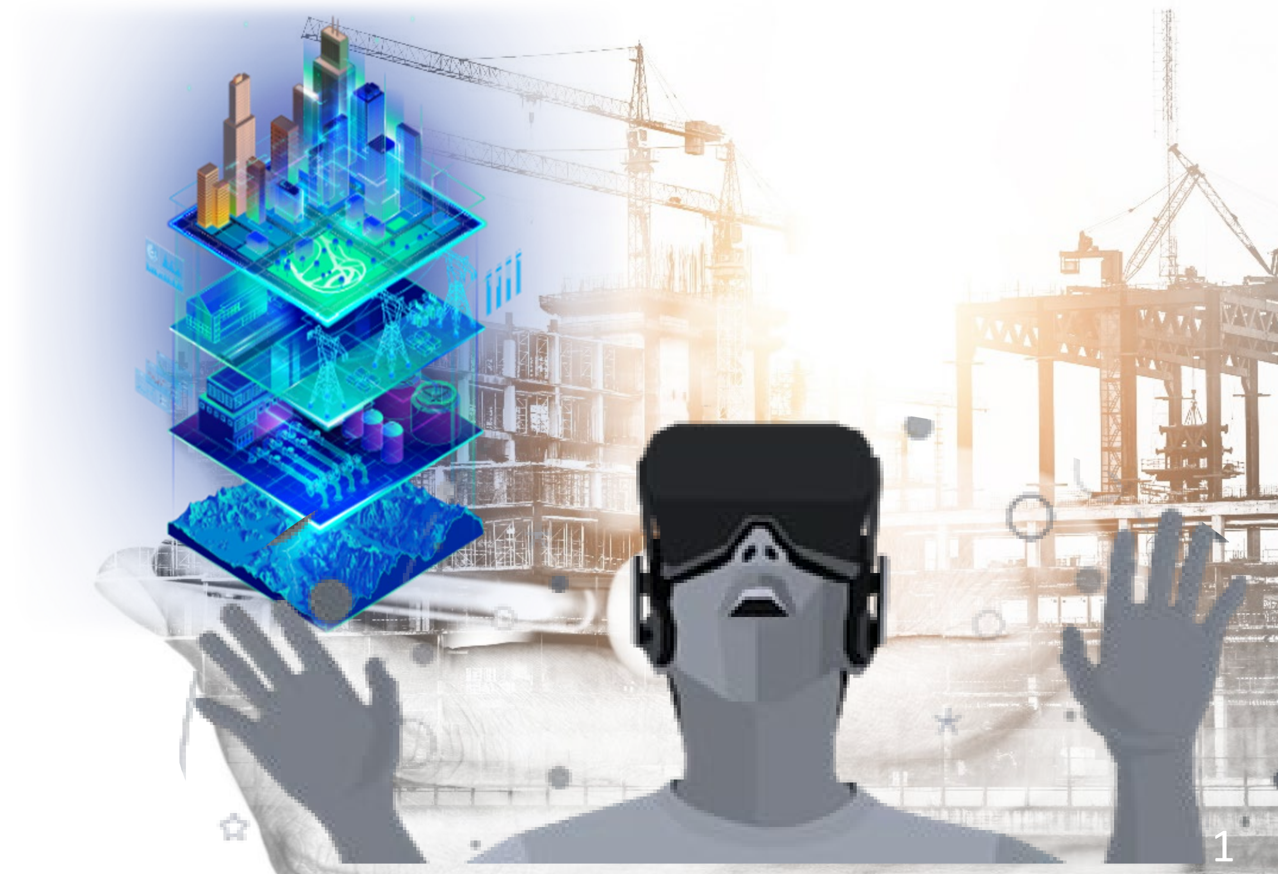
Shaping a Safer, More Inclusive, and More Intelligent Construction

Harnessing Human factors and Technological Innovations for Enhanced Safety and Decision-Making in Construction



I²SAFE

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November 17, 2024

I²SAFE LAB (Intelligent-Inclusive-Safe Lab)

PURDUE UNIVERSITY

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Education

Ph.D.; CE; Virginia Tech, 2020

M.S.; CEM; University of Nebraska–Lincoln, 2017

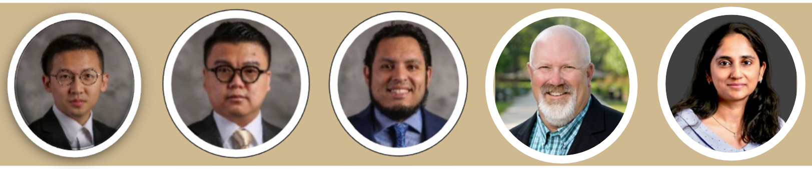
Minor; STAT, University of Nebraska–Lincoln, 2016

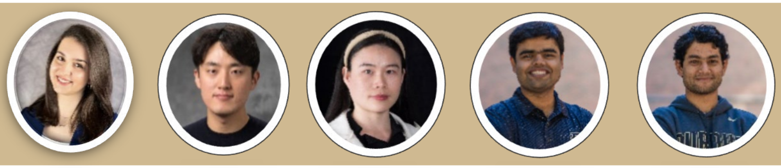
M.S.; CEM; Shahid Beheshti University, Iran, 2013

B.S.; AE; Shahid Beheshti University, Iran, 2011

Research Focus

- ***Advancing smart construction safety and building smart communities*** *by integrating advanced technologies, cyber-physical-human-systems, Digital Twin VR/AR/MR, robotics, and AI* ***to enhance safety, efficiency, and decision-making in construction environment.***



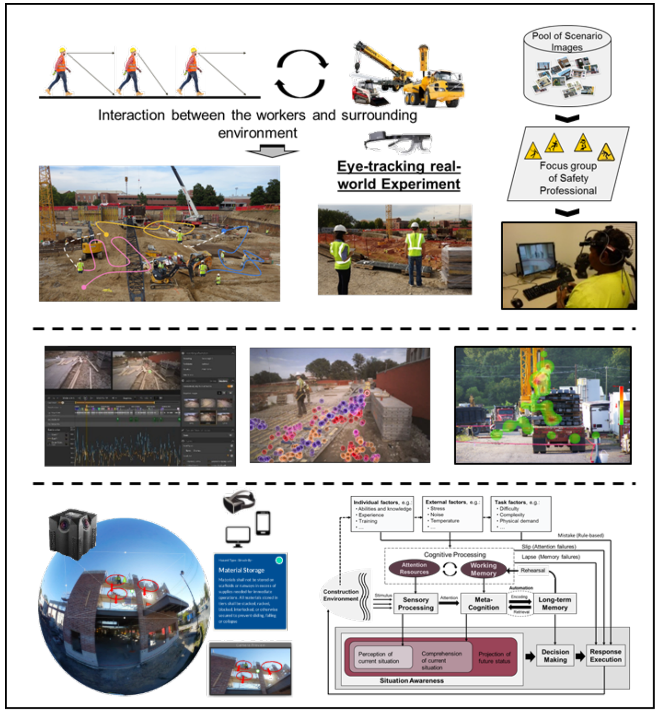


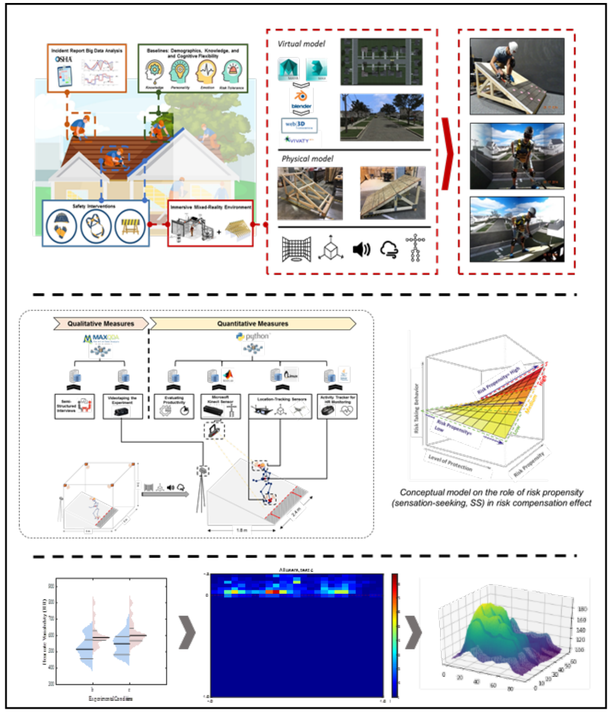
I²SAFE LAB (Intelligent-Inclusive-Safe Lab)

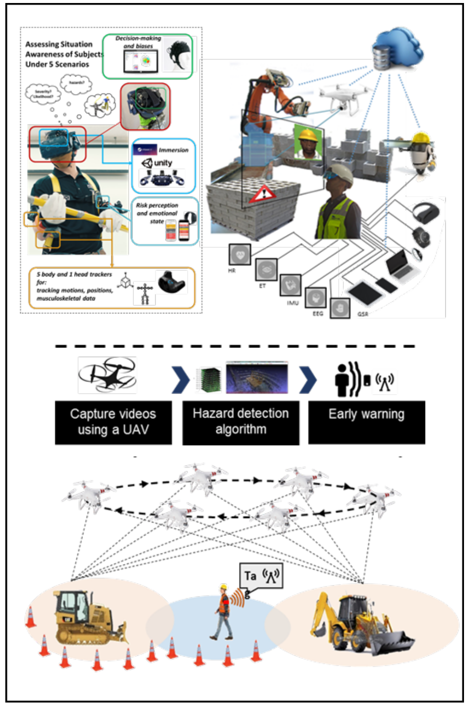
What our team is doing at Purdue CCE:

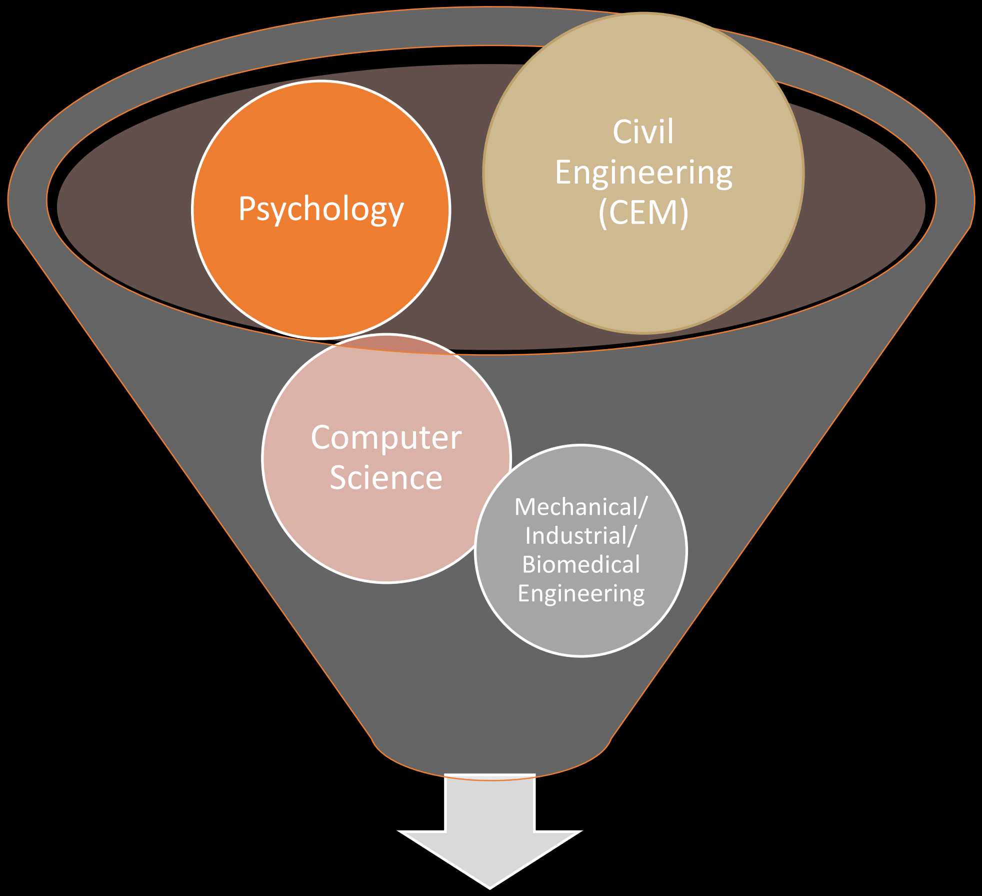
Explore several aspects of technology and applied science to suggest engineering solutions and behavioral interventions in response to the current and future challenges in our community and complex construction projects.

- Undertake a transformative interdisciplinary research in close collaboration with construction industry partners
- Address real-world challenges in current and future infrastructure design and construction
- Translate our research results into practices
- Prepare the next generation of professionals and competent workforce for our industry







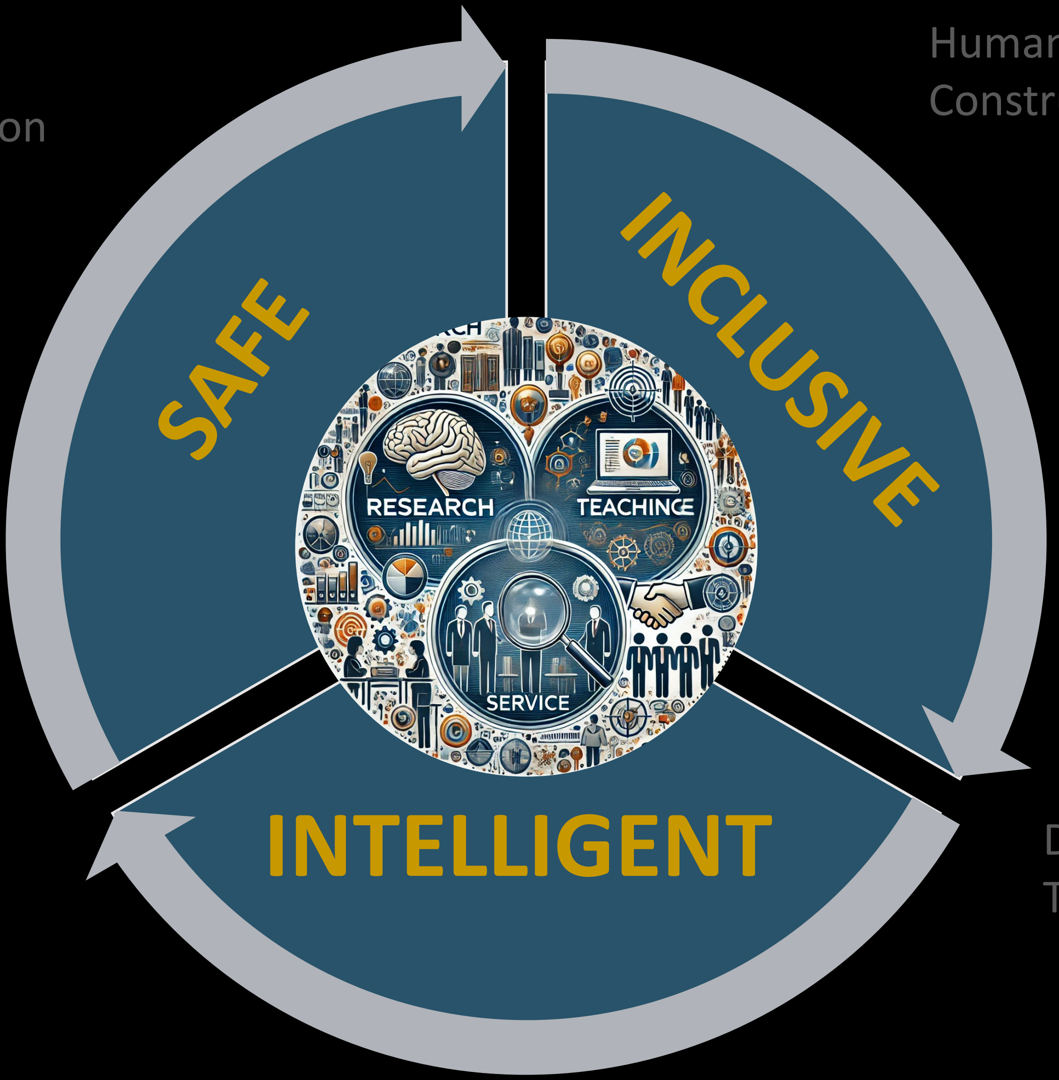


Interdisciplinary Research

Human Factors and Safety in Construction

Human-AI Teaming in Construction

Smart Technologies for Safety and Risk Management



Experiential Learning in Smart Construction Education

Personalized A-Driven Simulation-Based Safety Training

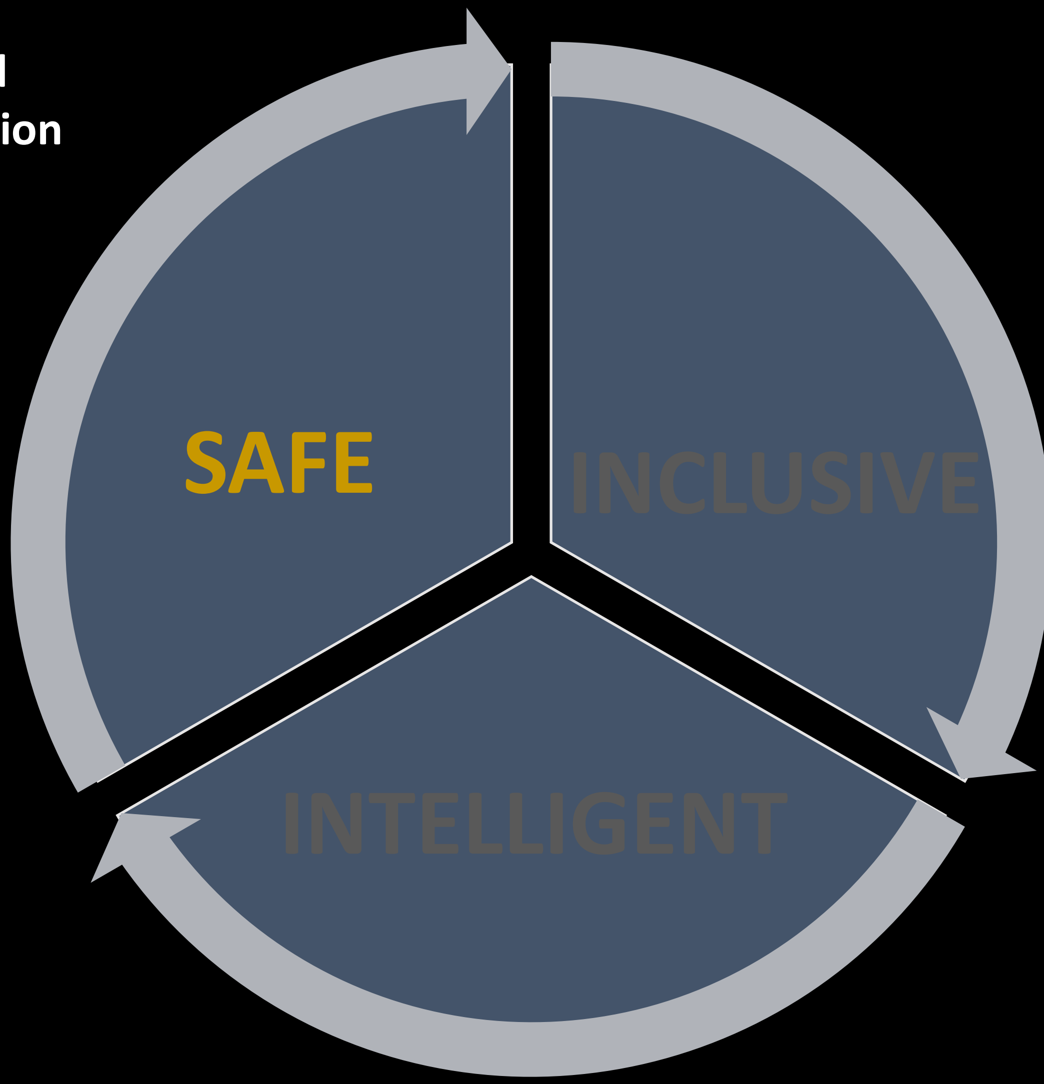
Digital Twin-Driven Adaptive Thermal Comfort Systems

Digital Twins for 3D Printing

Digital Twins for Smart Workzones

Human Factors and Safety in Construction

Smart Technologies for Safety and Risk Management



Unsafe Site Conditions

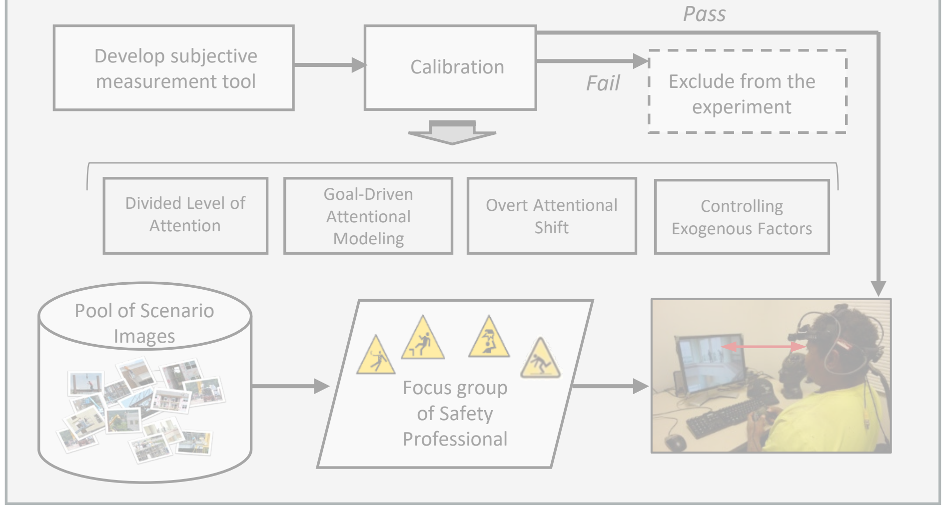
Unsafe Behaviors

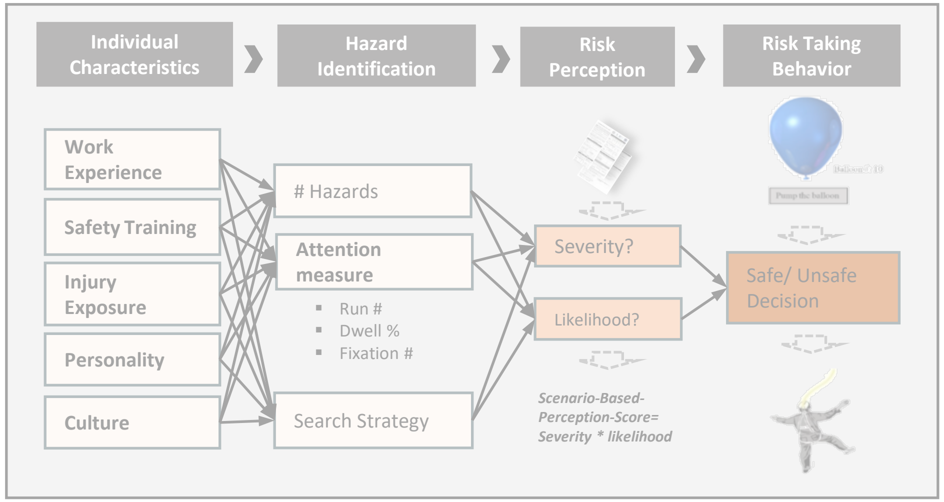
Objective

Apply well-established theories in the cognitive science literature to the creation of a novel hazard identification strategy for proactive accident prevention in the construction industry.

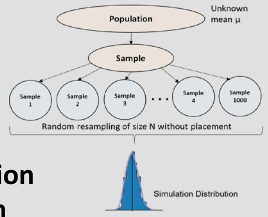
Human Error Detection (HED): Wearable ET Technology

Does HI modulate attentional distribution towards safety hazards?



