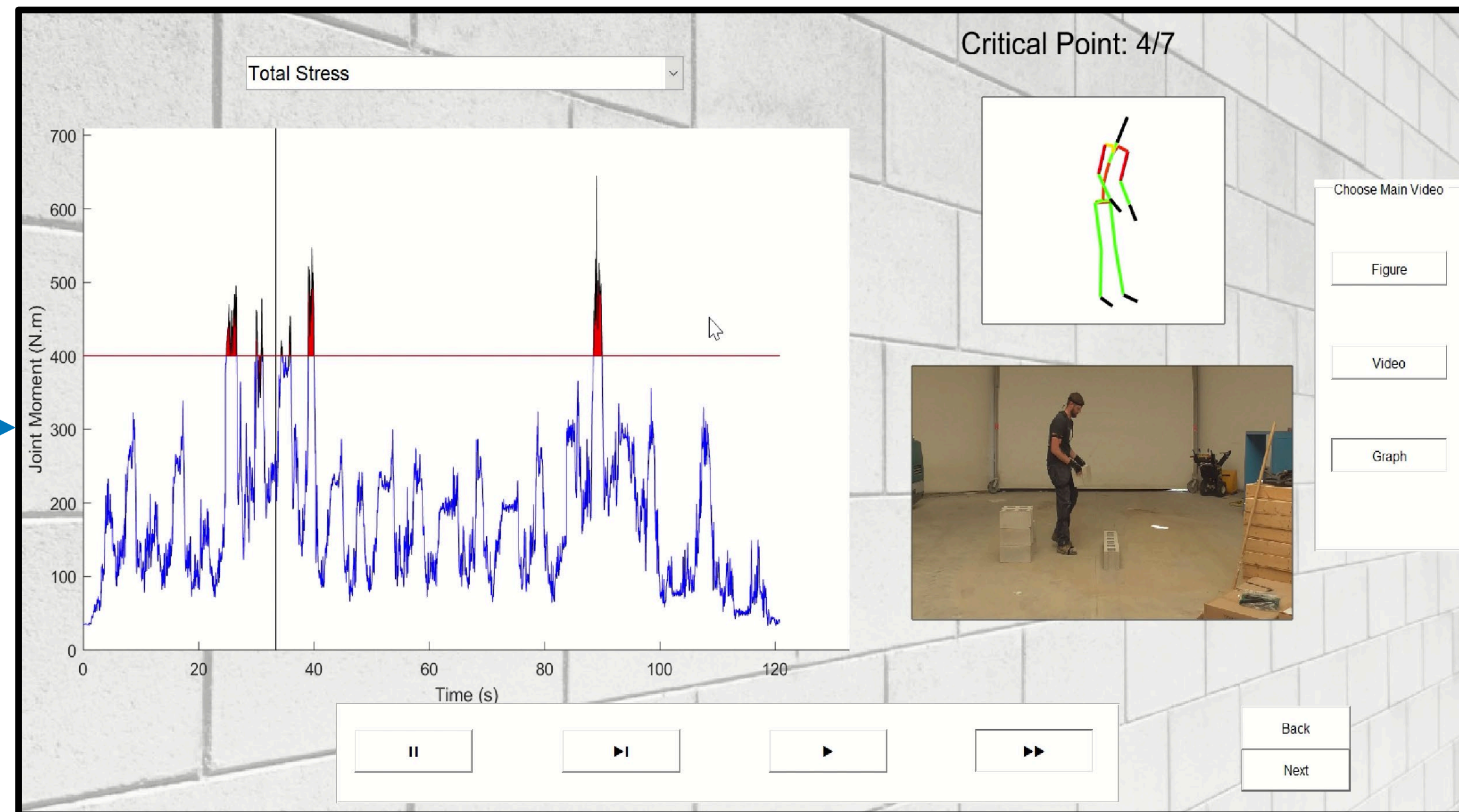




# Enhanced On-site Ergonomic Assessment Tool

- Integrating with smart insole sensors
  - Automated ground reaction force data synchronization (external load detection)
- Including the time to hold load in analysis (e.g., reinforced wall)
  - Estimate cumulative body load over time