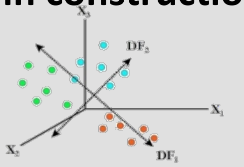


- **Do individual subject characteristics play a crucial role in workers' cognitive failure and missing to detect a hazard?**

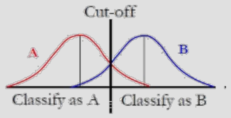


Permutation Simulation

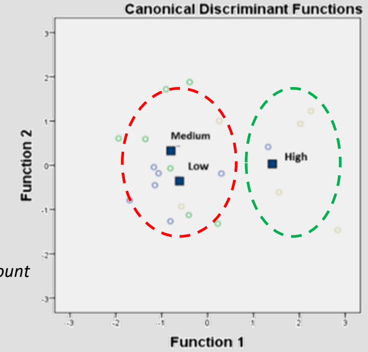
- **Which eye-movement metrics can be used for detecting at-risk workers in construction environment?**



MANOVA

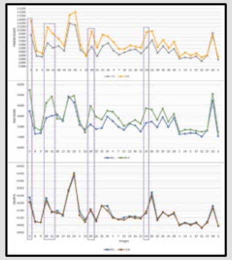


Discriminant Analysis



Discriminant Score$_2$ = $0.583 * Z_{Dwell\%} + 1.542 * Z_{Run\ Count} - 0.695 * Z_{Fixation\ Count}$

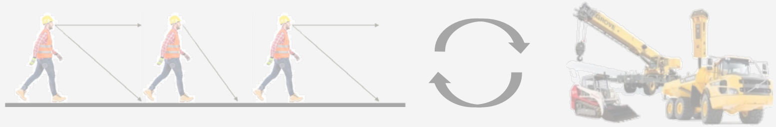
- **Is it possible to determine skill-based errors among at-risk workers identify the need for training a worker about a specific hazard?**




Tobii Pro Glasses 2
Wearable Eye-tracker
(Head Unit)
Micro HDMI connector
Protective lens
4 Cameras (Eye tracking sensors and IR illuminators)
Wide angle HD camera (16:9) + microphone
HDMI connector
LAN port and connectors
SD memory card slot
Battery compartment
Recording Unit

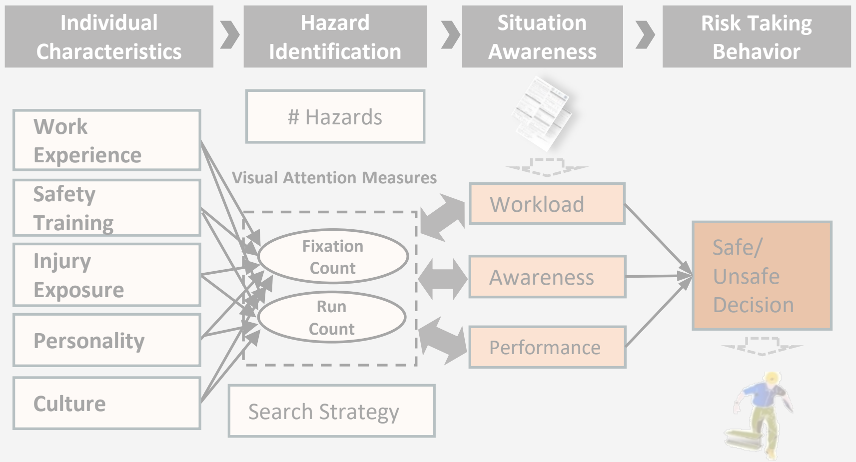
Human Error Detection (HED): Wearable ET Technology

Does SA modulate attentional distribution towards safety hazards?

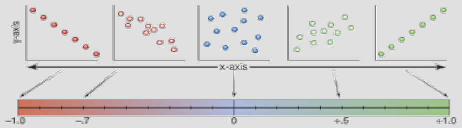


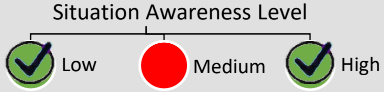
Interaction between the workers and surrounding environment

Eye-tracking real-world Experiment



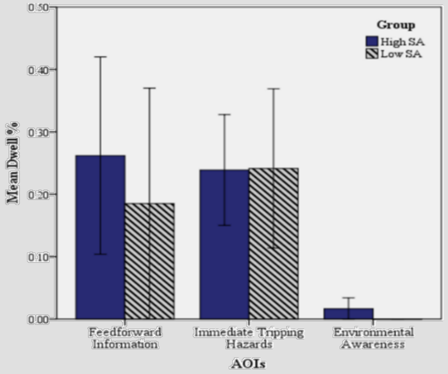
Correlational Analysis





SA-score= (Understanding Situation - Demand Attention)+ Supply Attention

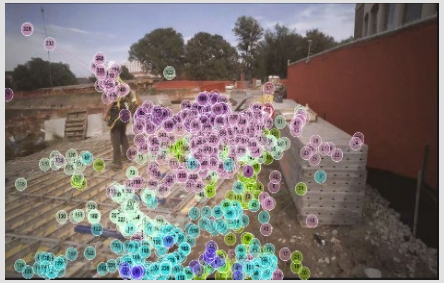
Real-time mapping using image-recognition technology



Time SA group spent looking at each AOI in the scenario.

✓ To walk safely at jobsite >> <u>balance in their attentional allocation to look down and scan ahead</u> searching for tripping hazards

>> maintaining environmentally awareness

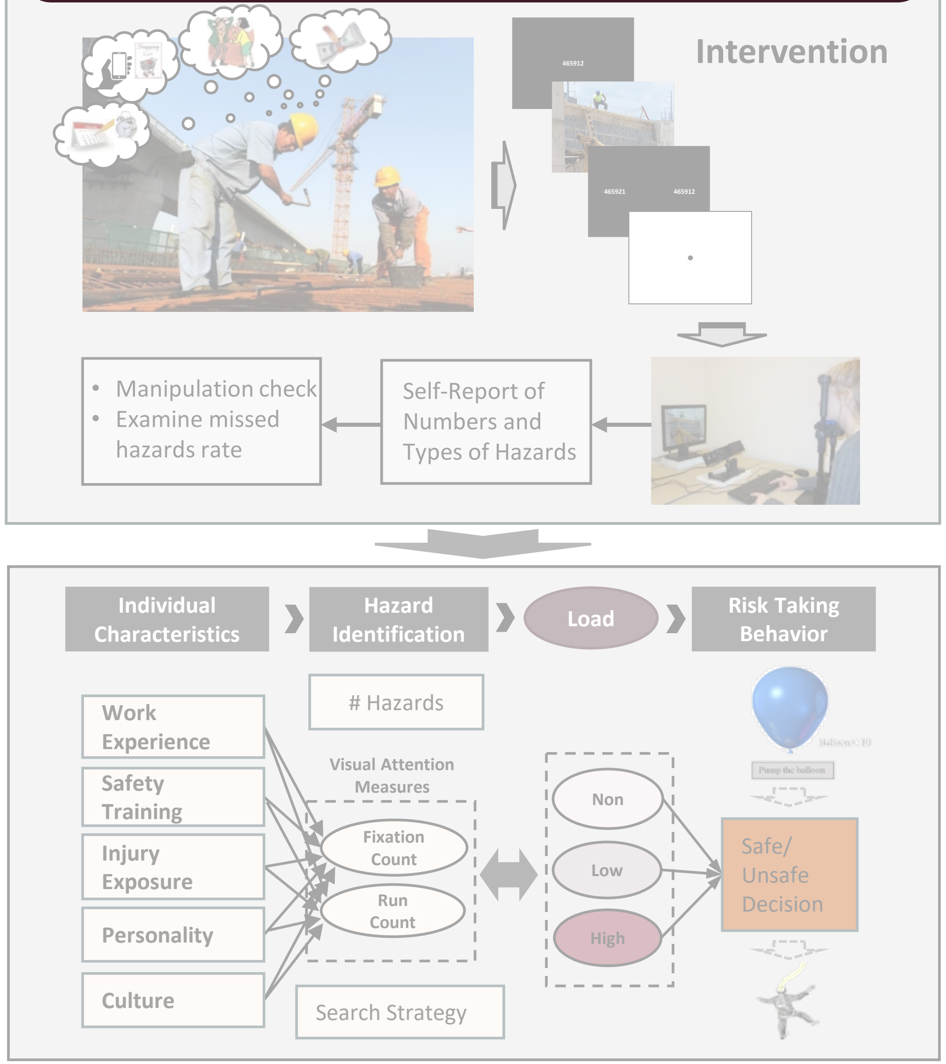


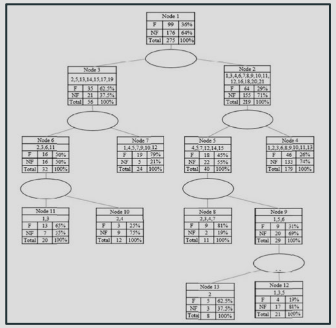
High SA

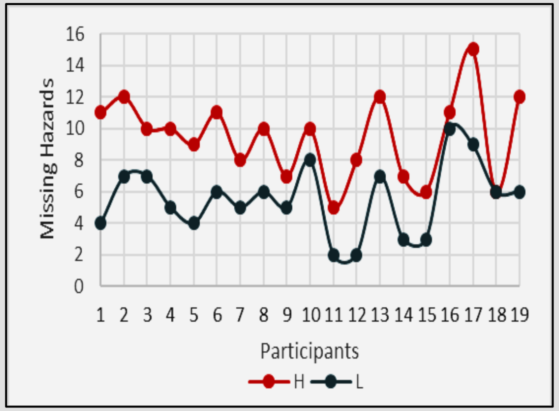
Low SA

Human Error Detection (HED): Wearable ET Technology

Do distraction and memory load cause inattentional blindness?





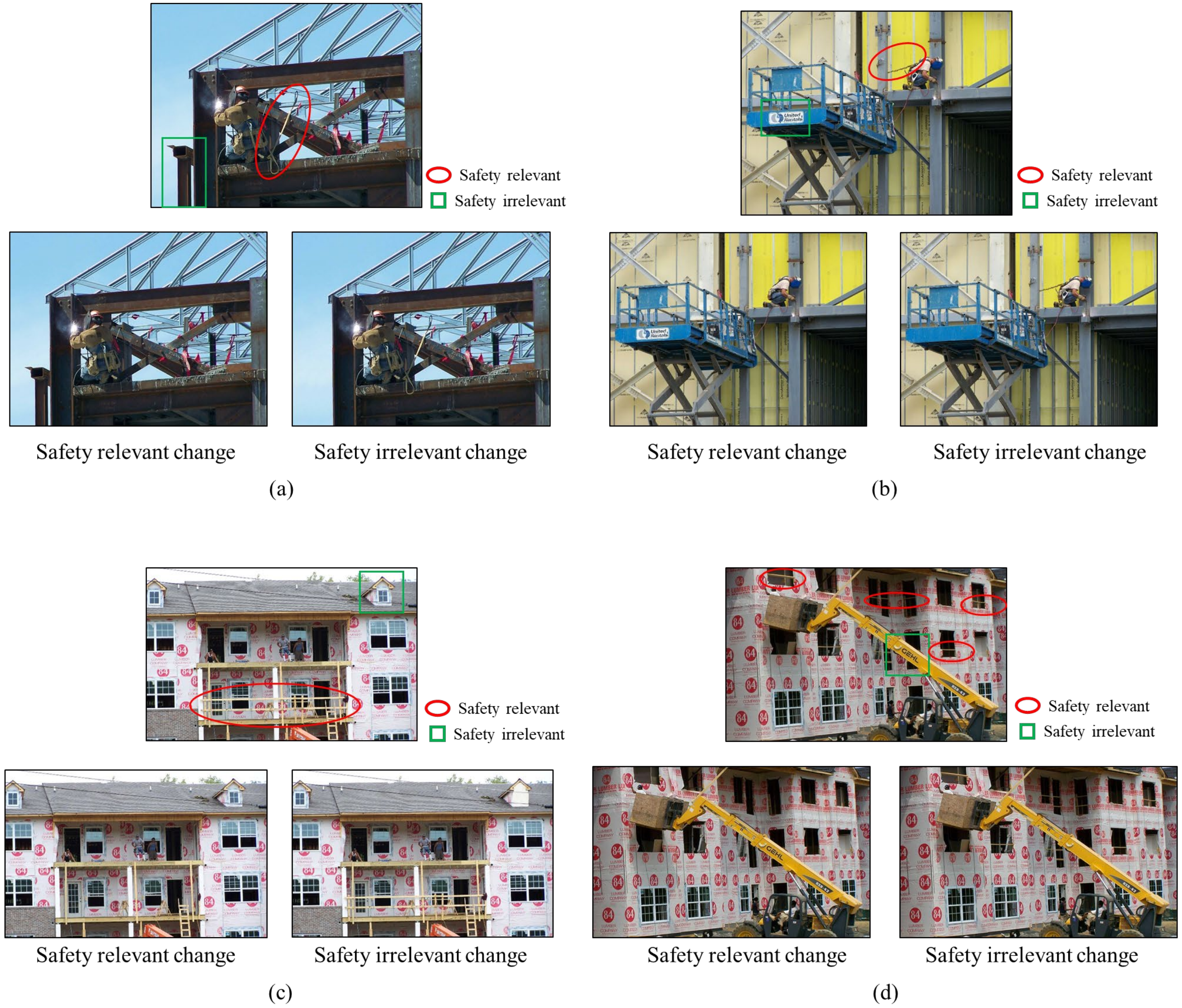


Distributions of missing hazards under low or high memory load

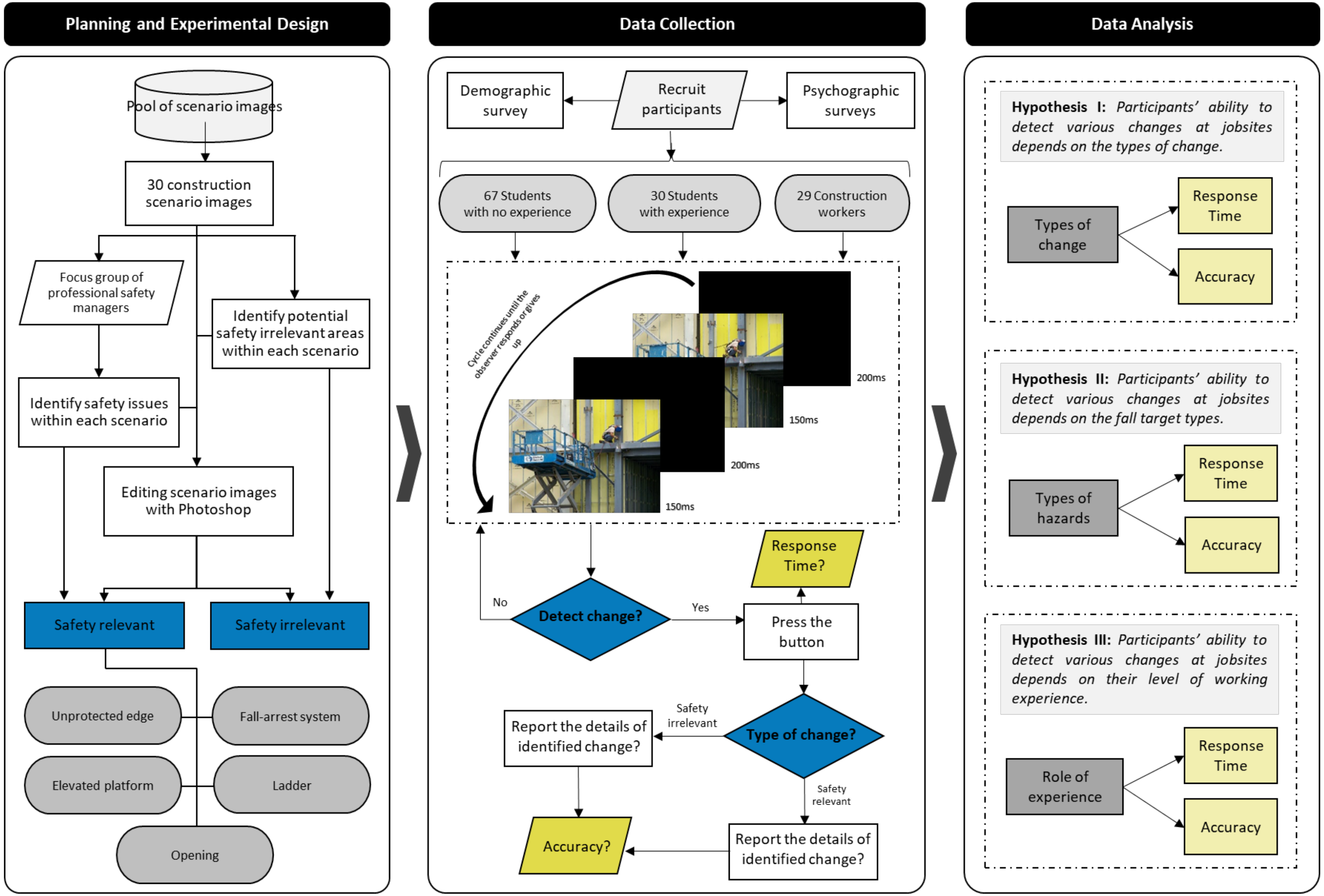
- ✓ As working memory load increases, the ability of participants to identify hazards decreases significantly.
- ✓ Under high-load conditions being **3.8 times more** likely to miss fall hazards.
- ✓ The ability to remain focused on a task is vital for any coherent cognitive function, especially when there might be potential interference from distractors that are irrelevant for the task.

Change Blindness in dynamic Jobsites

Does Change Blindness Degrade Worker Hazard Identification at Jobsites?



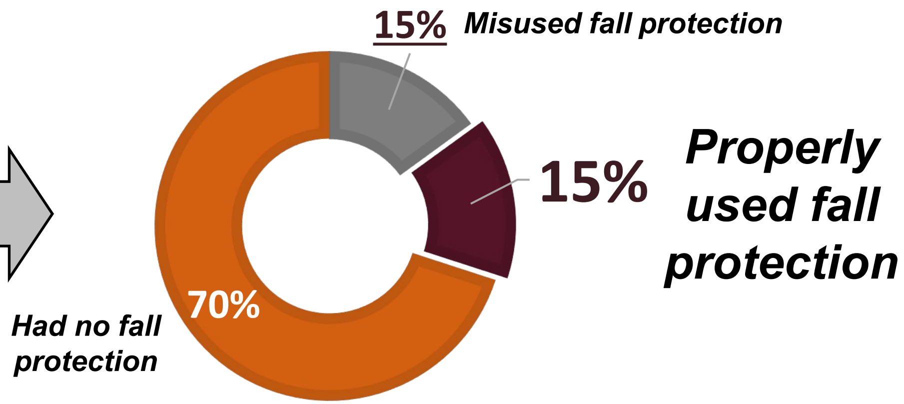
Change Blindness in dynamic Jobsites



The state of the practice suggests that the most effective strategy for reducing human error is
to increase the level of protection safeguarding workers

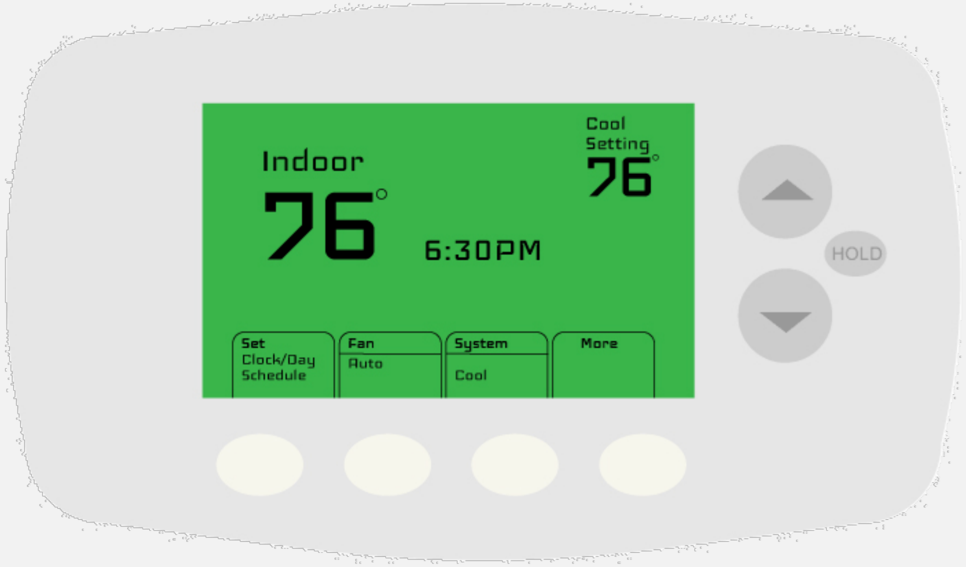
Incident reductions from increased protection were lower than expected.

Fall Incident Reports
(1997-present)



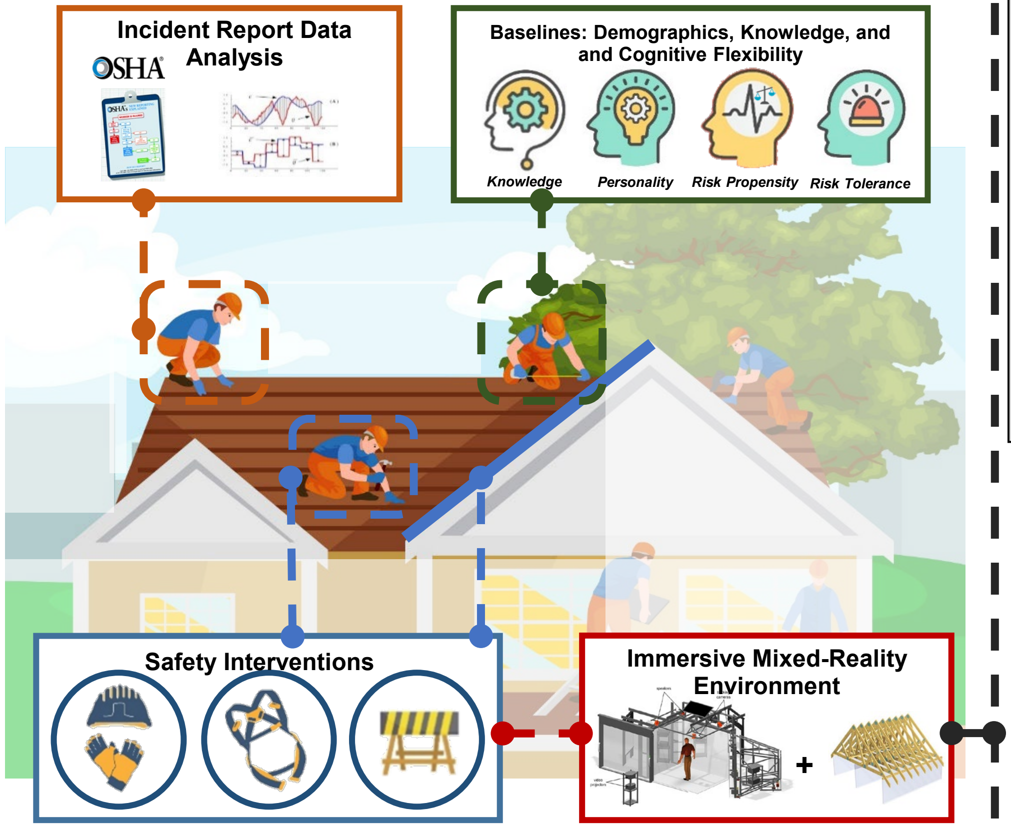
Why has the construction industry <u>not</u> experienced greater safety returns?

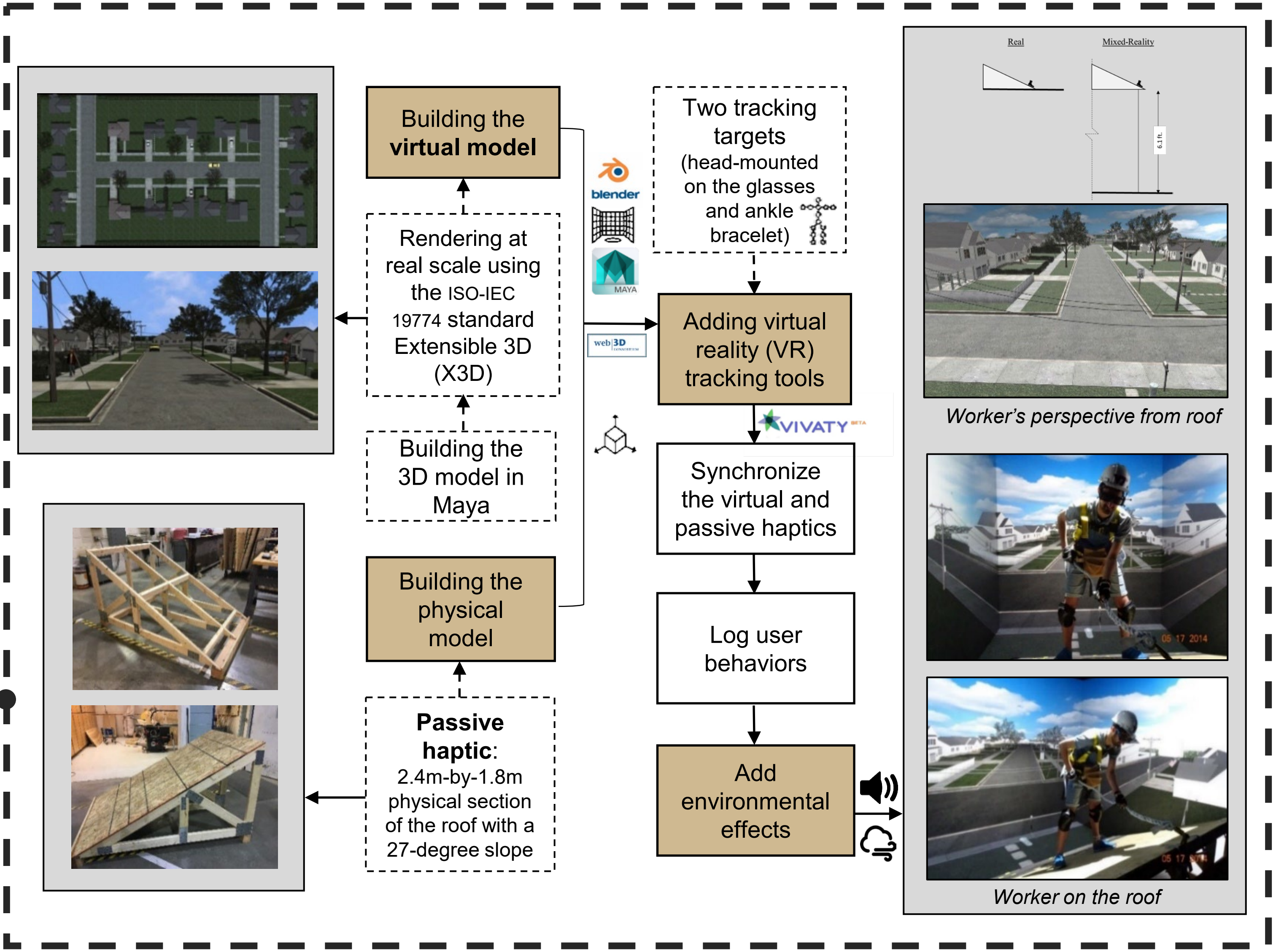
Risk Compensation Theory



Does workers compensate for greater levels of safety protection by behaving in a riskier fashion?

Latent Side-Effect of Safety Interventions: Residential Roofing





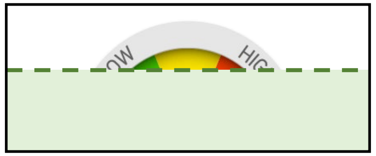
Latent Side-Effect of Safety Interventions: Residential Roofing

No Intervention

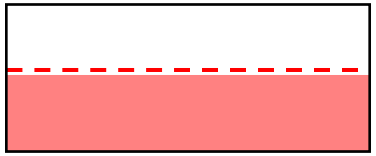
Injury-Reducing Intervention

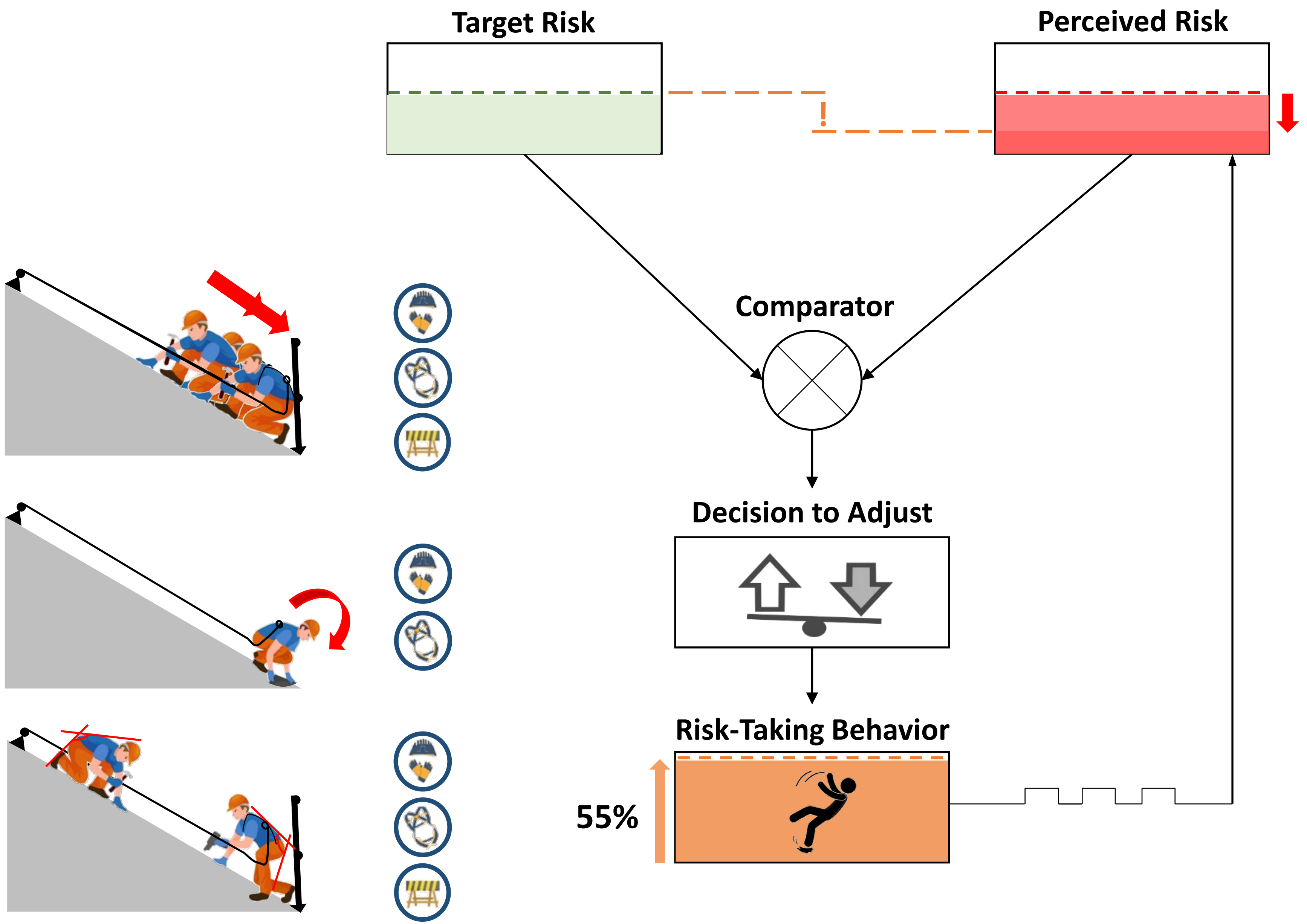
Injury-Preventing Intervention

Target Risk



Perceived Risk




Target Risk
Perceived Risk
Comparator
Decision to Adjust
Risk-Taking Behavior
55%

HOW CAN EXTERNAL STRESSORS AFFECT WORKERS' PRODUCTIVITY AND SAFETY PERFORMANCE?

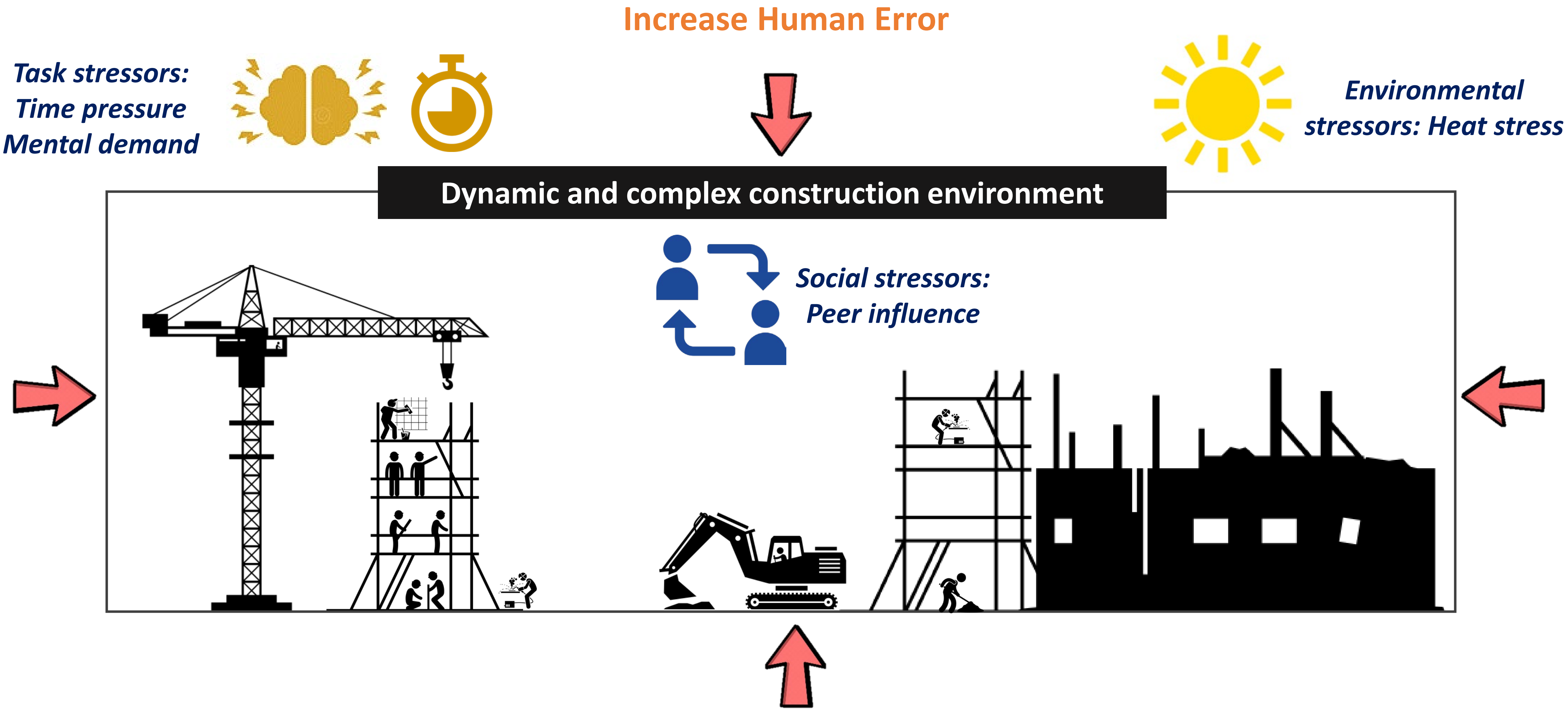
NSF

ELECTRI INTERNATIONAL
THE FOUNDATION FOR ELECTRICAL CONSTRUCTION INC.

Collaborators:
Thomas Redick
Scott Geller
Behzad Esmaeili


External Stressors
Internal Stressors

External Stressors in the Construction Industry



External Stressors in the Construction Industry

Increase Human Error

Task stressors:
Time pressure
Mental demand

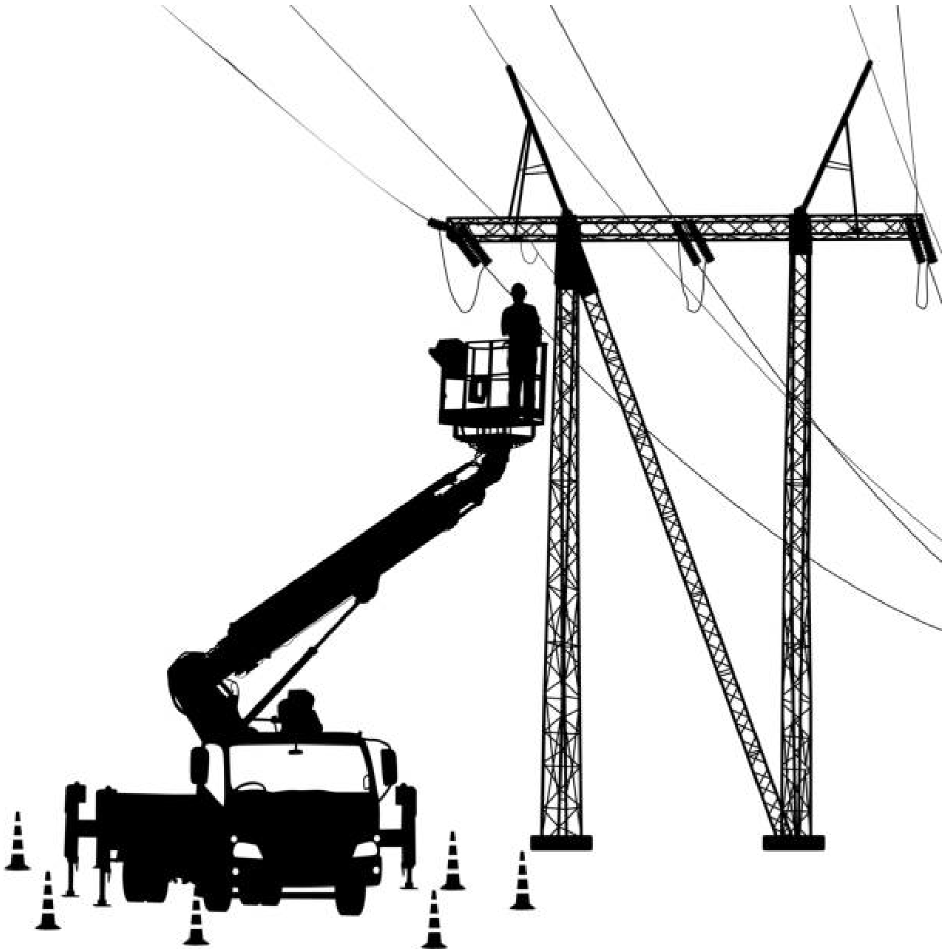
Environmental stressors: Heat stress

Dynamic and complex construction environment

Social stressors:
Peer influence

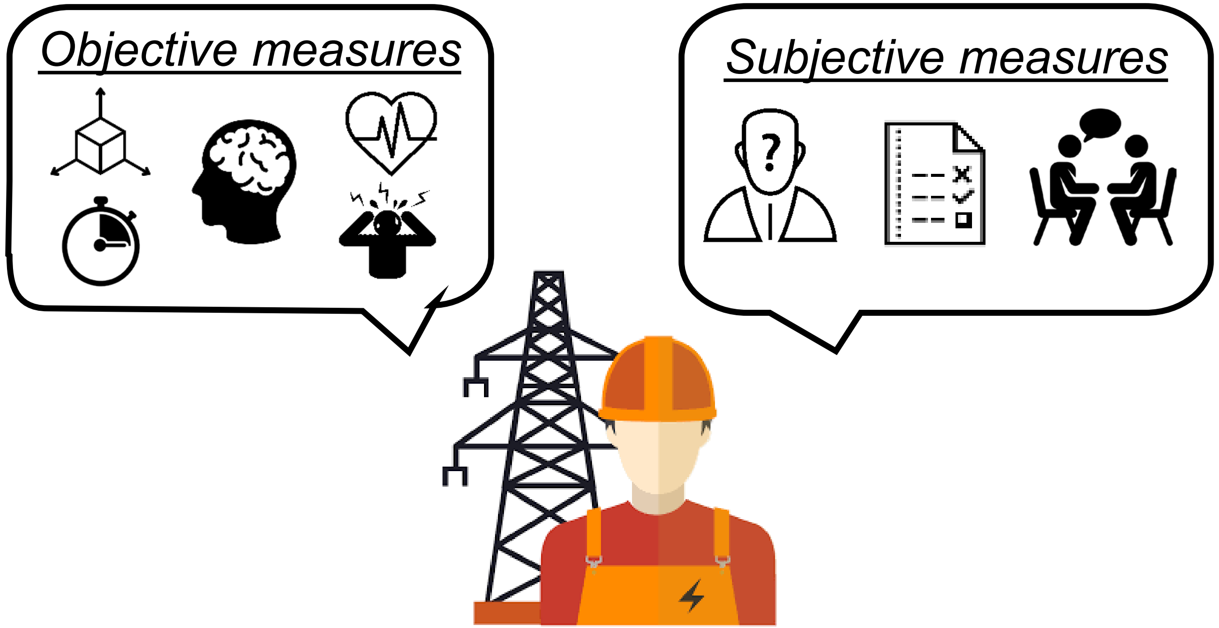
Research Methodology

Effects of Task Stressors



Replacing Pole

Moving Energized Powerlines from an old pole to a new pole



Research Methodology

Build the virtual model

Build the 3D model in Maya

Street's top view

Old pole (orange) and new pole (yellow)

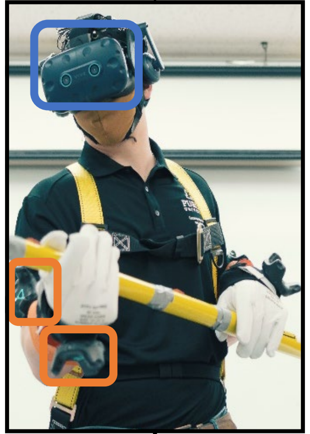
Build the physical model

Passive haptic:
- Bucket
- Insulating Gloves
- Hot-stick
- Fall Protection

Synchronize the virtual and passive haptics

Add environmental Modalities

Synchronize subject movements and virtual avatar



HTC VIVE Pro Eye headset for immersion in the simulated environment

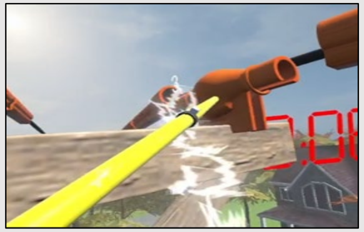
Movement trackers to sync actual and virtual movements: wrists (two), arms (two), waist (one)

Subject in the generated workplace

Subject in the real-world

Log user behaviors

Simulate arc flash animation and audio



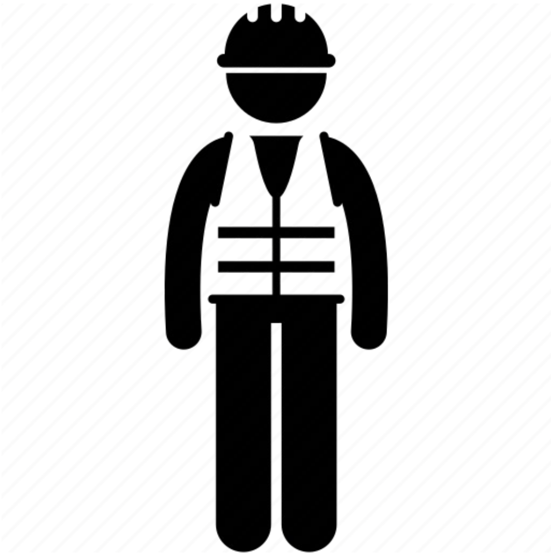
GUI to control the experiment and adjust conditions

Research Methodology

- **Experimental Conditions:**

- *Full protection*
- *Extra incentive in stressful conditions*

***I)* Normal**

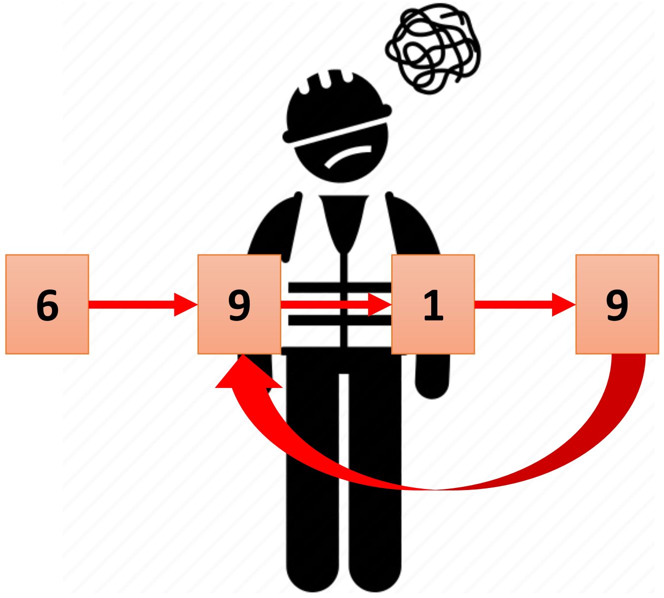


Duration: Subject's own pace

***II)* Time Pressure**

Duration: Normal – 10 Seconds

***III)* Time Pressure + Mental Demand**



2-back Task

Duration: Normal – 10 Seconds

Research Methodology

Building the 3D model in Maya

Building the virtual model

+

Building the physical model

Passive haptic:
- Bucket
- PPE & Fall Protection

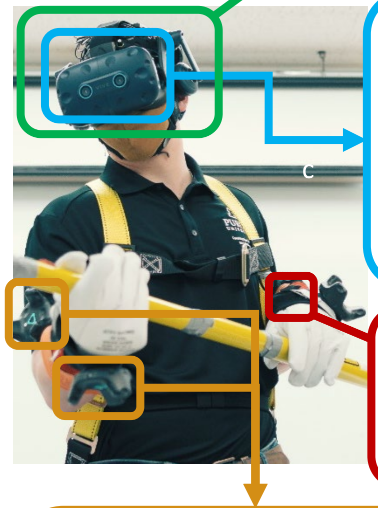
Synchronize the virtual and passive haptics

Add environmental effects

Log user interactive behaviors

Decision-making dynamics

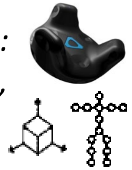
(Brite wearable non-intrusive fNIRS)

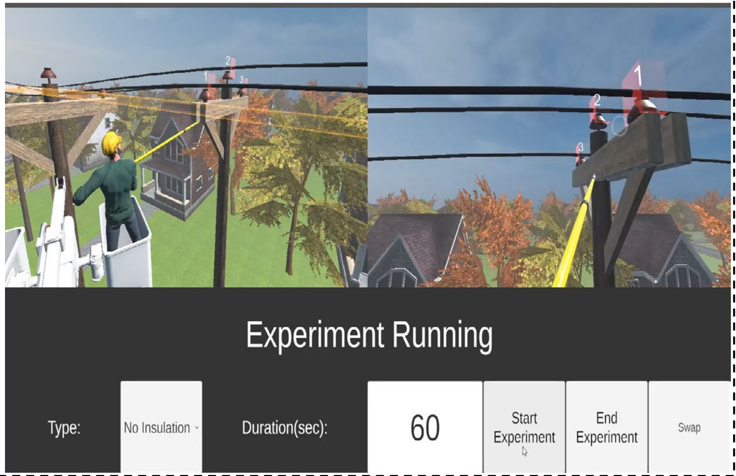


Hazard identification
Eye-tracking
Immersion

Risk perception (Empatica E4)

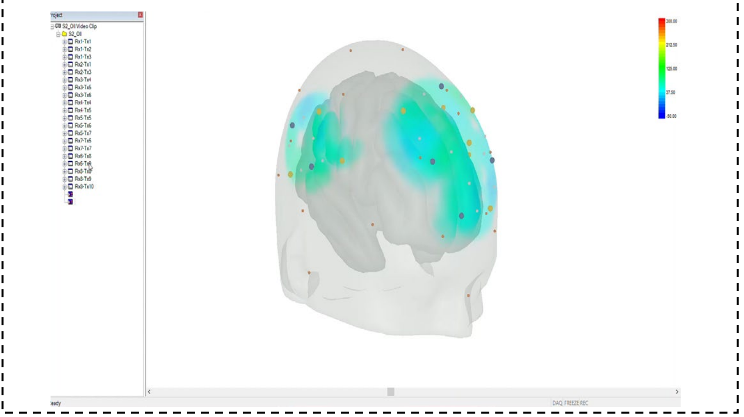
5 body and 1 head trackers: tracking motions, positions, musculoskeletal data



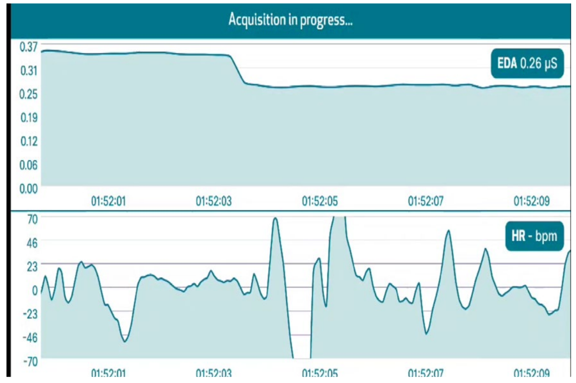


Virtual-Reality 5 Experimental Conditions

Real-Time + Passive Haptics



Brain Activation



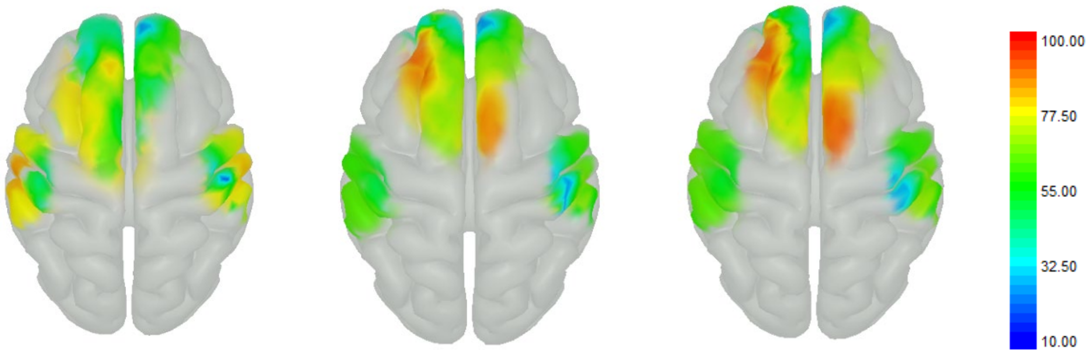
E4 Empatica (GSR & HR)

Multi-Model Mixed Reality (MR) Environment

Findings

Effects of Time Pressure and Cognitive Demand

Brain Activation and Decision Dynamics



Condition I ***Condition II*** ***Condition III***

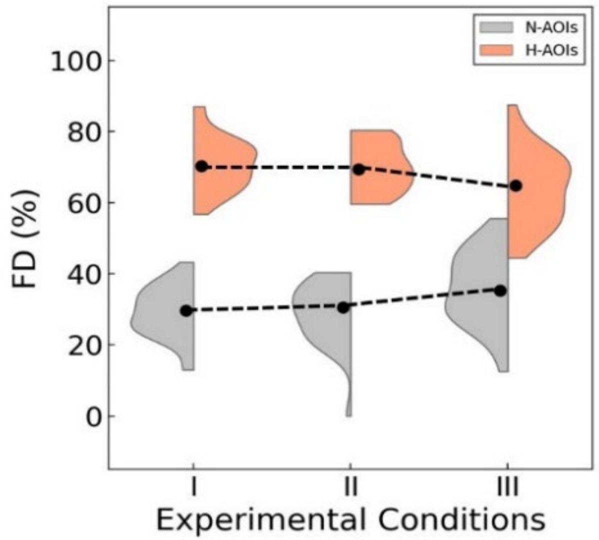
- ✓ A **higher cognitive response** is illustrated in the **Prefrontal Cortex** (shown by red color) correlating with demanding conditions *II* and *III*, reaching the highest in condition *III*.
- ✓ **Increased rate of activation** during the risk decision-making process
- ✓ These findings demonstrate the **dominant function of the Prefrontal Cortex** in the risk decision-making process.