## Smart Insoles

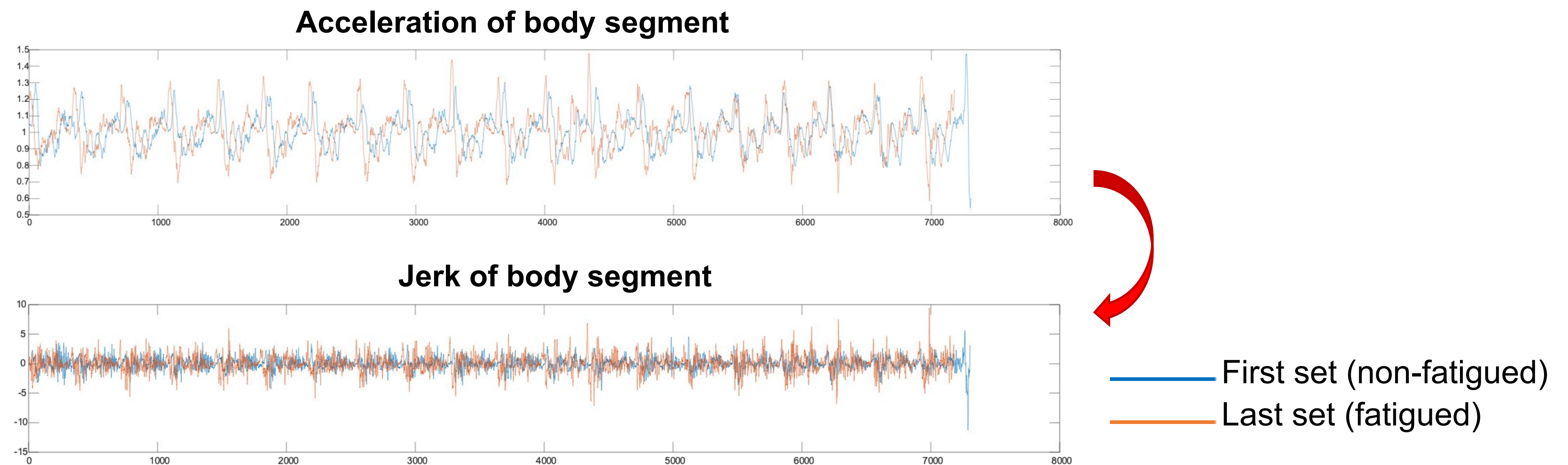




“Jerk as an indicator of physical exertion and fatigue”,  
*Automation in Construction* (2019)