I) Normal Condition
II) Time Pressure Condition
III) Time Pressure + Cognitive Demand Condition

Findings

Effects of Time Pressure and Cognitive Demand

Attentional Distribution Measured by Fixation Duration



✓ Task stressors disturbed attentional distribution in stressful conditions; lower %FD is associated with **H-AOIs**

I) Normal Condition
II) Time Pressure Condition
III) Time Pressure + Cognitive Demand Condition

Hazardous Areas of Interest *H-AOIs*

Hazardous areas within the scene :
- **Power cables**
- **Poles**
- **Hot stick**

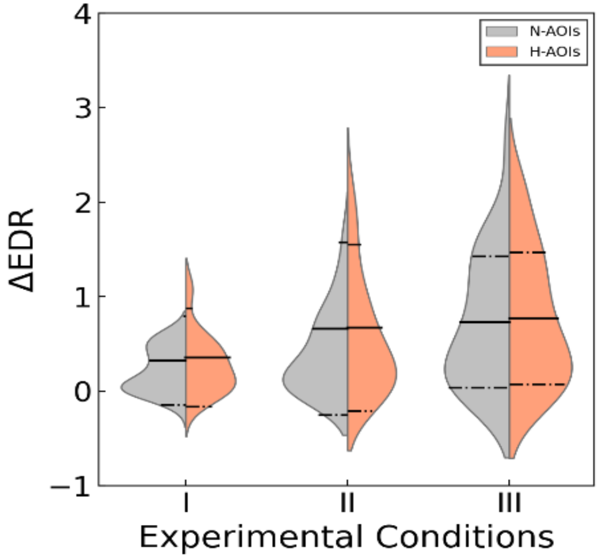
Non Hazardous Areas of Interest *N-AOIs*

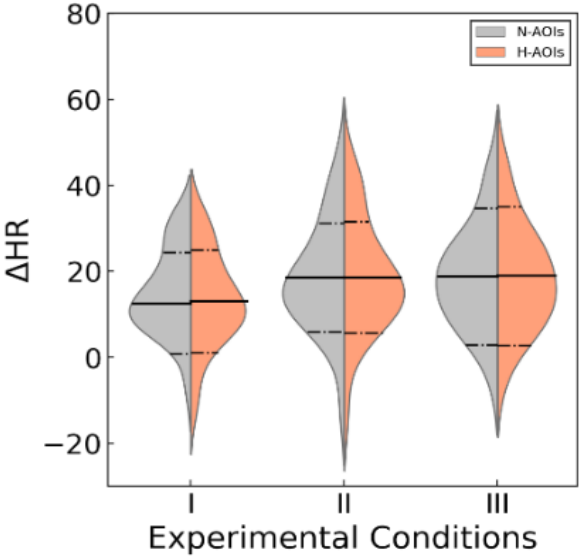
- **Non-hazardous areas within the scene**

Findings

Effects of Time Pressure and Cognitive Demand

Stress level measured by EDR and HR





✓ Higher stress level is associated with the **H-AOIs under normal condition**

I) Normal Condition
II) Time Pressure Condition
III) Time Pressure + Cognitive Demand Condition

Hazardous Areas of Interest ***H-AOIs***

Hazardous areas within the scene :

- **Power cables**
- **Poles**
- **Hot stick**

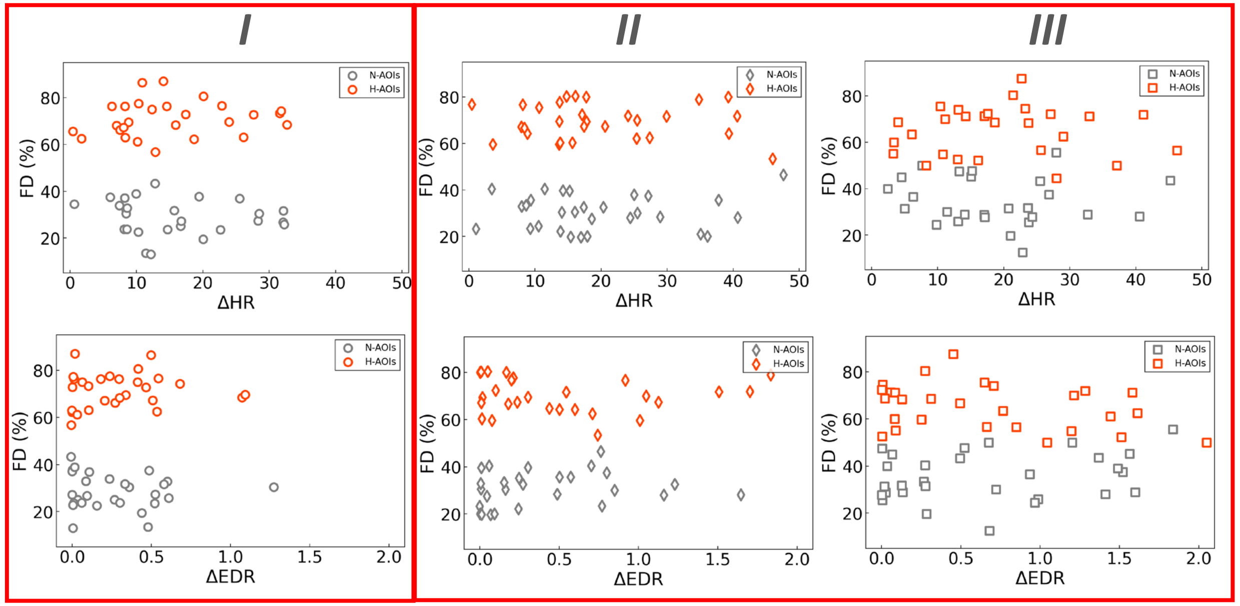
Non-Hazardous Areas of Interest ***N-AOIs***

- **Non-hazardous areas within the scene**

Findings

- **Effects of time pressure and mental demand on workers' situational awareness**

  Correlation between attentional distribution and stress level



I) Normal Condition

II) Time Pressure Condition

III) Time Pressure + Mental Demand Condition

H-AOIs: Hazardous Areas of Interest

N-AOIs: Non-hazardous Areas of Interest

- ✓ As the task stress levels increase from Conditions I through to Condition III, the differences between attentional allocations toward H-AOIs versus N-AOIs **reduced**
- ✓ The demands occupied participants' available cognitive resources, so their attentional resources ended up being shared between environmental elements, showing a lack of focus
- ✓ Cognitive capacity to attend hazardous AOIs **decreased; impaired selective attention**
- ✓ Selective attention enables individuals to focus on a task at hand and filter out irrelevant information

Findings

Effects of Time Pressure and Cognitive Demand

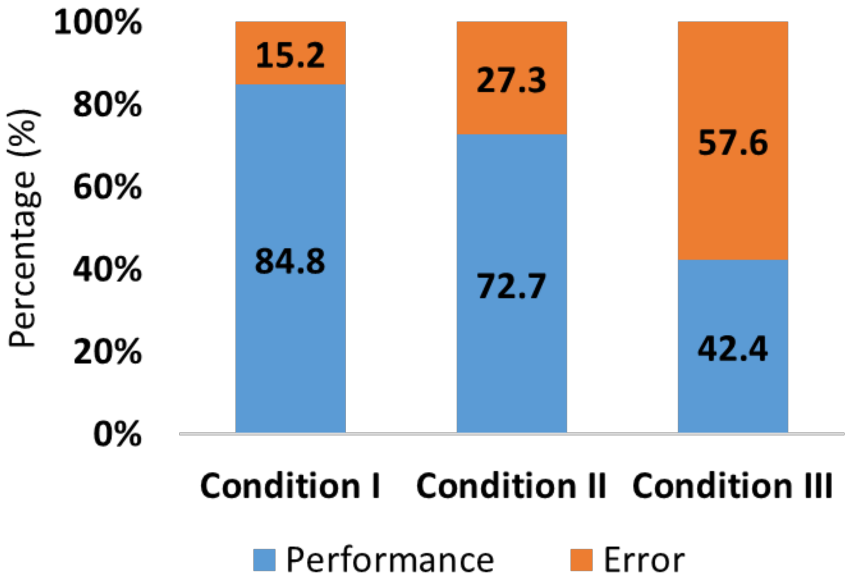
Performance Measures

Condition I ➢ *Not experiencing arc flash*

Condition II ➢ *Not experiencing arc flash* *+ Finishing on time*

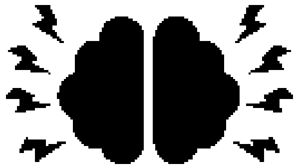
Condition III ➢ *Not experiencing arc flash* *+ Finishing on time* *+ accuracy rate*

Safety Performance



✓ The overall performance **reduced significantly** under demanding conditions, by 13% in Condition *II* and 42% in Condition *III* compared to their performance in completing the task under normal condition (Condition I).

Time Pressure

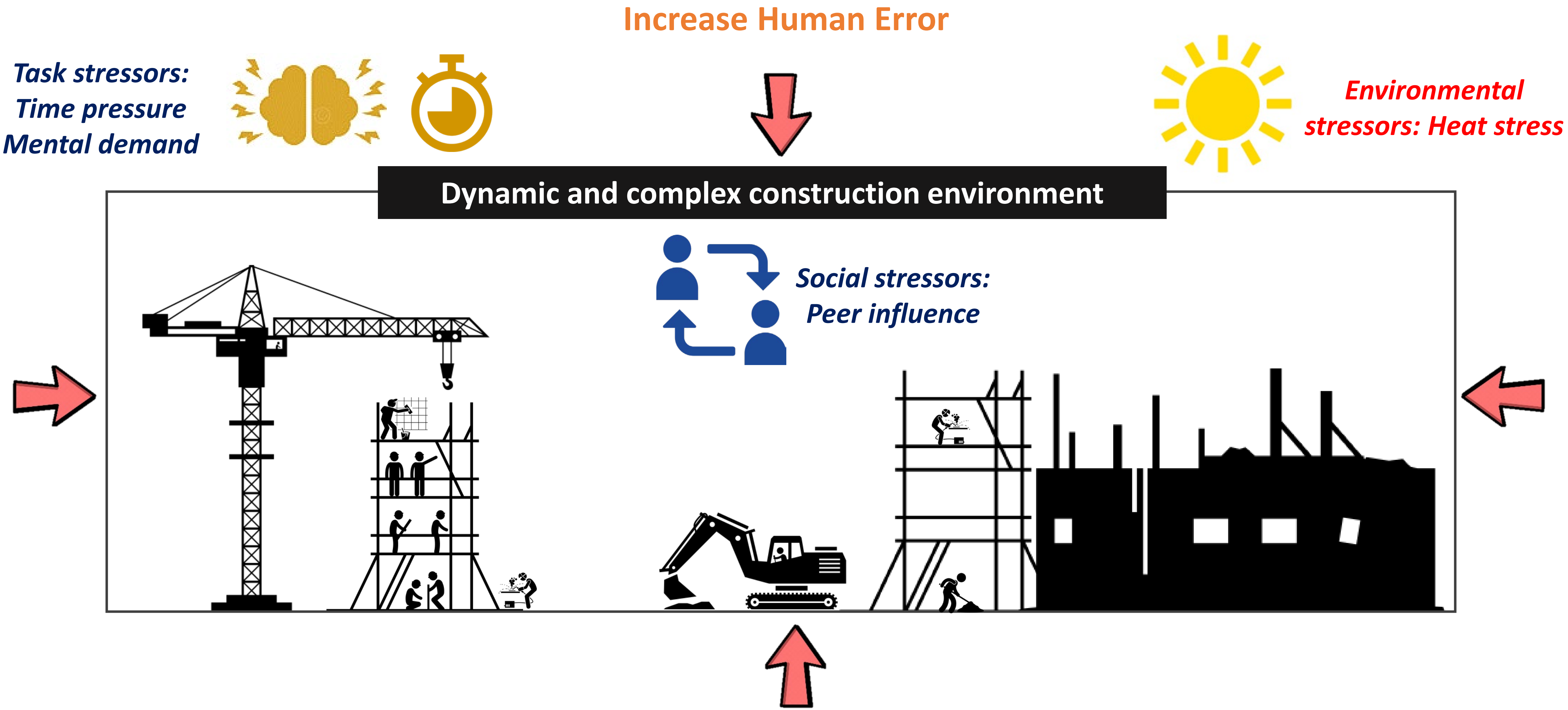


Cognitive Demand

Worsen the Effect of Risk Compensation and increase risk-taking behaviors

I) Normal Condition
II) Time Pressure Condition
III) Time Pressure + Cognitive Demand Condition

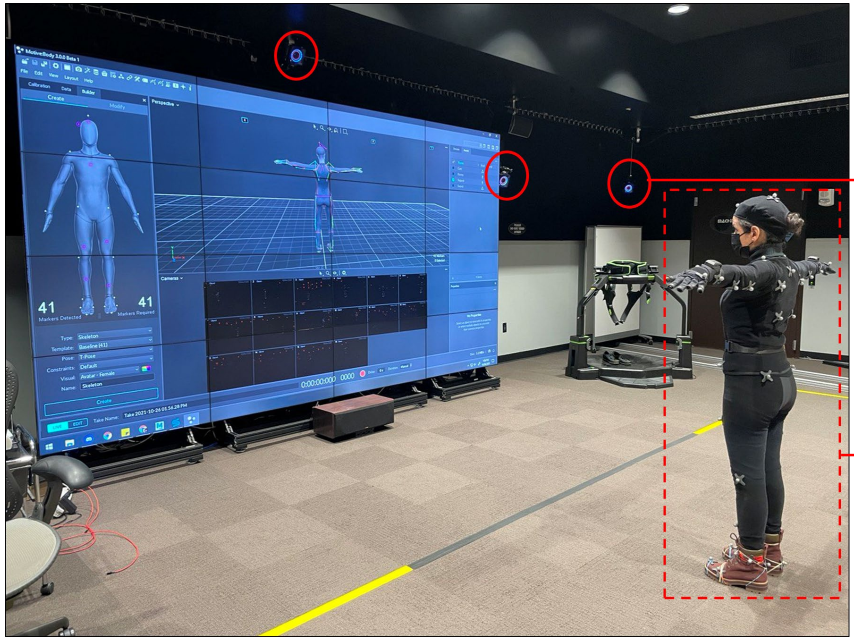
External Stressors in the Construction Industry



Research Methodology

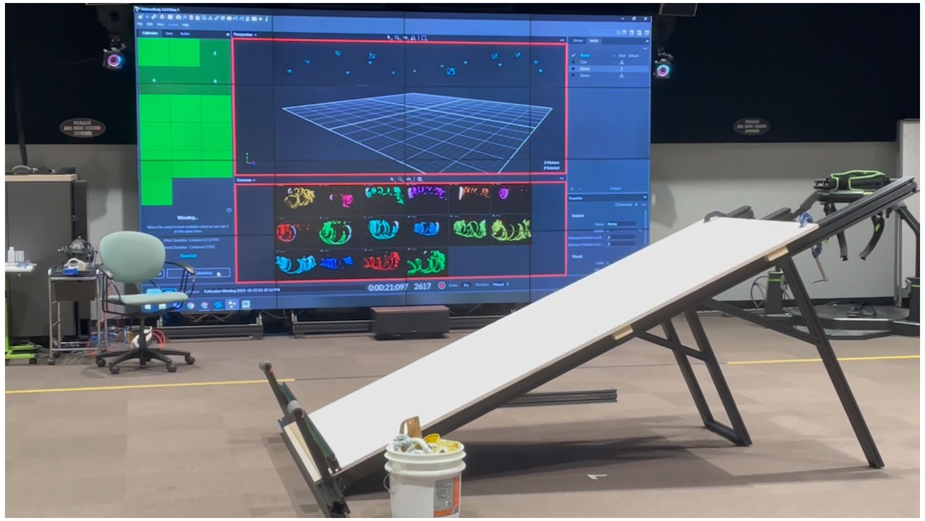
- **Model development**

OptiTrack Motive Body: creating a pre-configured actor with skeletal properties through a full skeletal motion tracking



OptiTrack cameras

Motion-tracker suite

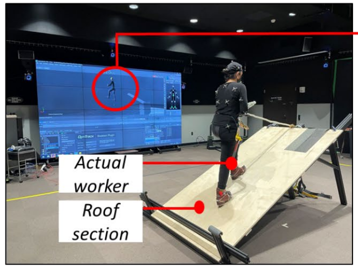


Research Methodology

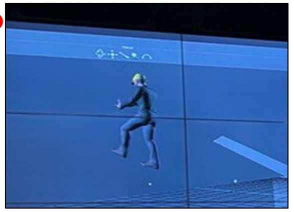
Creating the animated virtual worker based on different scenarios

Autodesk MotionBuilder

Using the data of the Motive Body software to create the animated virtual worker performing the roofing task scenarios



Going up the roof



Virtual worker

Leaning on the guardrail

Leaning on the toe board while installing shingles

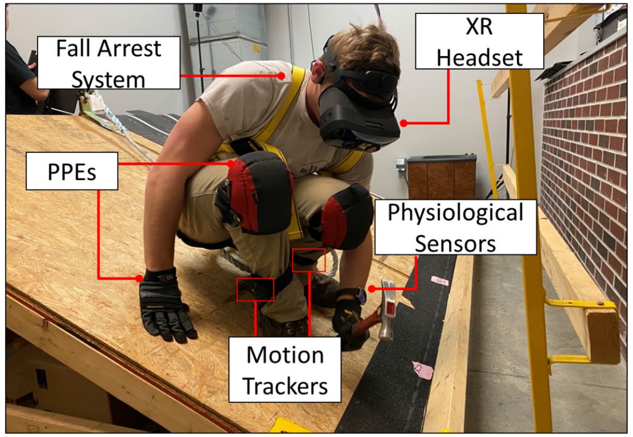
Importing the created avatar into Unity 3D

Unity 3D

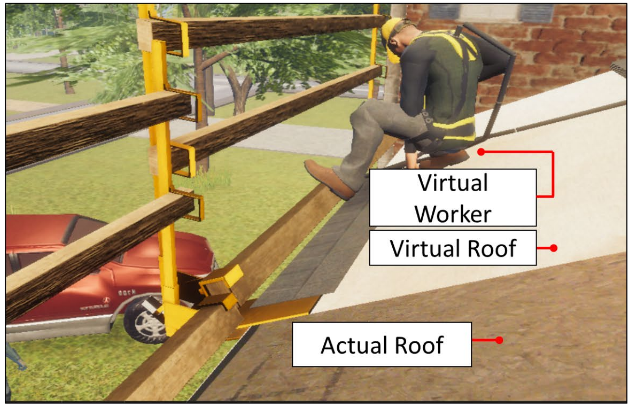
Creating a US suburban area and simulating the virtual worker on top of a 2-story building

Immersing participants in the generated XR environment

Subject in the real environment



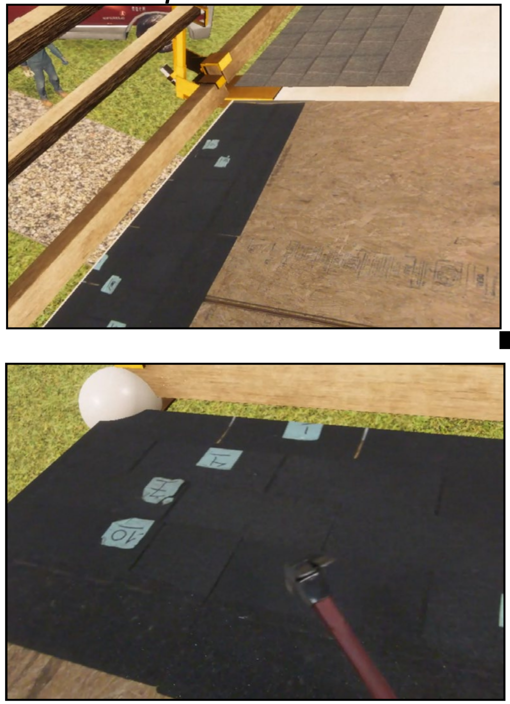
Virtual peer in the XR environment



Research Methodology

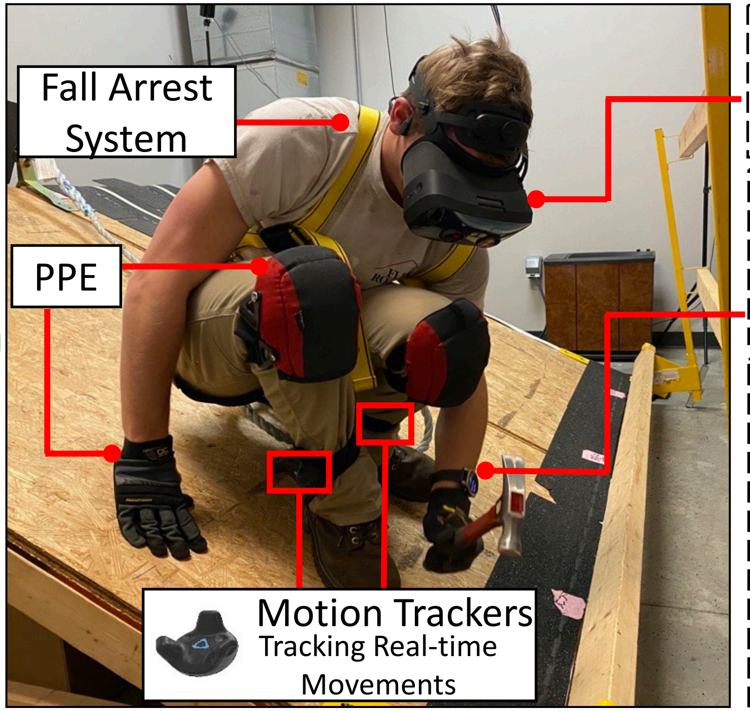
True-to-life virtual visualizations in XR environment

Third-person view	*First-person view*



+

Passive haptics for natural see-through in XR environment



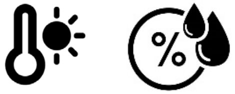
Varjo XR headset

Immersion + Eye tracking

Physiological sensors (Empatica E4)

Stress level, Heart rate

Climate chamber



<u>3 Heat conditions</u>

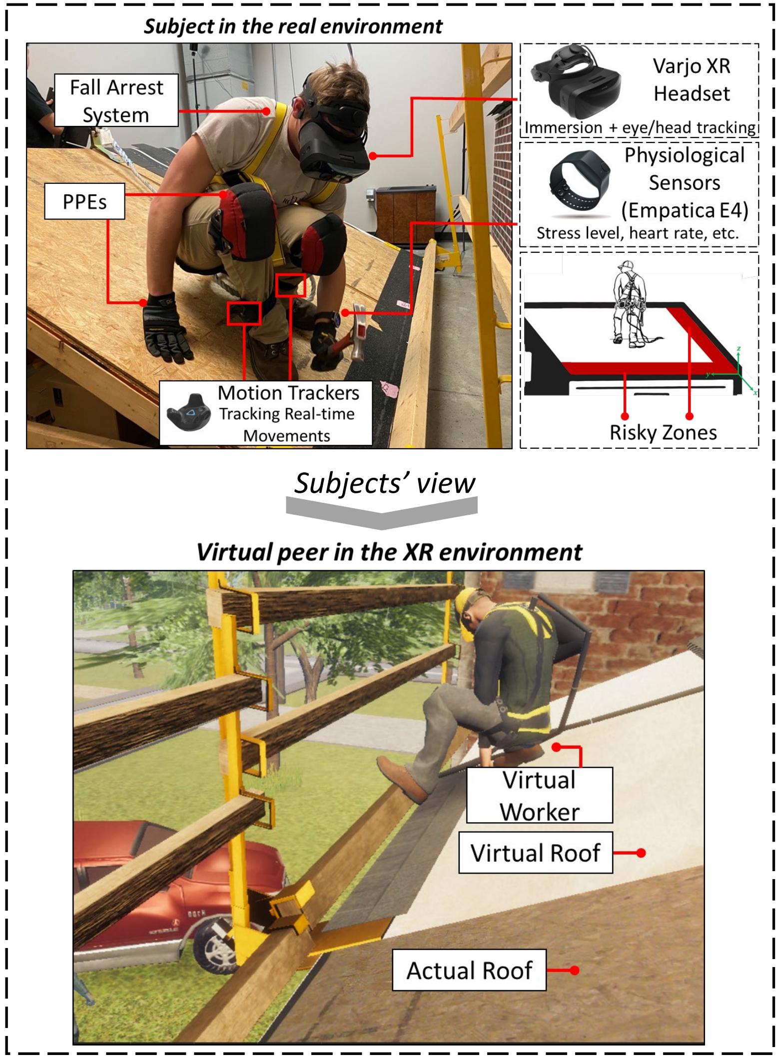
1) *No heat*
2) *Low heat (HI= 86F)*
3) *High heat (HI= 107F)*

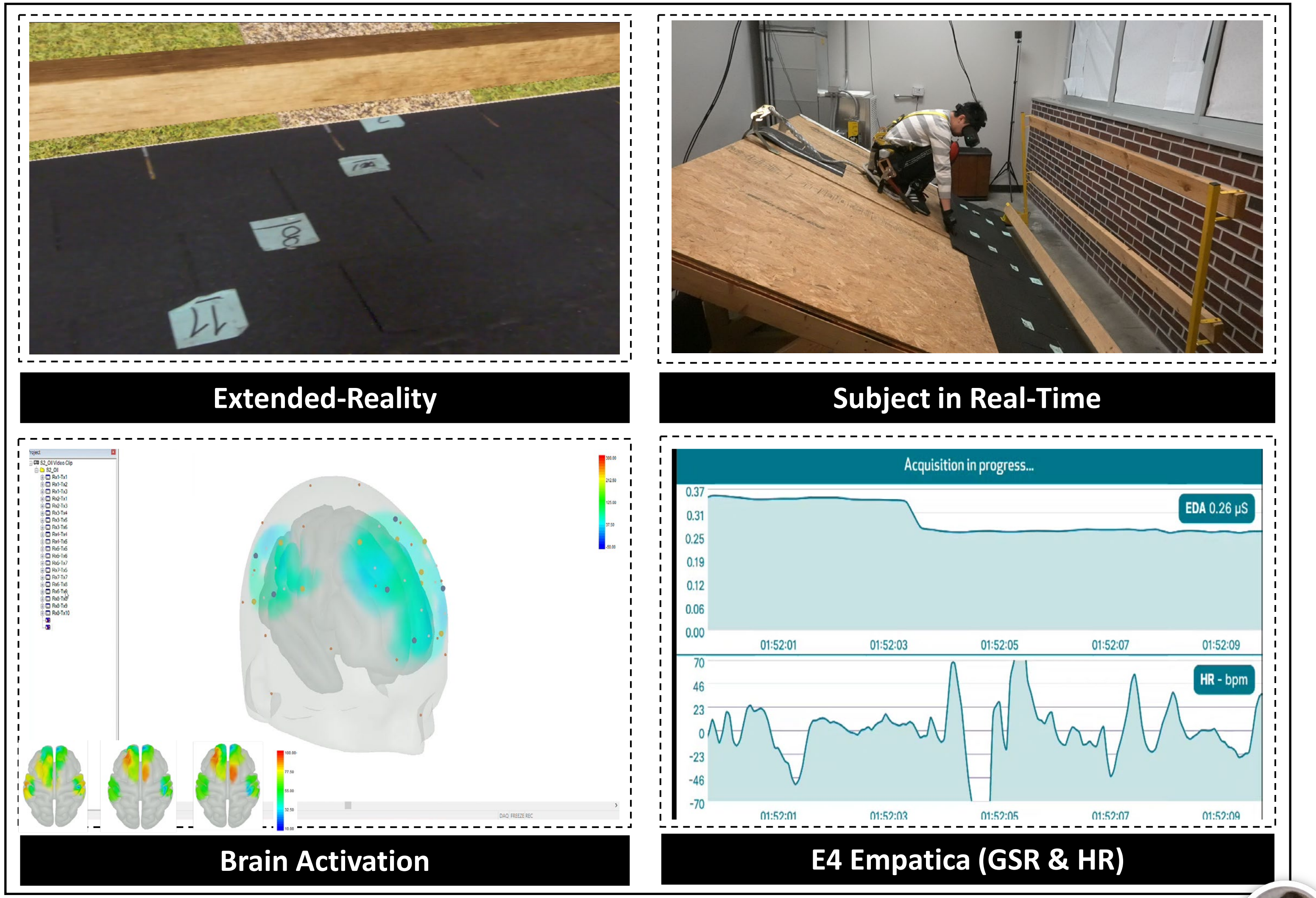
National weather service:

	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%
115	103	107	111	115	120	127	135	143	151								
110	99	102	105	108	112	117	123	130	137	143	151						
105	95	97	100	102	105	109	113	118	123	129	135	142	149				
100	91	93	95	97	99	101	104	107	110	115	120	126	132	136	144		
95	87	88	90	91	93	94	96	98	101	104	$\boxed{107}$	110	114	119	124	130	136
90	83	84	85	86	87	88	90	91	93	95	96	98	100	102	106	109	113
85	78	79	80	81	82	83	84	85	$\boxed{86}$	87	88	89	90	91	93	95	97
80	73	74	75	76	77	77	78	79	79	80	81	81	82	83	85	86	[illegible]
75	69	69	70	71	$\boxed{72}$	72	73	73	74	74	75	75	76	76	77	[illegible]	[illegible]
70	64	64	65	65	66	66	67	67	68	68	69	69	70	70	70	[illegible]	[illegible]

Research Methodology

Multi-Sensor Extended Reality (XR) Environment





Research Methodology

- **Measurements:**

Physical Fatigue → During the roofing task →

Objective Measurements: (Empatica E4)

ΔEDR — ΔHR — ΔST

Subjective Measurements: (Borg scale)

Likert-scale from 1 (no tired) to 6 (exhausted)

Mental Fatigue → During the roofing task →

Measurements: (Varjo eye trackers)

FD%: bottom and side edges

Mental Fatigue → After the roofing task: HI task →

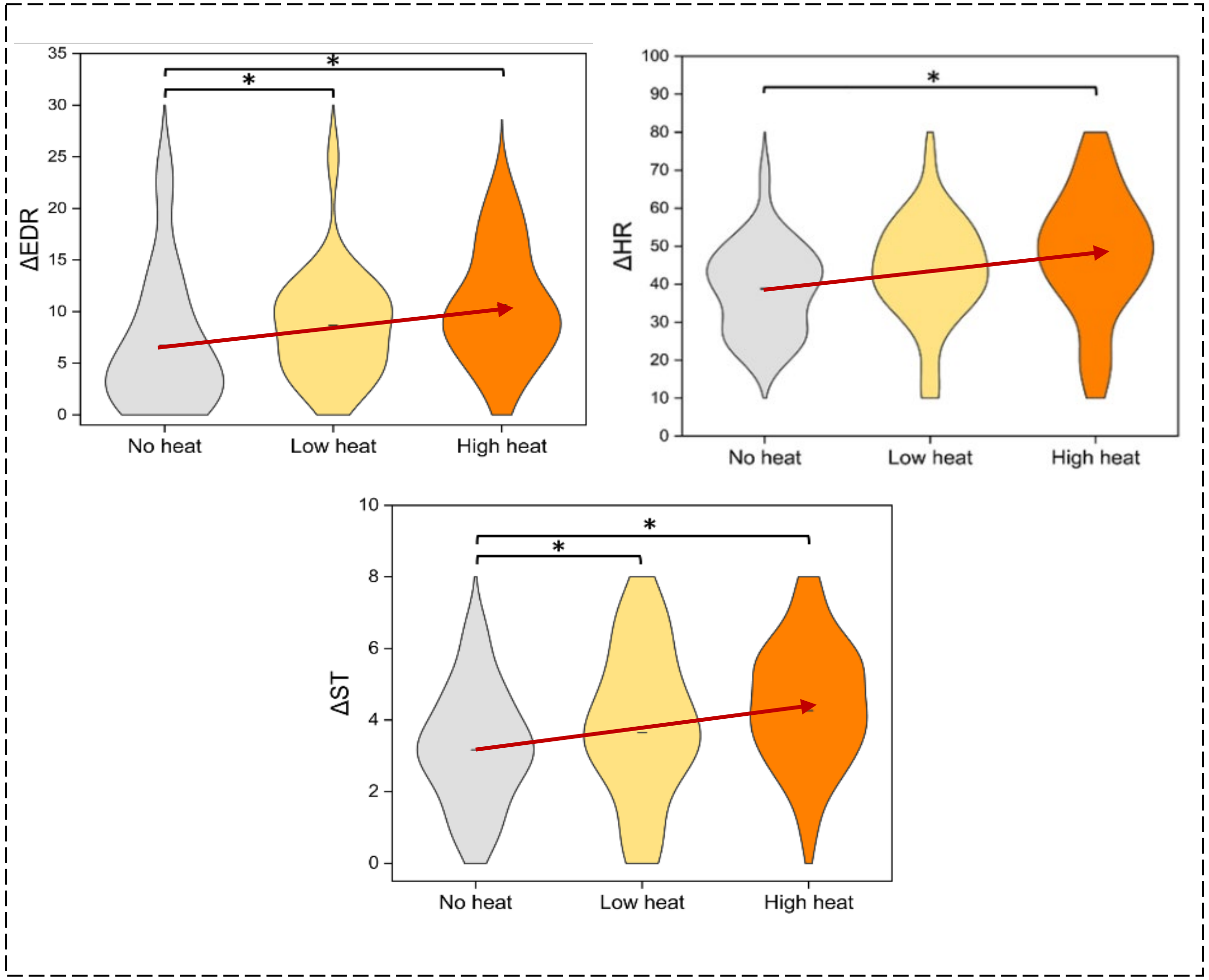
Measurements: (Tobii eye trackers)

FD, TFF, VC : fall- and ladder-related hazards

Findings

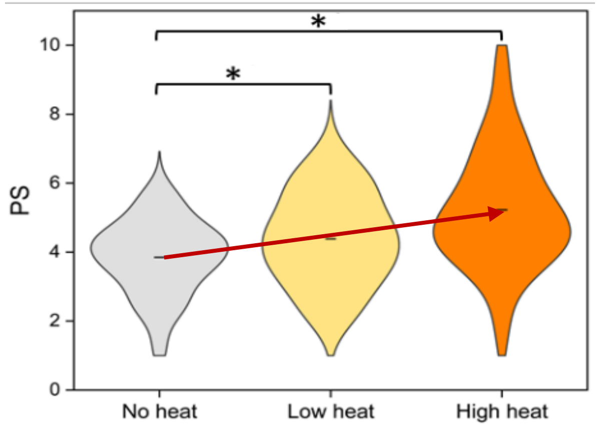
- **Effects of heat stress on <u>physical fatigue</u>:**

  Physical fatigue measurement: physiological responses (ΔEDR, ΔHR, ΔST)



✓ **Increases** in physical fatigue by increasing the heat level

✓ $$\text{Physical stress index (PS)} = \left[5 \times \frac{\Delta \text{ST}}{39.5 - \text{STb}} + 5 \times \frac{\Delta \text{HR}}{180 - \text{HRb}}\right]$$ (Anwer et al., 2020)

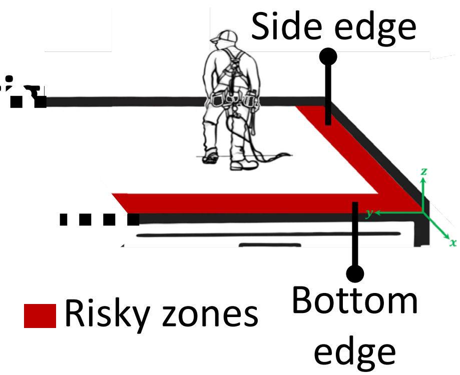


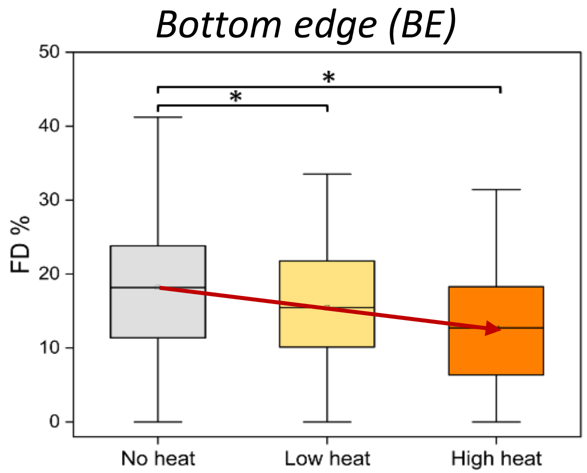
No heat
Low heat
High heat
******P-value < 0.05*
*******P-value < 0.1*

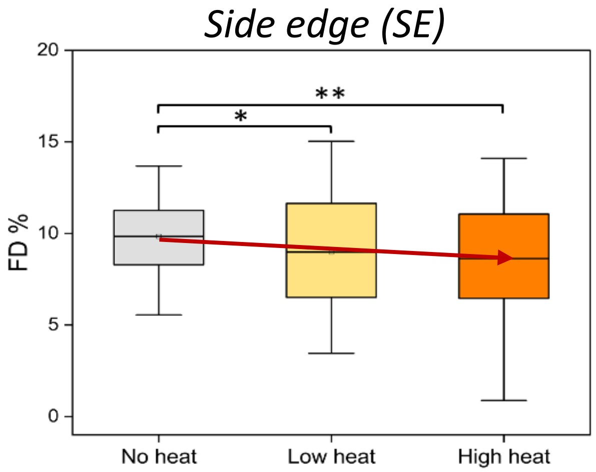
Findings

- **Effects of heat stress on <u>mental fatigue</u> during the roofing task (shorter-term mental fati**

Mental fatigue measurement: FD% over bottom and side edges







✓ **Significant decreases** in participants' FD% over BE and SE from No to High heat conditions

✓ **Higher decreases** in the attentional distribution over BE and SE in High heat condition

✓ Heat stress impaired **attentiveness** to the areas of interest showing distraction

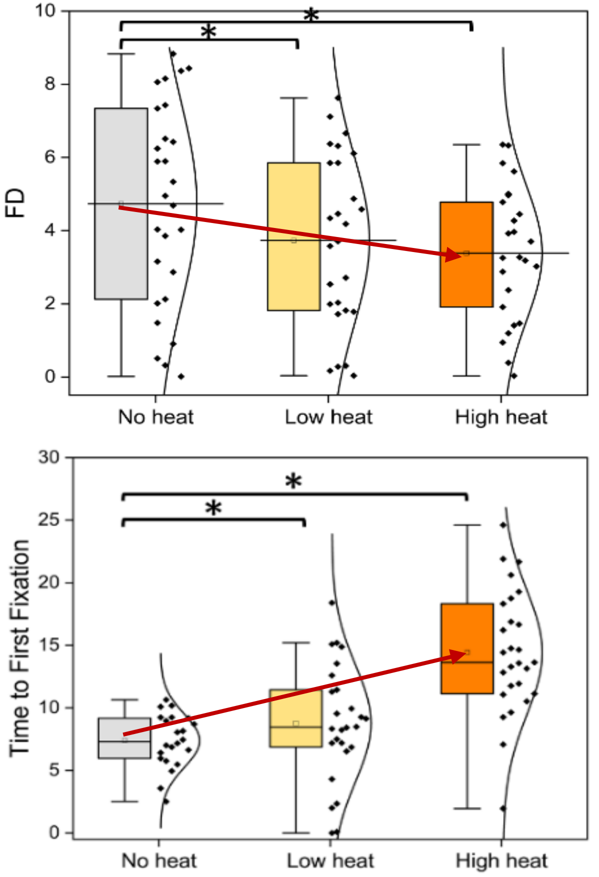
No heat
Low heat
High heat
**P-value* < 0.05
***P-value* < 0.1

Findings

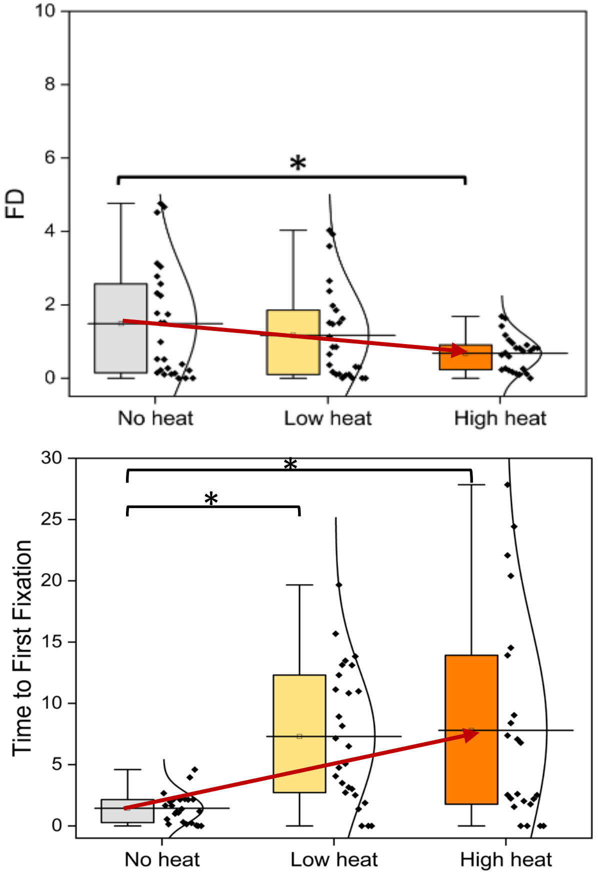
- **Effects of heat stress on <u>mental fatigue</u> after the roofing task (longer-term mental fatigue)**

  Mental fatigue measurement: FD% and time to first fixation over fall-and ladder-related hazards

Fall-related hazards:

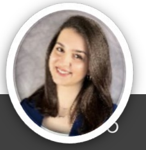


Ladder-related hazards:



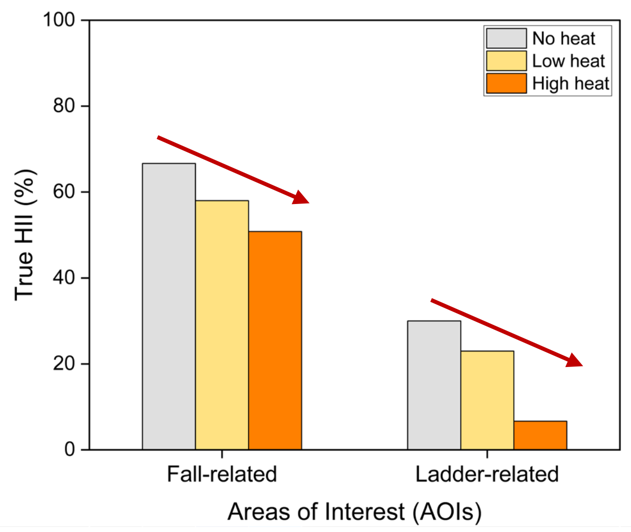
- ✓ **Lower** FD over the hazards by increasing the heat level
- ✓ **Higher** time to first fixation over the hazards by increasing the heat level
- ✓ **Heat** impaired situational awareness and attentional distribution

No heat
Low heat
High heat
**P-value < 0.05*
***P-value < 0.1*



Findings

- **Effects of heat stress on mental fatigue after the roofing task (longer-term mental fatigue)**
  HII: hazard identification index



No heat
Low heat
High heat
******P-value < 0.05*
*******P-value < 0.1*

✓ **HII** = the number of truly identified hazards /total number of hazards

✓ **Decreases** in number of fall-related identified hazards by increasing the heat level

✓ **Decreases** in number of ladder-related identified hazards by increasing the heat level

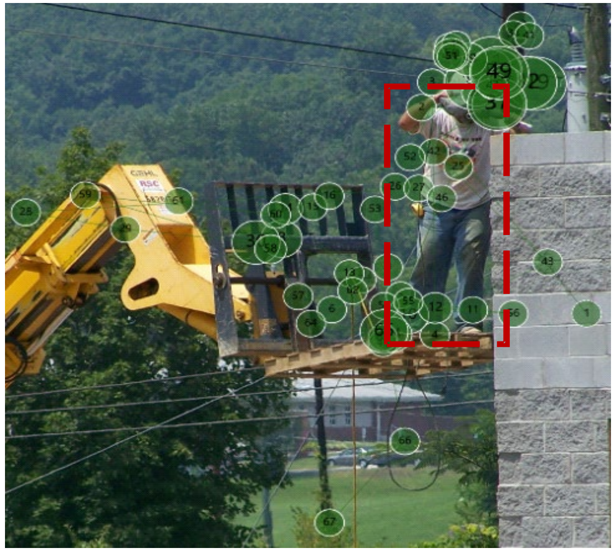
✓ High ambient temperature impaired participants' focus

Findings

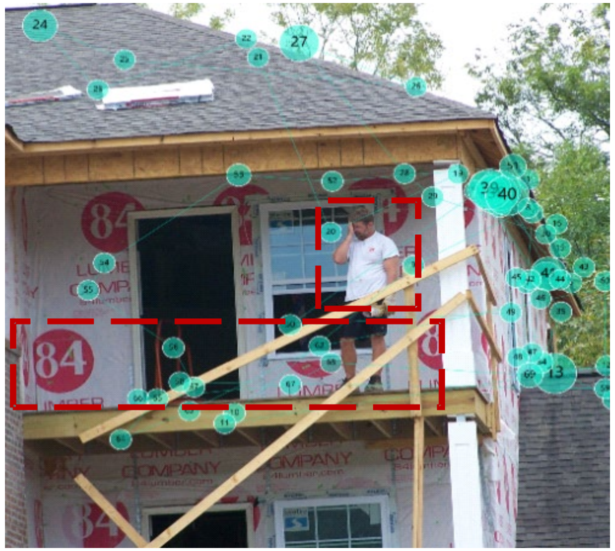
- **Effects of heat stress on <u>mental fatigue</u> after the roofing task (longer-term mental fatigue)**

  Mental fatigue measurement: Visual search patterns over the fall-related hazards

No heat



Low heat



High heat

✓ Participants **could not focus** their attention on the hazard related areas

✓ **Heat** impaired situational awareness and caused **cognitive confusion**

Research Methodology

- **Experimental conditions:**

Condition 1	Condition 2
Unsafe peer	*Safe peer*

Condition 1

Unsafe peer

Near miss

Leaning

Using phone

Experiencing the fall

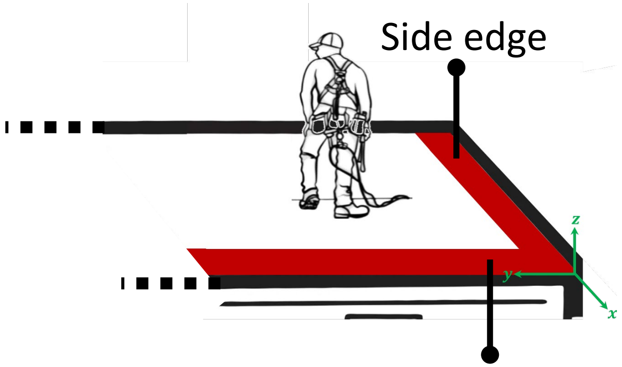
Condition 2

Safe peer

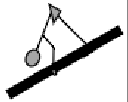
Performing the task cautiously

Findings

- **Measurements:**

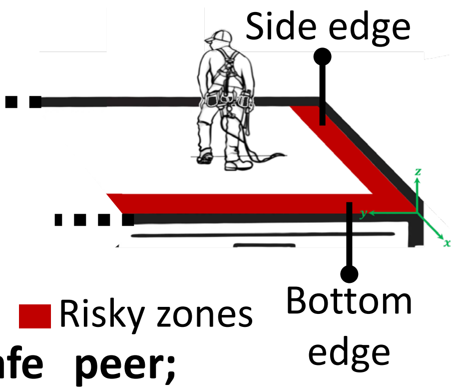


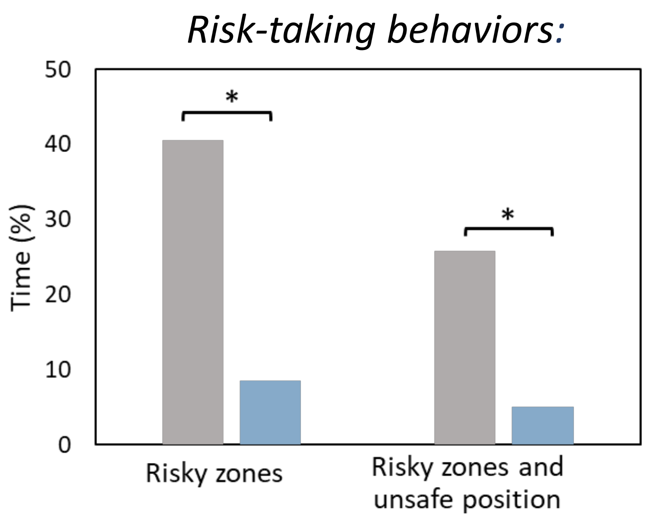
Biomechanical Measures	Cognitive Measures	Physiological Measures
▪ Time spent in risky zones (%) ▪ Unsafe position in risky zones (%) ▪ Movement intensity (MI)	▪ Attentional distribution over the bottom and side edges (FD%)	▪ Electrodermal activity (EDR)