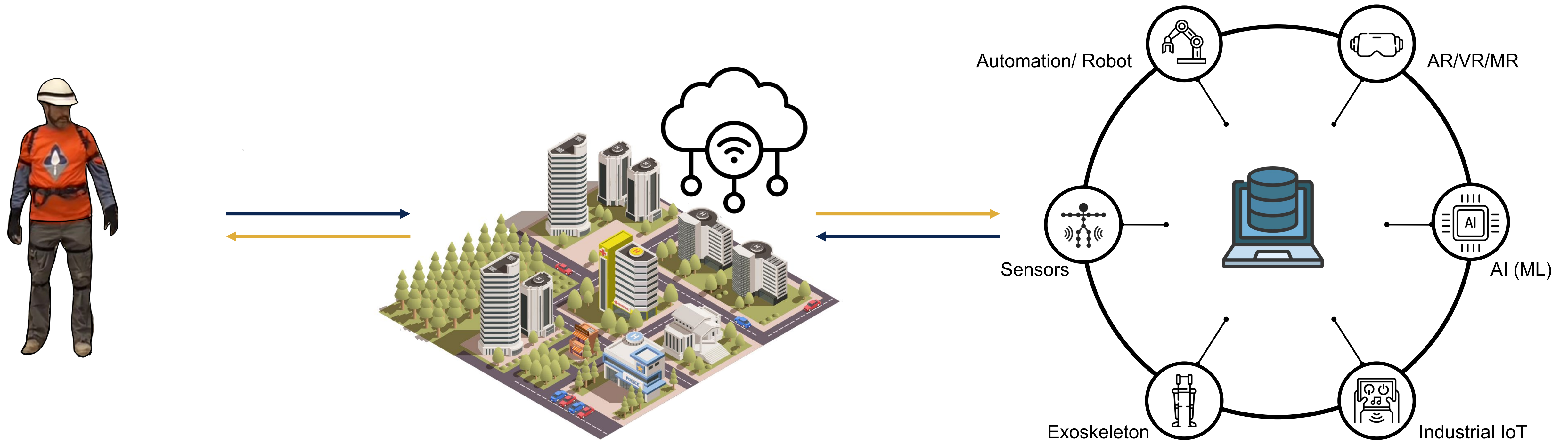


- Jerk
  - Differential of acceleration ( $da/dt$ ) & Measure of motor control
  - Influenced by exercise-included fatigue and task fluency
- Analysis: Compare jerk at non-fatigued and fatigued states
  - A useful indicator of physical exertion and experience level