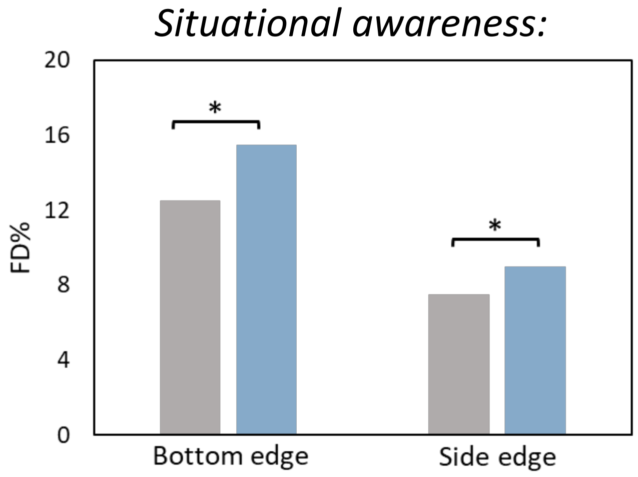


Findings

- **Effects of safe/unsafe peers on workers' risk-taking behaviors and situational awareness**

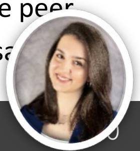






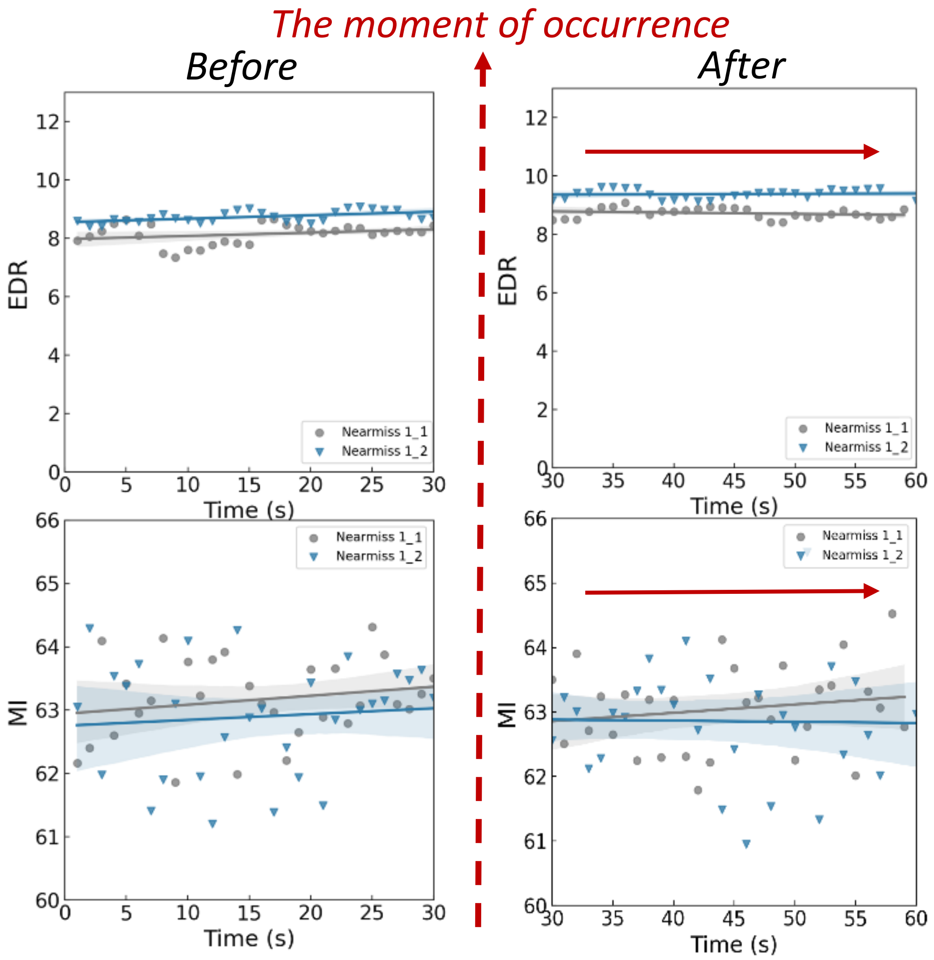
- ✓ Higher **risk-taking behaviors** alongside the **unsafe peer;** more time spent in risky zones and in risky zones while taking unsafe positions
- ✓ Less **attentiveness** toward the bottom and side edges alongside the **unsafe peer**
- ✓ Higher **distraction** alongside the **unsafe peer**
- ✓ Social learning theory: individuals learn and imitate behaviors by observing others

Safe peer
Unsa



Findings

- **How might peer's unsafe behaviors impact others' behavior: Near misses**
  Less potential near misses: briefly slid across the roof

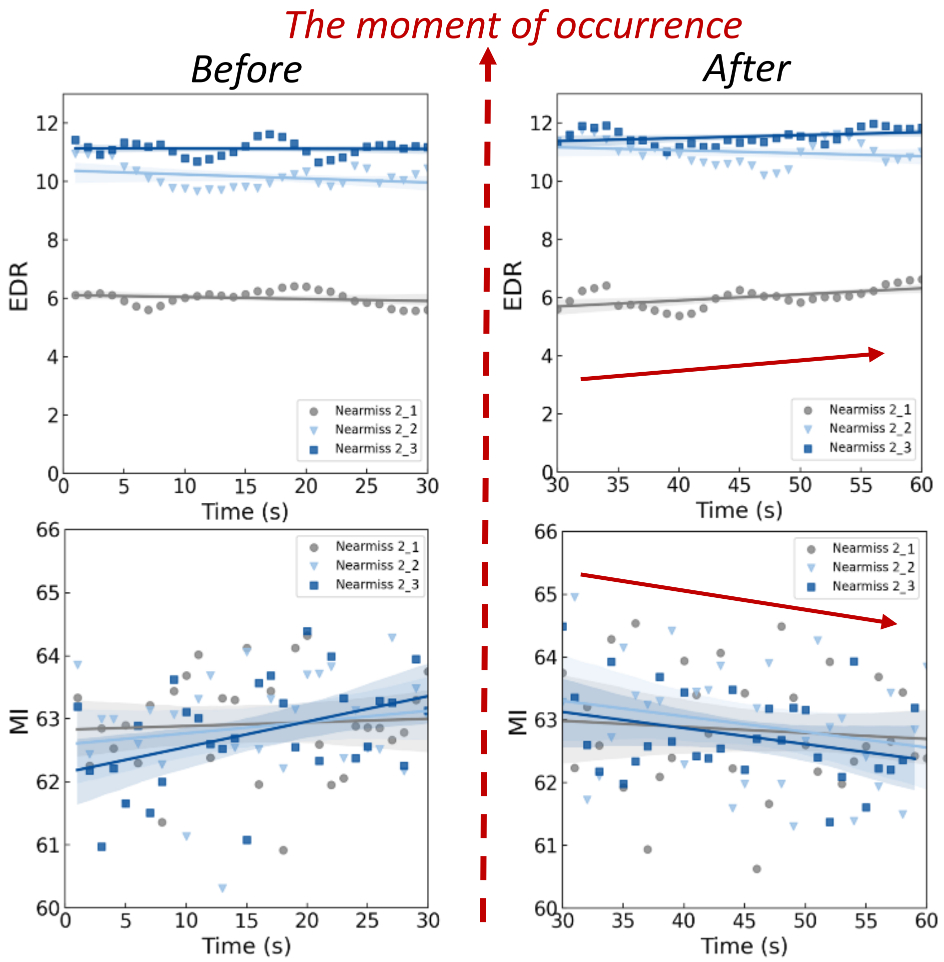


✓ No changes in **arousal level** measured by EDR after and before the event

✓ No changes in **movement intensity** after and before the event

Findings

- **How might peer's unsafe behaviors impact others' behavior: Near misses**
  High potential near misses: a forceful slide across the roof

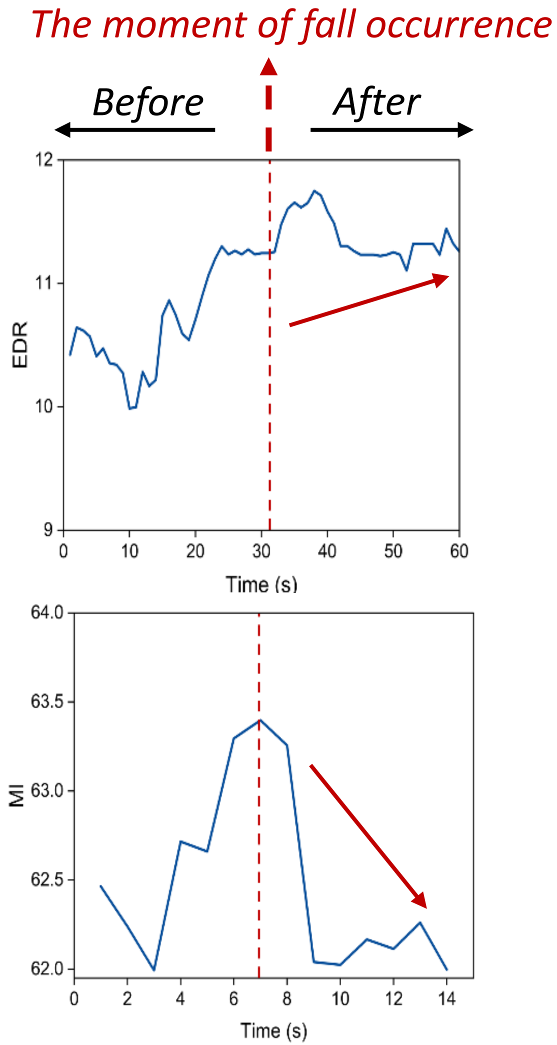


✓ **Considerable** changes in **arousal level** measured by EDR after and before the event; increases

✓ **Considerable** changes in **movement intensity** after and before the event; decreases

Findings

- **How might peer's unsafe behaviors impact others' behavior: Fall**

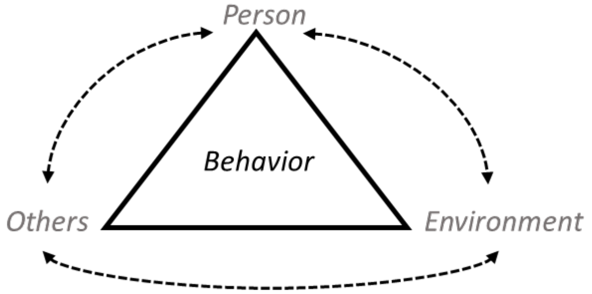


✓ **Considerable changes** in arousal levels and movement intensity after and before the fall

✓ After observing the peer's fall, individuals **modified** their behaviors and were more **cautious**

✓ Reactions and behavioral changes depend on the severity of incidents

✓ Behavioral adjustment theory: individuals continuously assess their surroundings and adjust their actions

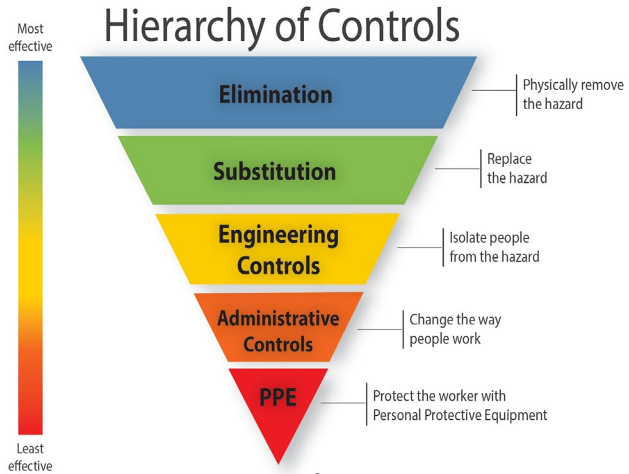


Takeaways

✓ Task stressors **deteriorate safety performance** and **disrupt attention, increase the cognitive load** and **limit the required attentional resources**.

✓ Social stressors due to an unsafe peer, **disturbs workers' awareness** and increase their risk-taking behaviors; and the incident experienced by the peer **alters** individuals' behavior.

✓ Environmental stressors **exacerbate physical fatigue** and **increase mental fatigue** and involvement in high-risk behaviors.



Immediate
Proactive
Protective

- ➢ Identify conditions under which workers get more involved in high-risk behaviors (external stressors).
- ➢ Analyze the associated risks and offer intervention given the condition

This innovative study can help the construction industry regarding the control needed for designing evidence-based and practical safety interventions to mitigate the adverse effects of external stressors.

HOW CAN EXTERNAL STRESSORS AFFECT WORKERS' PRODUCTIVITY AND SAFETY PERFORMANCE?

Journal Papers

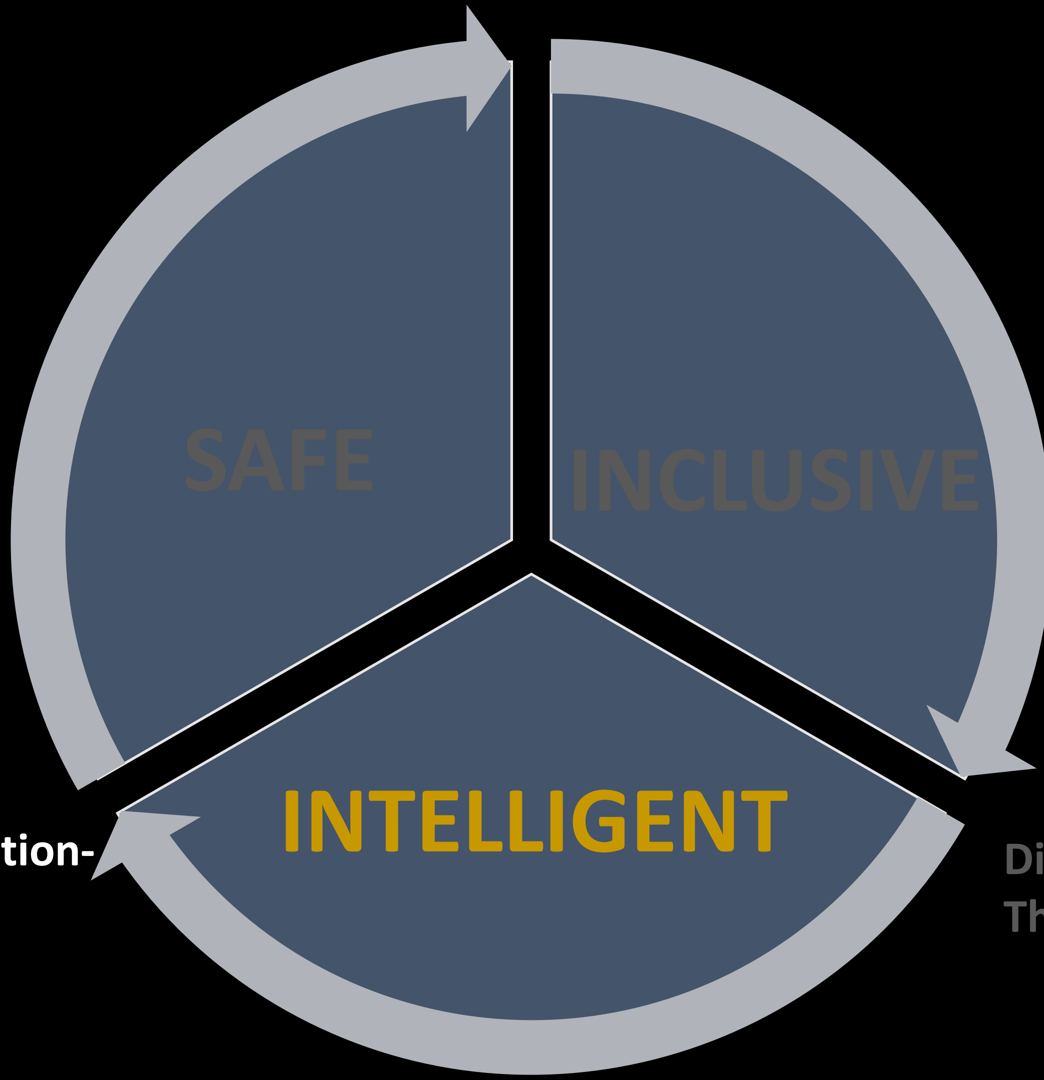
1. Pooladvand, S., Chang, W., Hasanzadeh, S., (2024) "Identify At-Risk Workers Using fNIRS-Based Mental Load Classification: A Mixed Reality (MR) Study", Journal of Automation in Construction, Elsevier.
2. Pooladvand, S., Hasanzadeh, S., (2023), "Impacts of stress on workers' risk-taking behaviors: cognitive tunneling and impaired selective attention", Journal of Construction Engineering and Management. (*Published- Editor's Choice Award*)
3. Pooladvand, S., Hasanzadeh, S., (2022), "A Neurophysiological Method to Evaluate Workers' Decision Dynamics Under Time Pressure and Increased Mental Demand: A fNIRS study in a Mixed-Reality Environment", *Journal of Automation in Construction.*
4. Pooladvand, S., Hasanzadeh, S., "Effects of Heat Stress on Workers' Physical and Mental Fatigue: An XR Simulation of a Roofing Task", Safety Science, Elsevier. *(under-review)*
5. Pooladvand, S., Hasanzadeh, S., "Impacts of Peer Pressure on Workers' Risk-Taking Behaviors; an Extended Reality (XR) Environment", Journal of Management in Engineering. *(under-review)*

Conference Papers

1. Pooladvand, S., Hasanzadeh, S., (2024), "Can Workers' Physical Fatigue Cause Mental Fatigue and Impaired Cognitive Functioning in Physical Demanding Construction Tasks?", CRC 2024.
   Pooladvand, S., Hasanzadeh, S., (2024), "Exploring Peer Influence on Risk Perception and Safety Performance in Collaborative Construction Workplaces ", I3CE 2024.
2. Pooladvand, S., Hasanzadeh, S., (2023), "Social Contagion Effect: Susceptibility to Peer Pressure and Safety Compliance among Construction Workers", I3CE 2023.
3. Pooladvand, S., Kiper, B., Mane, A., Hasanzadeh, S., (2022) "Effect of Time Pressure and Cognitive Demand on Line Workers' Risk-taking Behaviors: Assessment of Neuro-psychophysiological Responses in a Mixed-reality Environment", CRC 2022.
4. Pooladvand, S., Ay, D., Hasanzadeh, S., (2022) "The Neural Basis of Risk Attitude in Decision-Making Under Risk: fNIRS Investigation of the Simulated Electrical Construction Task", ISARC 2022.

Book Chapter

Pooladvand, S., Hasanzadeh, S., Garza, JM., (2024), "Applications of Immersive Technologies in Investigating Construction Workers' Risk-Taking Behaviors and Safety Performance" in Applications of Immersive Technology in Architecture, Engineering, and Construction (AEC), *Taylor & Francis.*



Personalized A-Driven Simulation-Based Safety Training

Digital Twin-Driven Adaptive Thermal Comfort Systems

Digital Twins for 3D Printing

Digital Twins for Smart Workzones

TOWARD AI-INFORMED PERSONALIZED SAFETY TRAINING

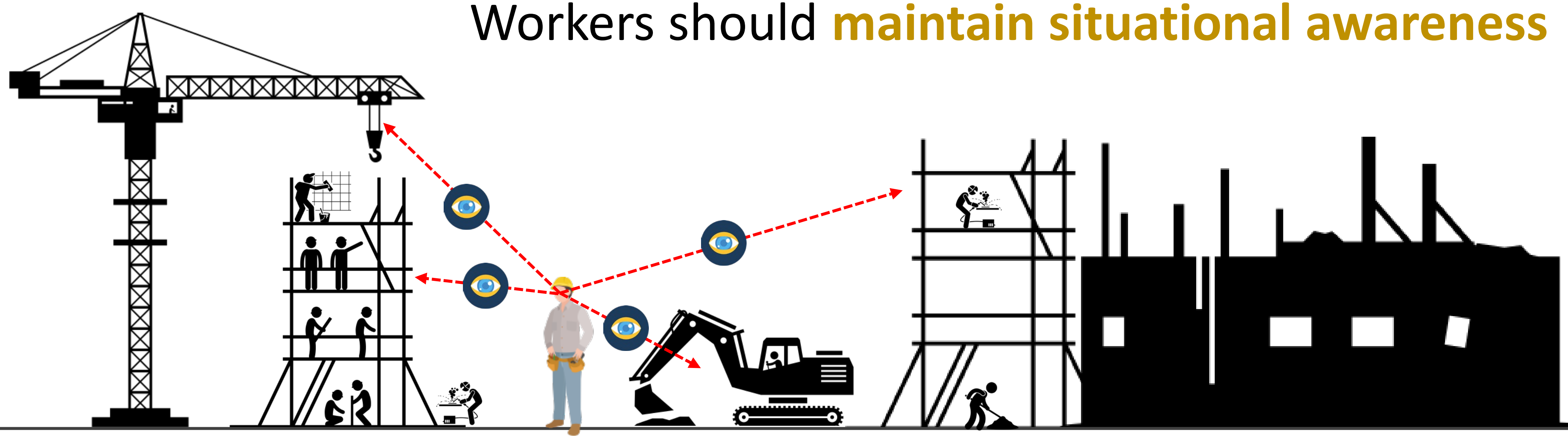
Collaborators:
Behzad Esmaeili
Michael Dodd

Research Background

- **Situational Awareness in Construction Site**
  - **Situational awareness** is demonstrated as the “perception of those elements in the environment within a volume of time and space (Level 1 SA), the comprehension of their meaning (Level 2 SA), and the projection of their status in the near future (Level 3 SA)” *(Endsley 1988, p.97)*

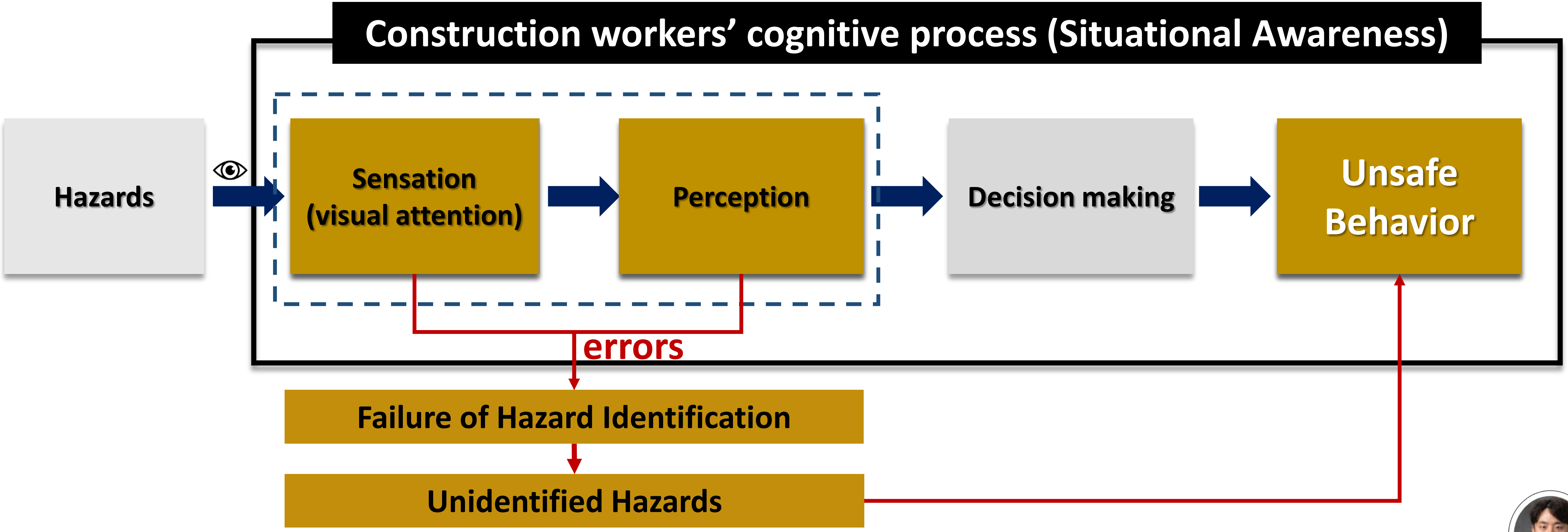
Dynamic and complex construction environment

Workers should **maintain situational awareness**



Research Background

- **Human Error in Situational Awareness**
  - **Skill-based (e.g., attentional failure)** and **perceptual-based (e.g., failure to identify and misperceptions)** errors are the main contributor to accidents *(Garrett and Teizer 2009; Shapperl and Wiegmann 2000; Hasanzadeh et al. 2017)*



Problem Statement

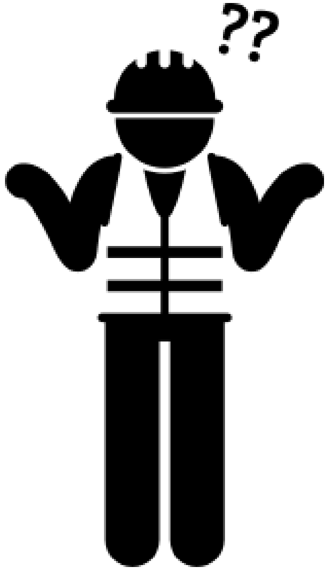
- **Reducing Human Error**
  - The state of the practice suggests that **the most effective strategy** for reducing human error is to increase **the level of protection safeguarding workers**

Legislation — **Safety Training** — **Safety Standards** — **Use of PPE**

Reducing skilled-based and perceptual-based errors

Limitation

Why do workers not achieve a high hazard identification performance as expected after receiving safety training?



Research Gaps

- **True Cognitive failures behind the Failure of Hazard Identification**
  - Researchers indicated that hazard recognition performance is affected by **human factors** such as visual search ability, risk tolerance, and the psycho-physiological state of workers. *(Jeelani et al. 2020)*

Individual factors
- Visual scanning ability
- Safety knowledge level
- Risk tolerance

→

Cognitive failures
- Attentional failure
- Inattentional blindness
- Inappropriate risk perception

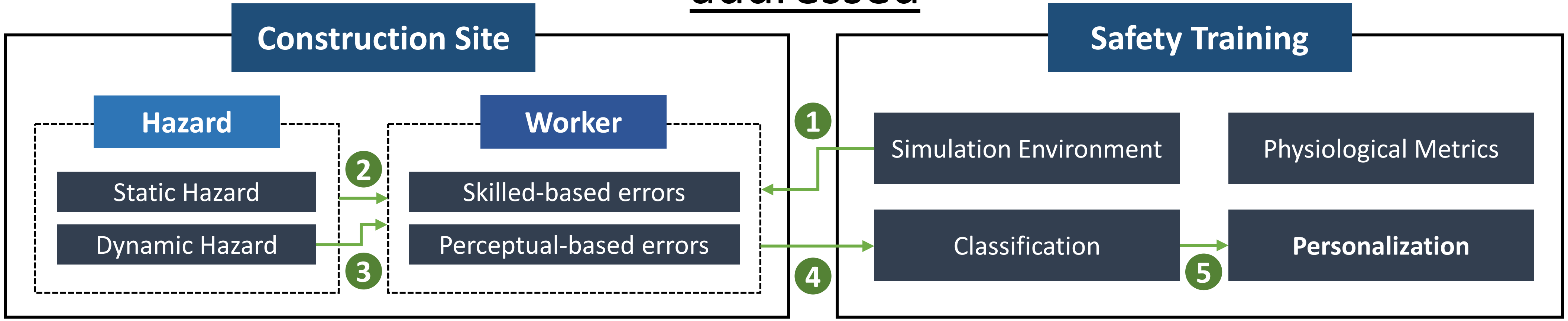
→

Failing to identify Hazards

Safety training must be personalized and comprehensively cover these cognitive failures to be more effective

Overall Goal

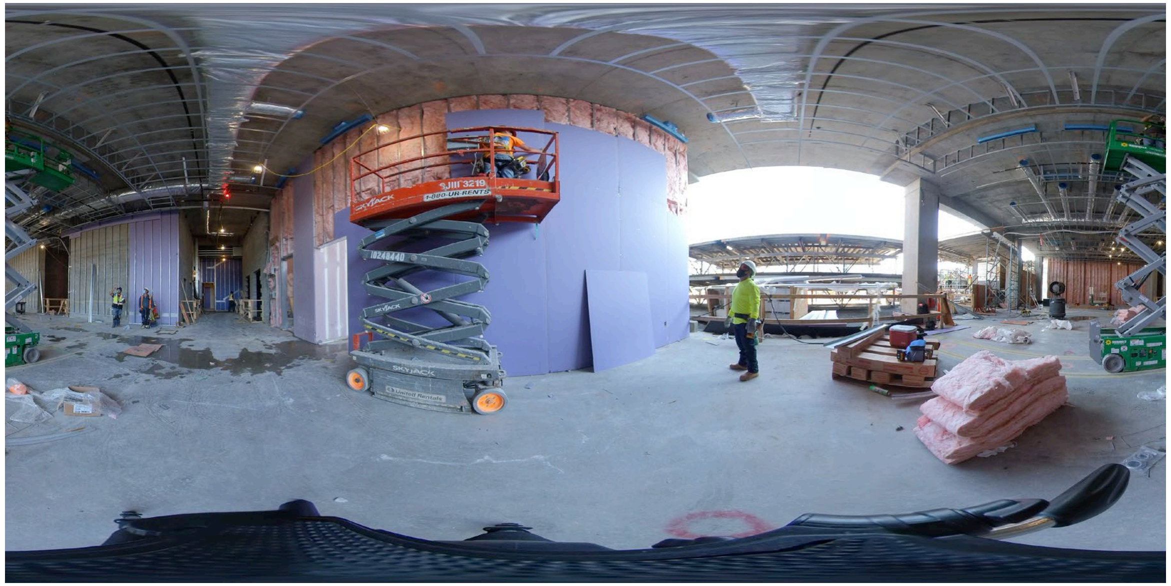
To accomplish the overall goal, <u>the following research gaps needs to be addressed</u>



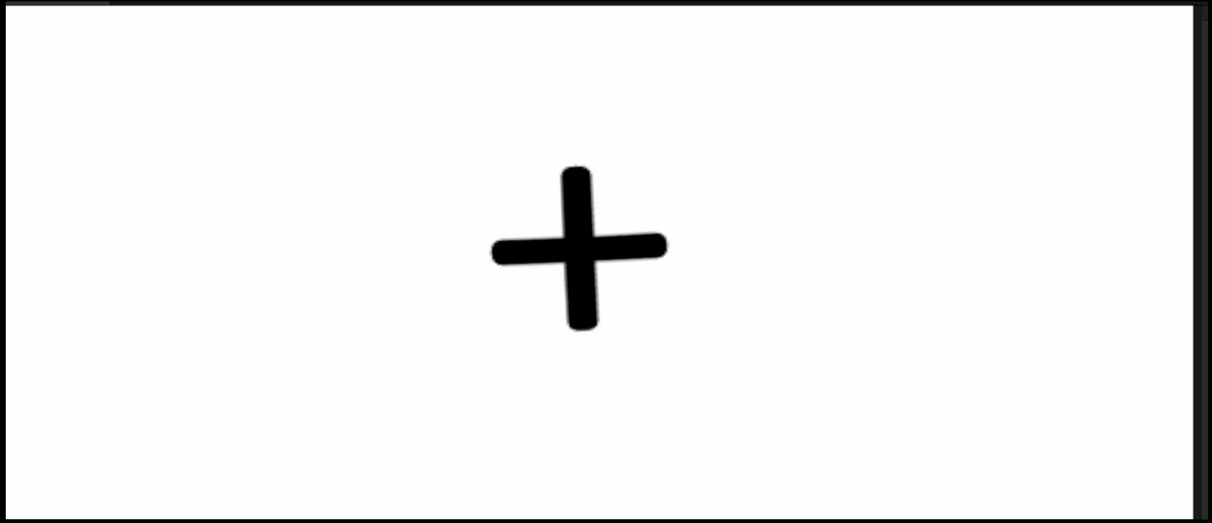
1. *The role of hazard delivery media*
2. *The impact of varied hazard types (i.e., static hazard vs dynamic hazard)*
3. *The impact of a spatial-temporal characteristic of dynamic hazard*
4. *Classification of at-risk workers’ cognitive failure*
5. *Evaluation of training effectiveness*

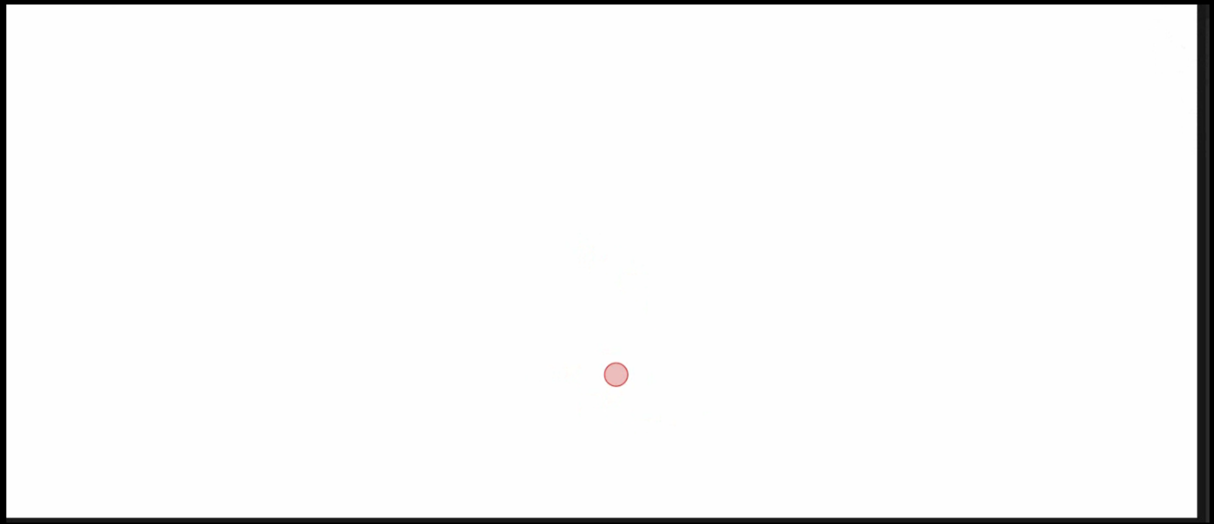
Foundation for developing the personalized safety training

Objective 1



Internal factors (e.g. different abilities of situational awareness)





- Lower situational awareness
- Higher situational awareness

Objective 1

Planning and Experimental Design

Pool of scenario images and videos

Select 23 360-images and videos

Capture, edit, augment, and immerse

Focus group of professional safety managers

Identify potential and active hazards within scenarios

Recruit 30 construction workers from jobsite

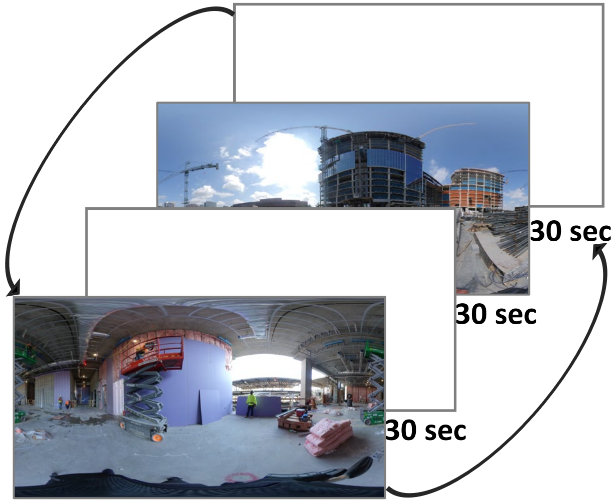
Demographic and psychographic survey

Instruction of whole experimental process

Image-based experiment

Video-based experiment

Cycle continues for all 23 scenarios



30 sec

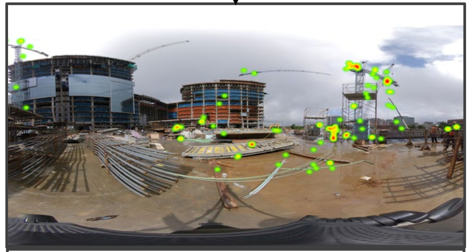
30 sec

30 sec

30 sec

Data Collection and Analysis

Immersion



Embedded Eye-tracking

Number of identified hazards for each scenario

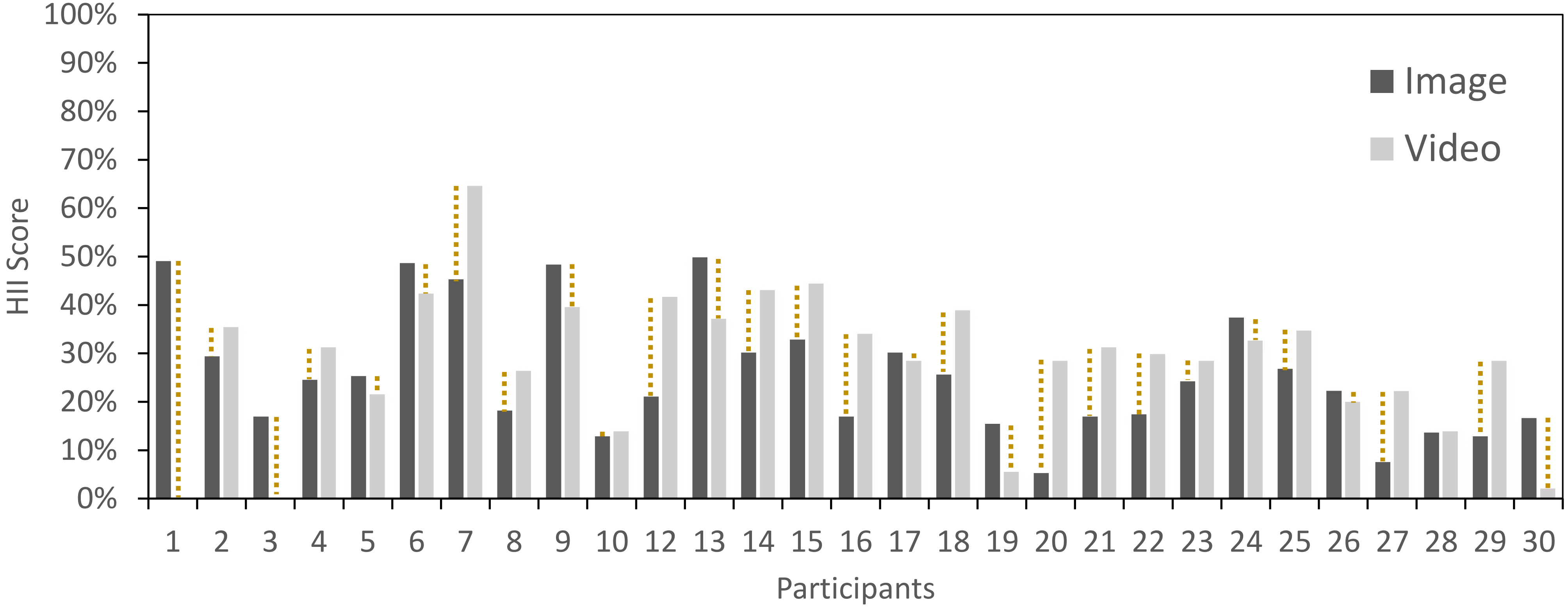
Hazard identification performance (calculate HII)

Visual search strategies

Assess an impact of the hazard delivery methods on worker's hazard identification ability and visual search strategies

Objective 1

- **Difference in hazard identification performance**



Average Hazard Identification Index Score

- Image: **26%**
- Video: **28%**
- Average: **27%**

On average, workers failed to identify 73% of hazards in the construction site

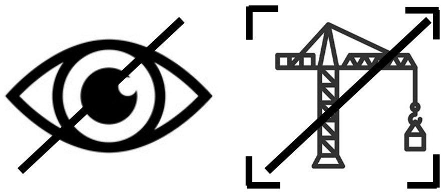
Research Methodology

Construction worker

Hazards → Sensation (visual attention) → Perception → Decision making → Behavior

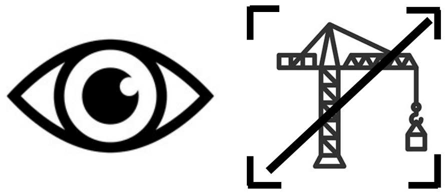
Step 1 (Sensation (visual attention)) · Step 2 (Perception)

Type 1 Cognitive Failure



- Not look hazards
- Not recognize hazard

Type 2 Cognitive Failure

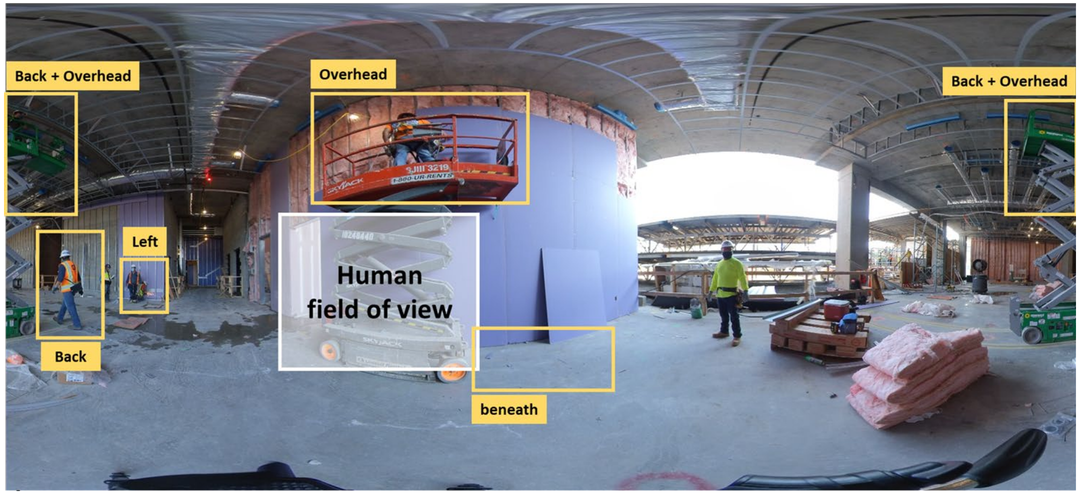


- look hazards
- Not recognize hazard

Research Methodology

- **Characteristics of dynamic hazard**

Spatial characteristic



360-spatial attention abilities → Workers' situational awareness performance

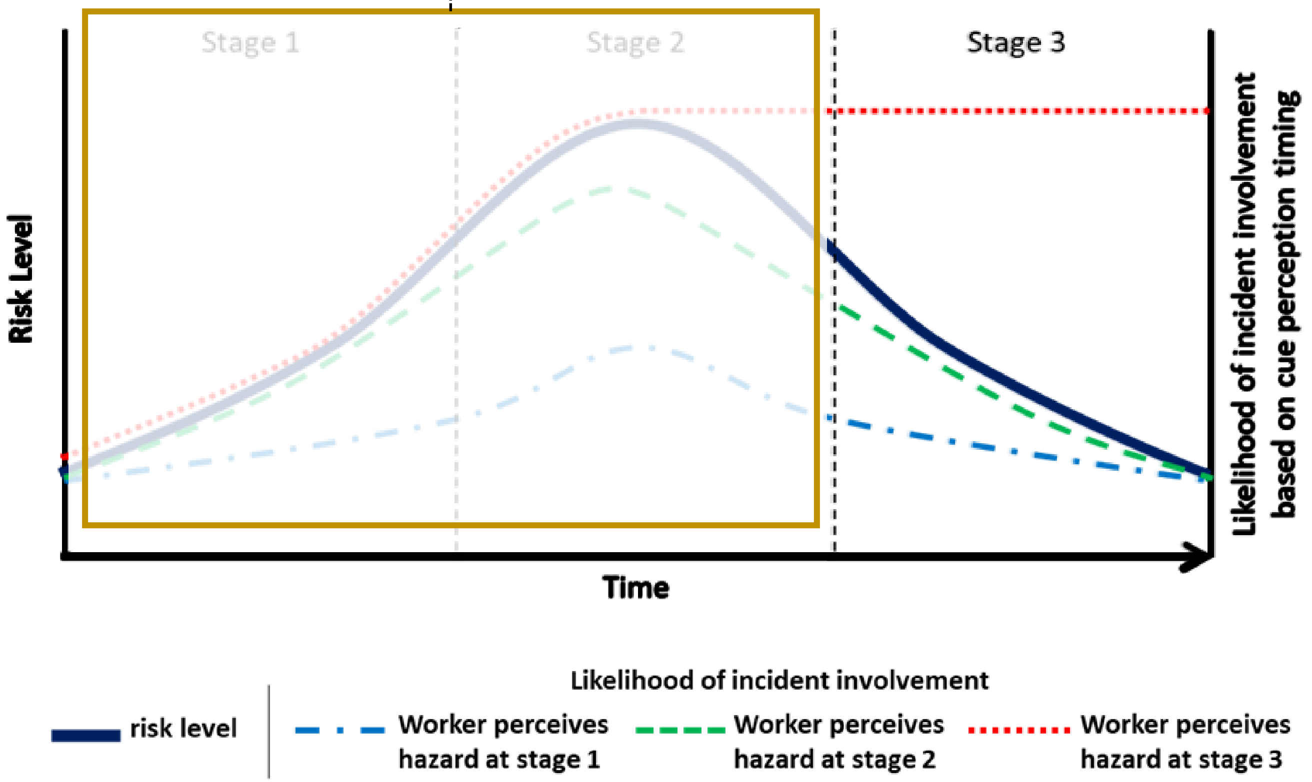
Temporal characteristic

Cue perception timing → Workers' situational awareness performance

Objective 3

- The impact of spatial-temporal characteristic of dynamic hazard

Workers must recognize the hazard and perceive risks in these stages



Schematic representation of overall risk level and the likelihood of incident involvement

Stage 1

- The hazard is not fully activated
- Workers can sense emergent cues signaling an upcoming hazard

Stage 2

- The hazard is fully activated
- Workers can sense active cues signaling an ongoing hazard

Stage 3

- The hazard is deactivated
- Workers can sense vanishing cues signaling a deactivation of hazard

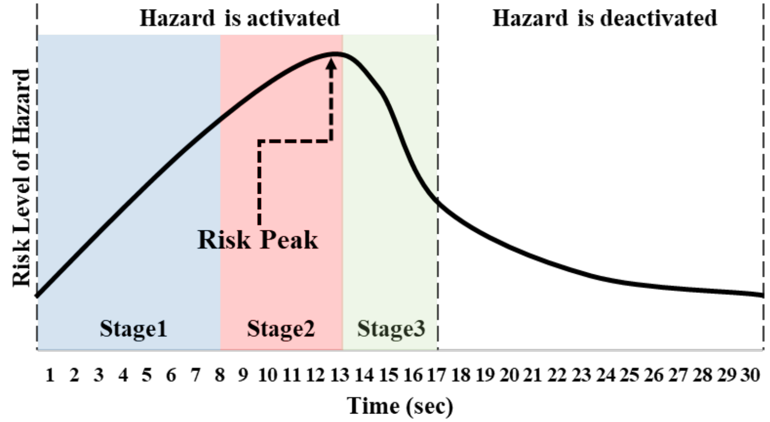
Objective 3

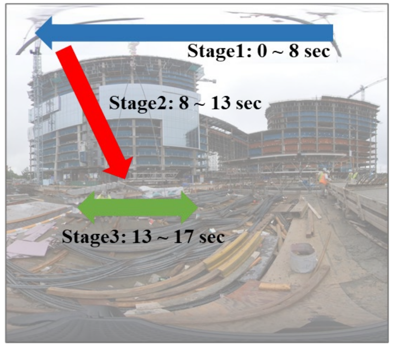
- **The impact of spatial-temporal characteristic of dynamic hazard**

Struck by Hazard (overhead crane operation)

Stage 2

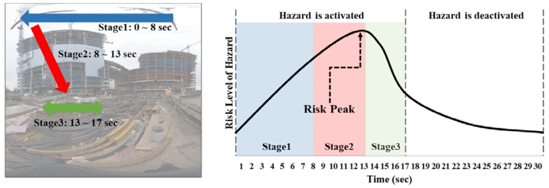
Risk model





Objective 3

- **The impact of spatial-temporal characteristic of dynamic hazard**

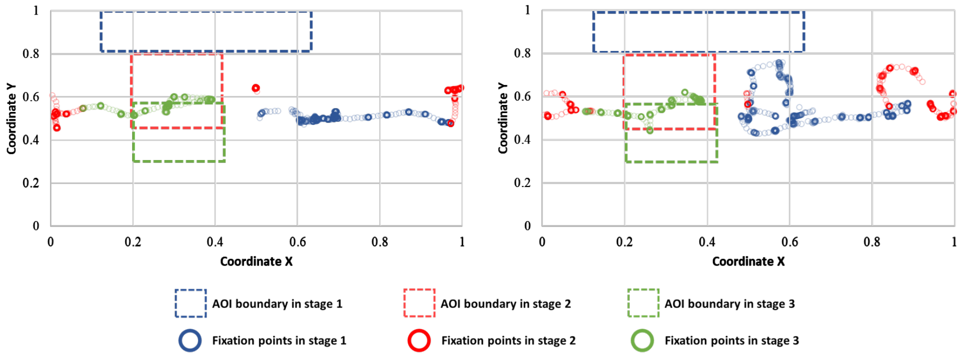


Workers' cue perception timing

Cue perception timing	Scenario 1-*AOI 1* (15 workers identified)			Scenario 2- *AOI 2* (21 workers identified)		
	Stage1	**Stage2**	**Stage3**	**Stage1**	**Stage2**	**Stage3**
Newly attended	4	9	2*	14	7	0*
Attended stage 1 and continued stage 2	-	4	-	-	13	-
Attended stage 2 and continued stage 3	-	-	11	-	-	13
Attended stages 1 and 3	-	-	0	-	-	1
Total	4	13	13	14	20	14
Looked all stages		3			9	

Numbers in the table represent the number of workers within each group
*Number of workers who experienced late anticipation