# Human-Centric Intelligent Systems

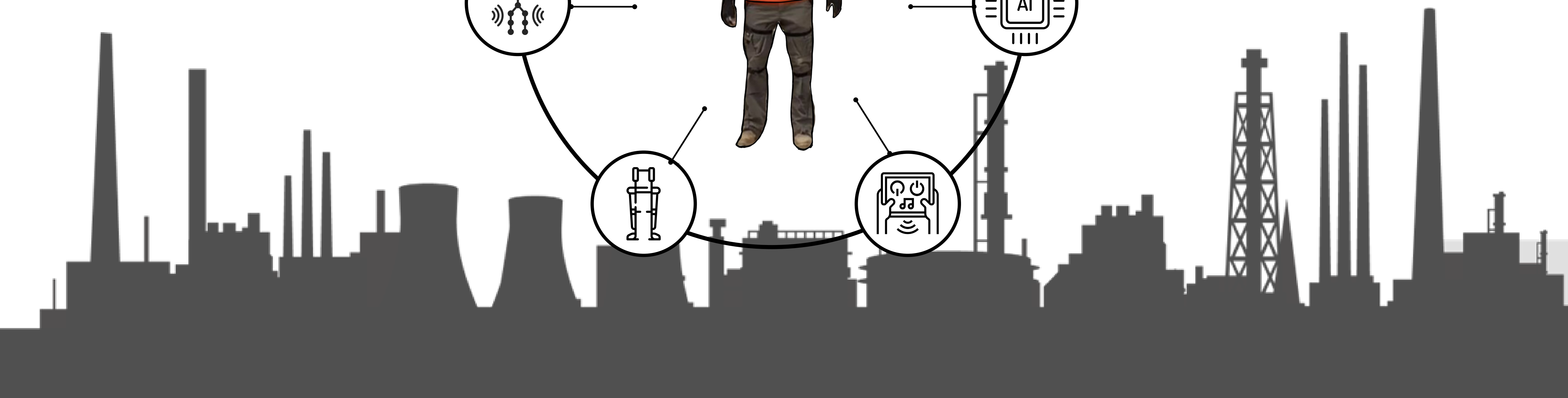
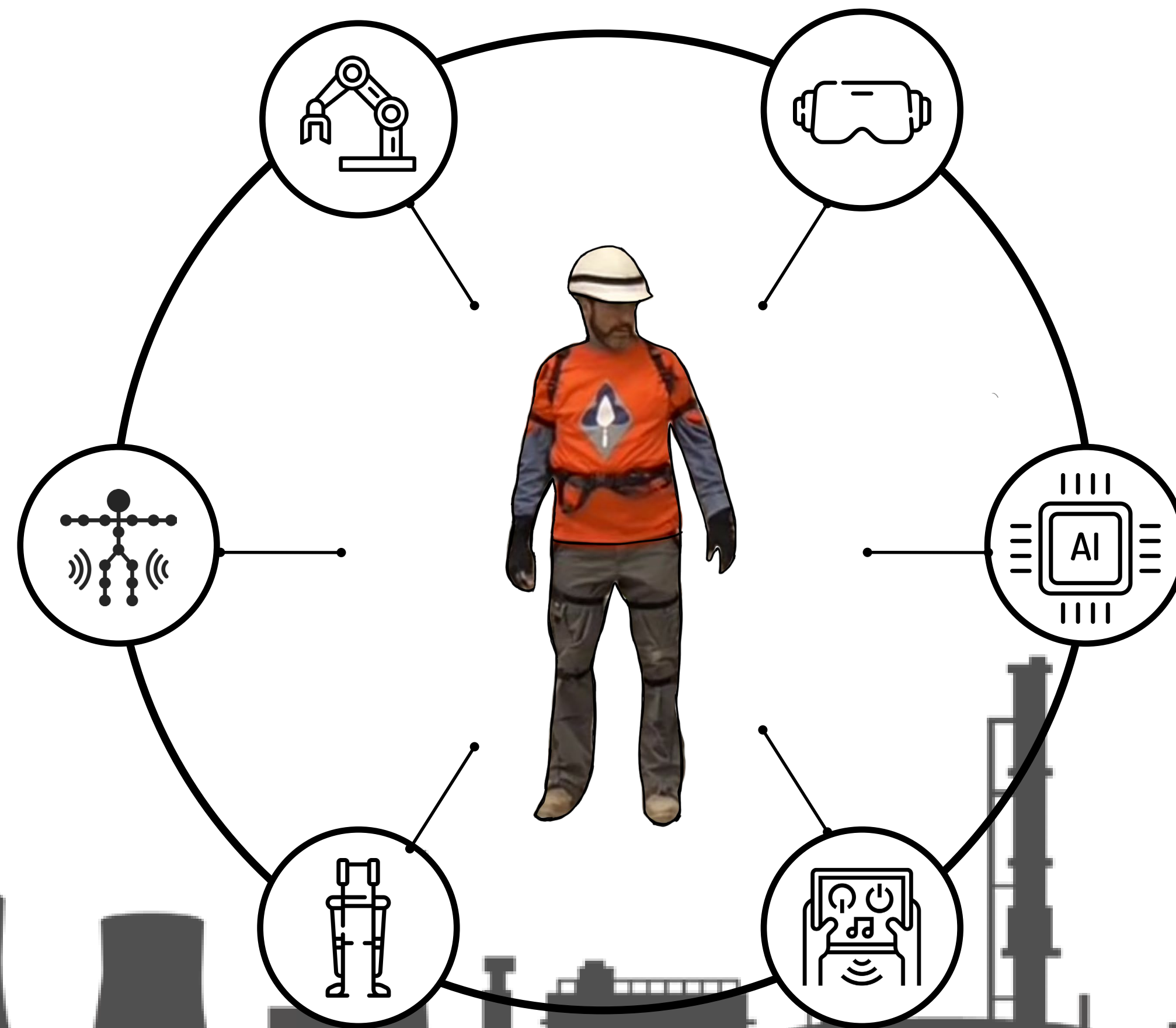
- Emerging technologies to design & manage Industrial workplace safety
  - Collect and analyze unique dynamics of humans in work sites
  - Interact human, devices, machines, and clouds
  - Improve people's lives and enable entrepreneurial, livable, and safer environments







# Human-Centered Intelligent Systems



# Transforming Construction Safety through Human-Centered Intelligence

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**Assistant Professor**

**Dept. of Industrial & Management Systems Engineering**

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