Late anticipation

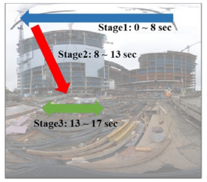


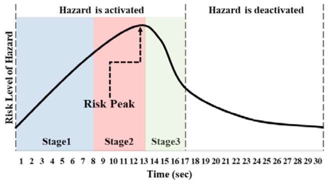
The problem embedded in binary hazard identification assessment (identified/missed)

Highlight the importance of timely hazard identification

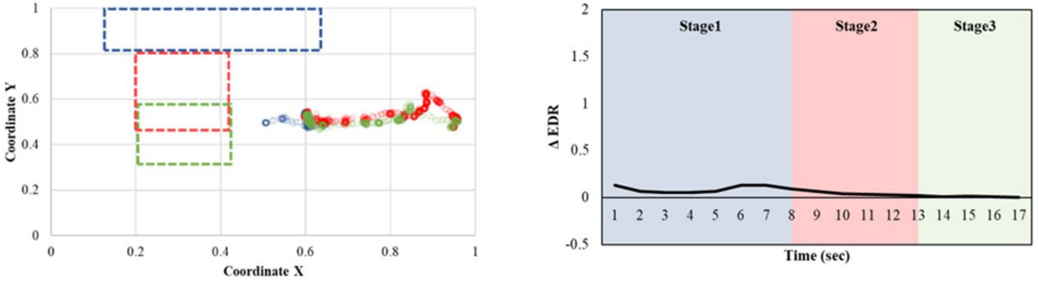
Objective 3

- **The impact of spatial-temporal characteristic of dynamic hazard**

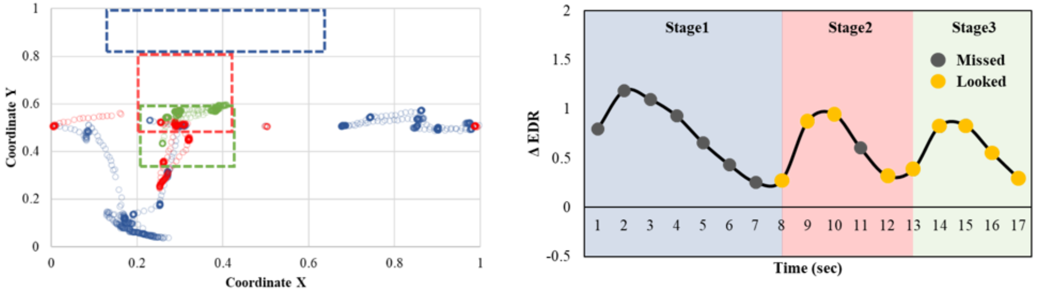




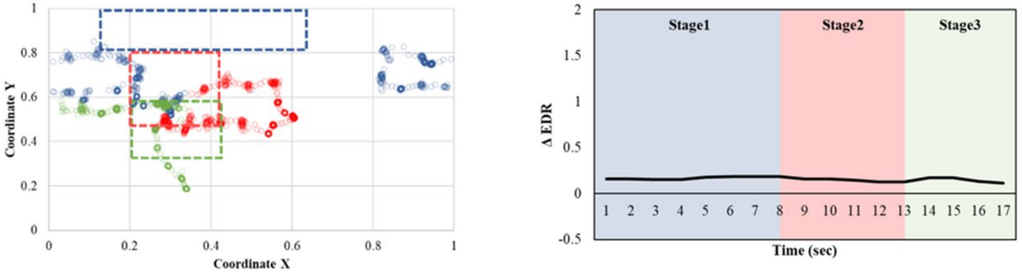
Attentional failure

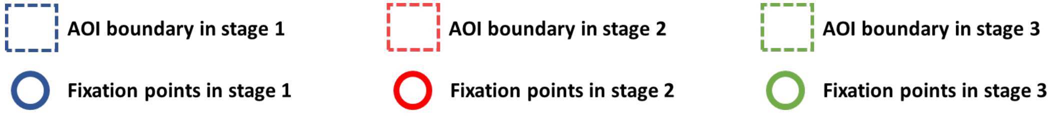


Low risk perception



Inattentional blindness

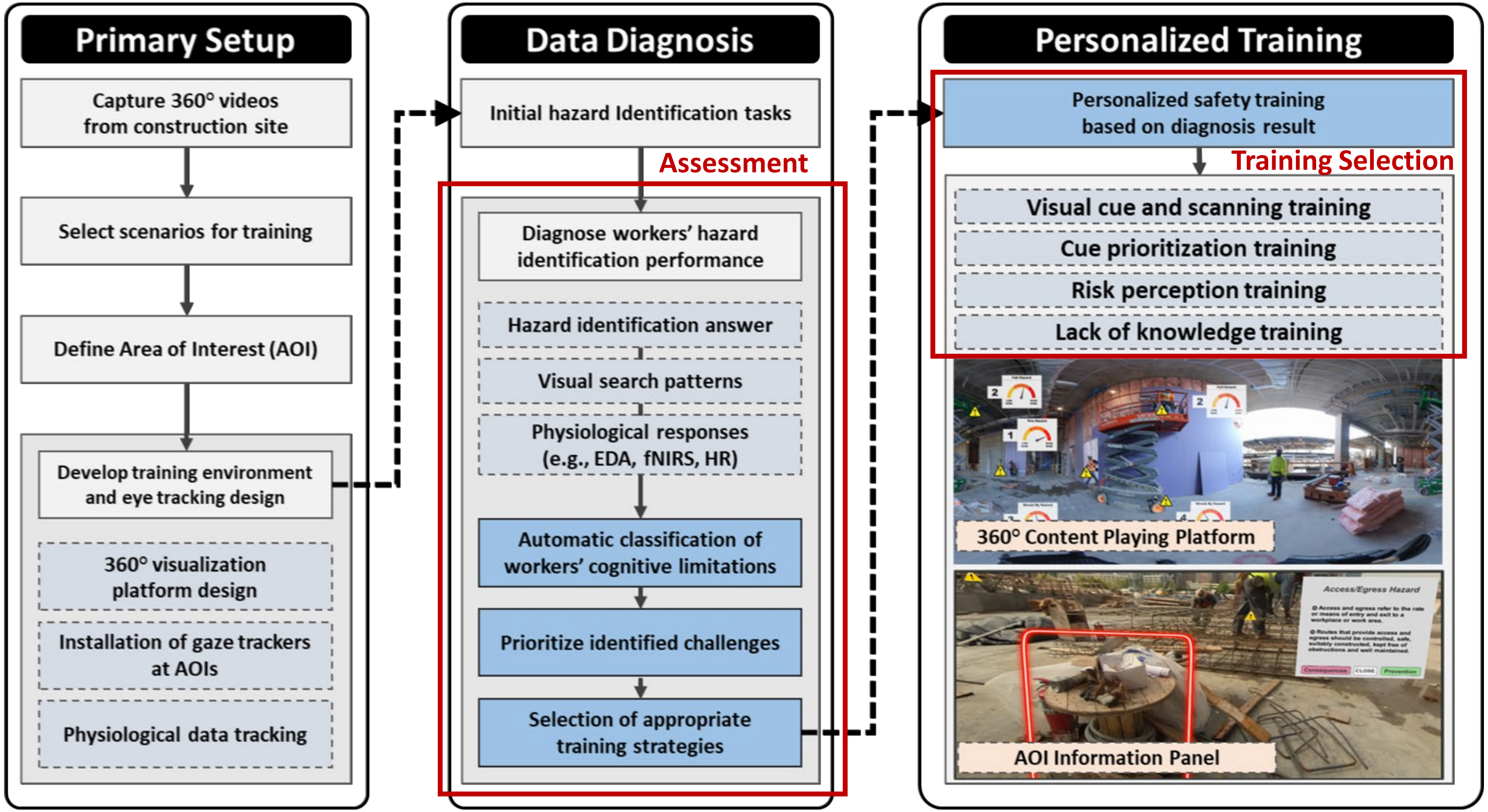




Classification of three key cognitive failures by combining multi-modal datasets

Training Development

- **Framework of the proposed safety training**



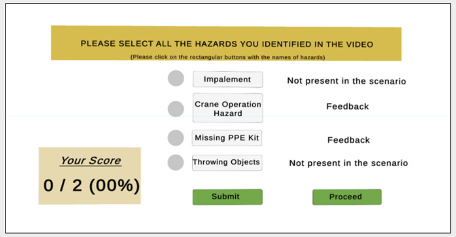
A Windows application incorporating with HTC Vive headset with embedded eye-tracking capability and an Empatica E4 medical wristband

Training Development

- **AI system embedded in the personalized training**

Assessment and training selection

Multi-modal data collection and preprocessing



Hazard identification task → Hazard identification quiz

Monitoring attentional distribution → Fixation on AOIs

Monitoring physiological response (EDA) → EDA decomposition

Extracted Dataset for the classification of cognitive status

Quiz results
(*identified vs missed*)

Visual search pattern
(*looked at each hazard in the scenario or not*)

ΔEDR
(*perceived risk of observed hazard or not*)

→

Classification of cognitive failures

↓

Personalized safety intervention based on classification results

Training Development

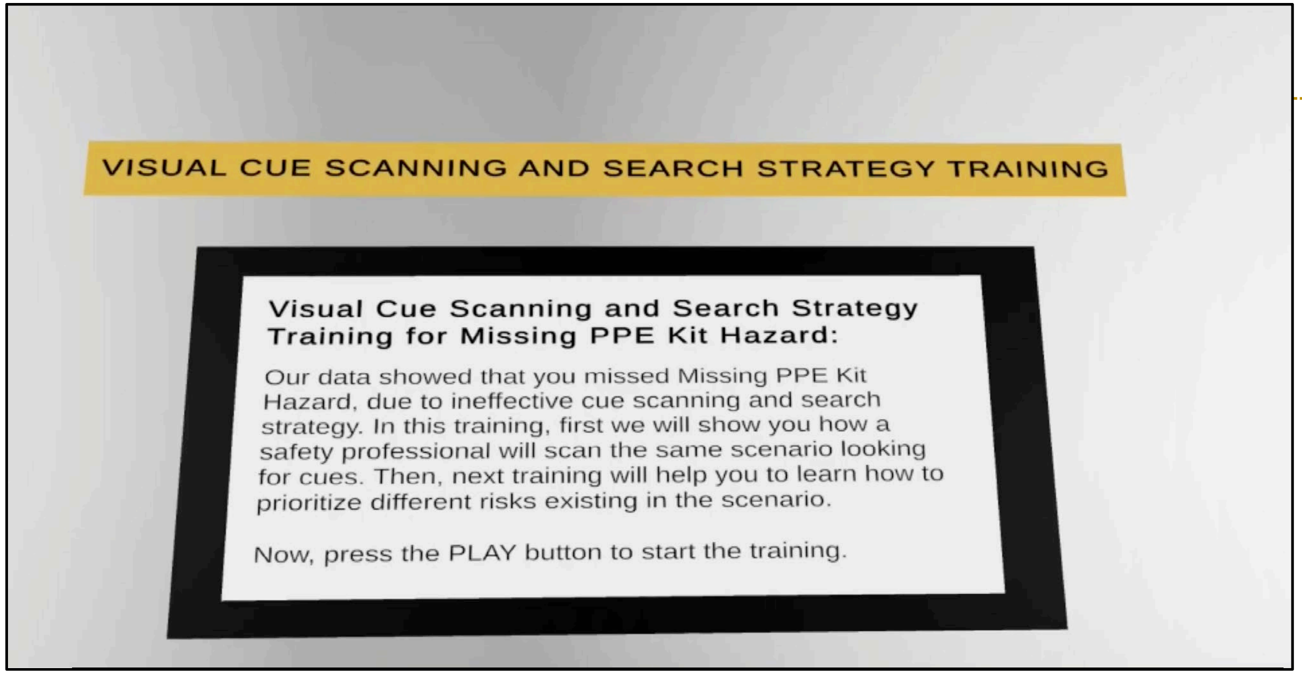
- **Cognitive failures and classification mechanisms**

Visual attention	Physiological reaction	Subjective report	Cognitive Status
No	No	Miss	**Attentional failure** (*i.e., when hazard is not viewed and not identified*)
Yes	No	Miss	**Inattentional blindness** (*i.e., when hazard is viewed and not identified + the risk of hazard is not perceived*)
Yes	Yes	Miss	**Low-risk perception/High-risk tolerance** (*i.e., when a hazard is viewed and not identified + the perceived risk associated with the hazard is below the individual's risk tolerance*)
Yes	Yes	Identify	**Correct hazard identification** (*i.e., when hazard is viewed and identified + the risk of hazard is perceived*)
No	No	Identify	**You got lucky** (*i.e., when hazard is not viewed and but reported as identified*)
Yes	No	Identify	**Inappropriate risk perception** (*i.e., when a hazard is viewed, but the risk of hazard is not properly perceived*)

Classification of key cognitive failures by combining multi-modal datasets

Training Development

- **Cognitive failures and recommended interventions**

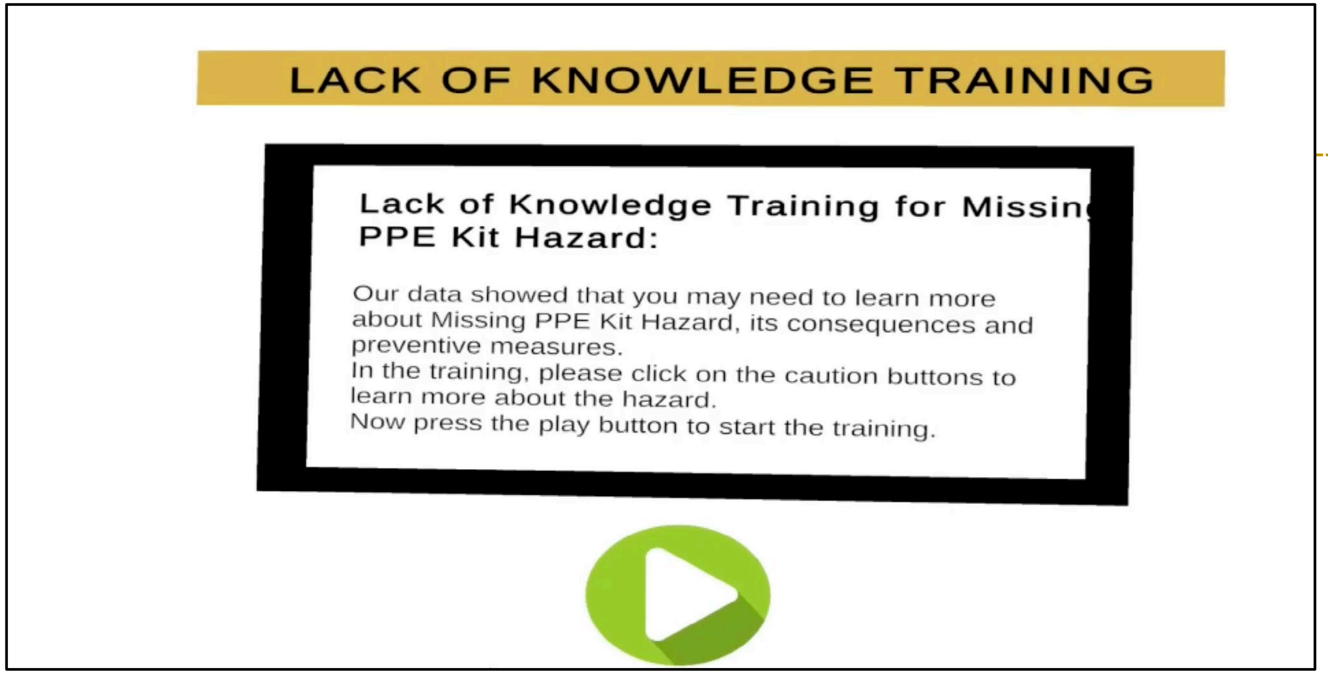


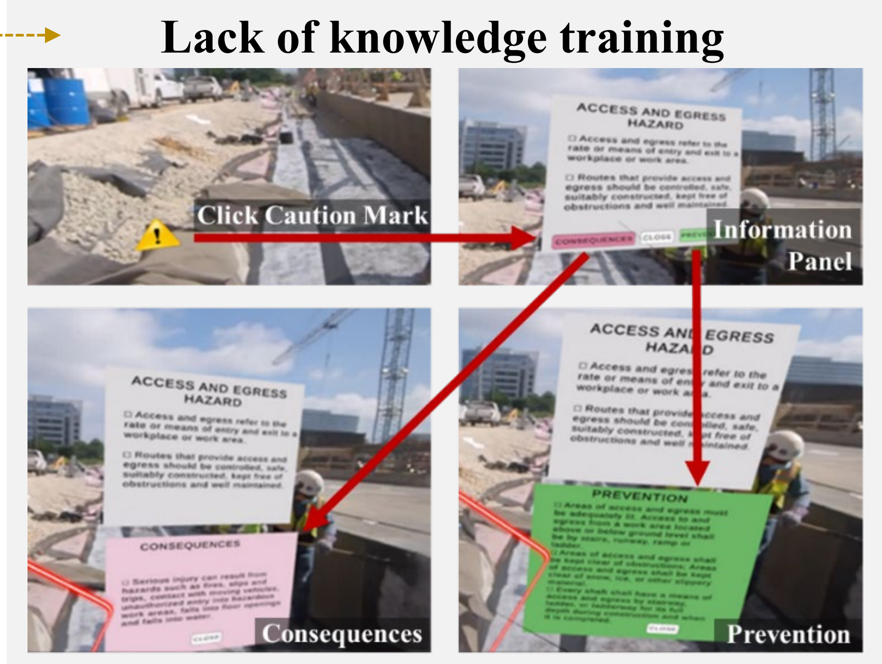
Visual search strategy training

Aiming to enhance workers' fundamental visual scanning abilities by showing an expert's visual search patterns

Training Development

- **Cognitive failures and recommended interventions**

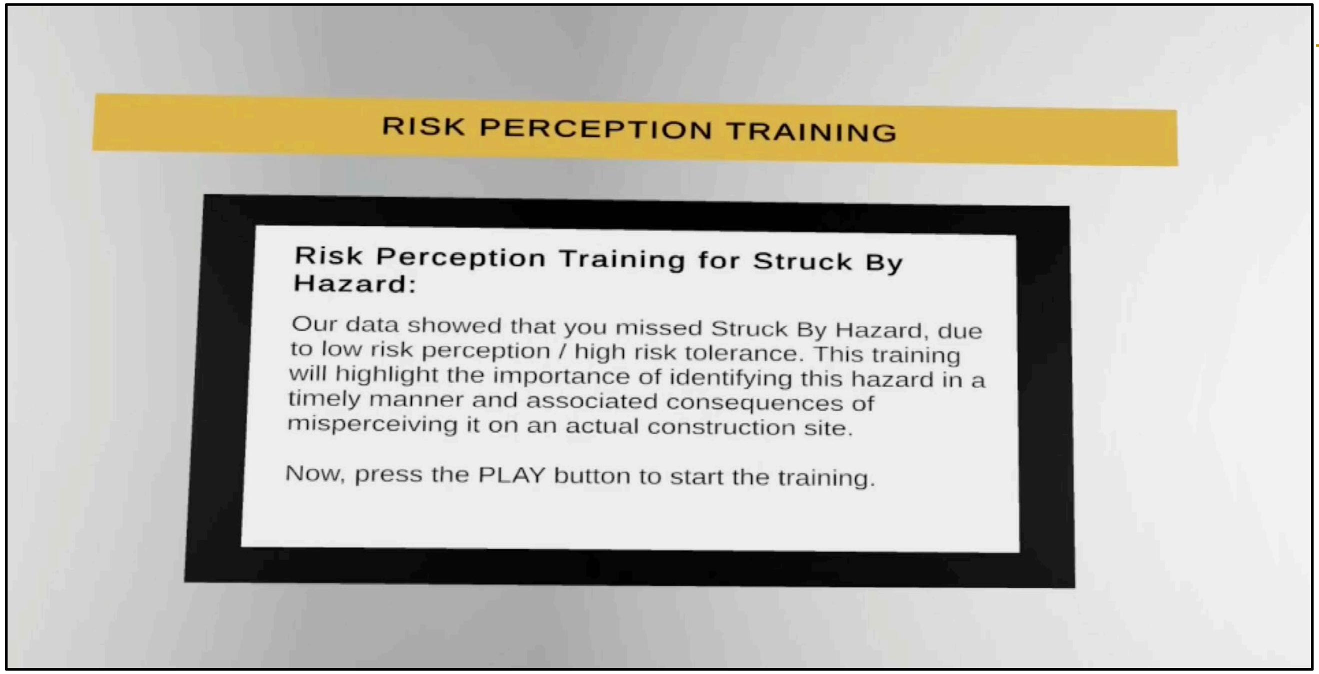




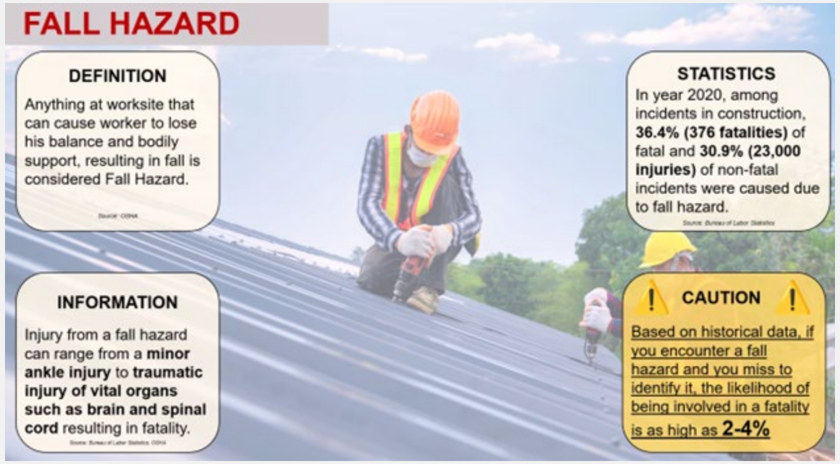
Aiming to enhance workers' safety knowledge by providing relevant information regarding different hazards

Training Development

- **Cognitive failures and recommended interventions**



Risk perception training



Aiming to enhance workers' perceived risk level by illustrating the severity of potential consequence of various hazard types

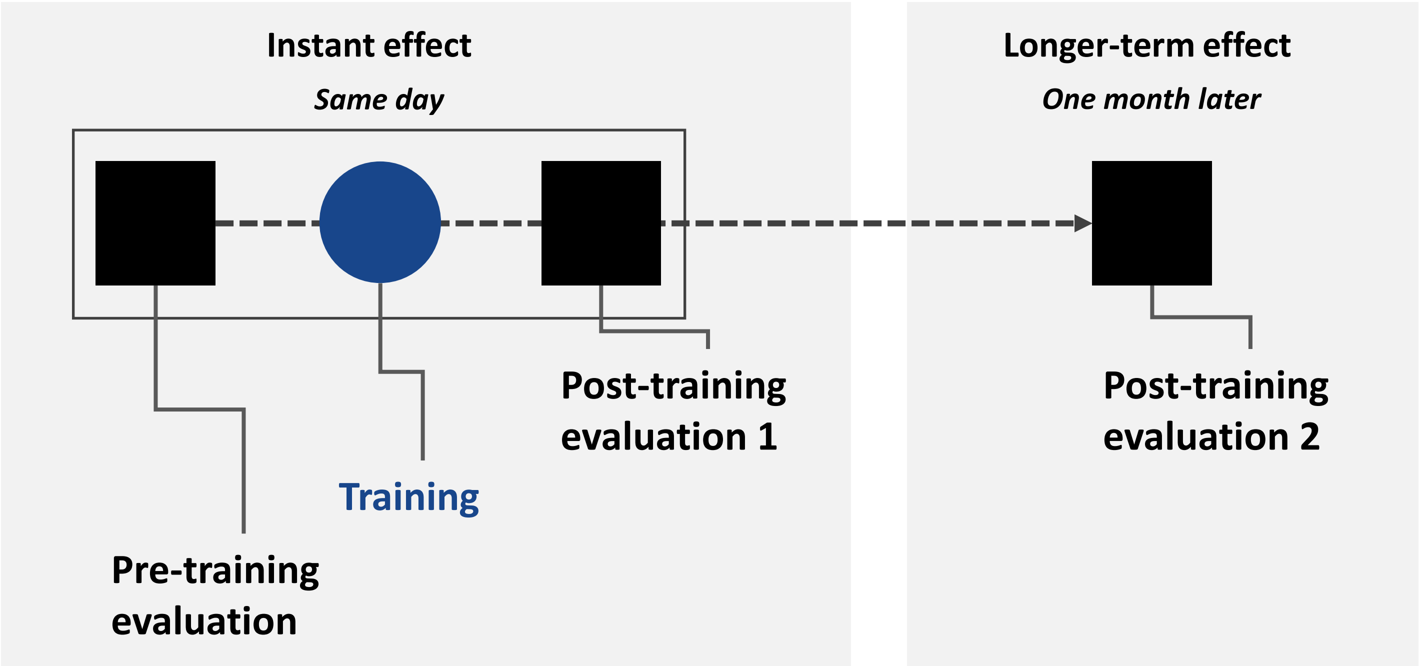
Validation

- **Research Task**

  Examine the immediate and longer-term effectiveness of the proposed personalized safety training

- **Research Framework diagram**

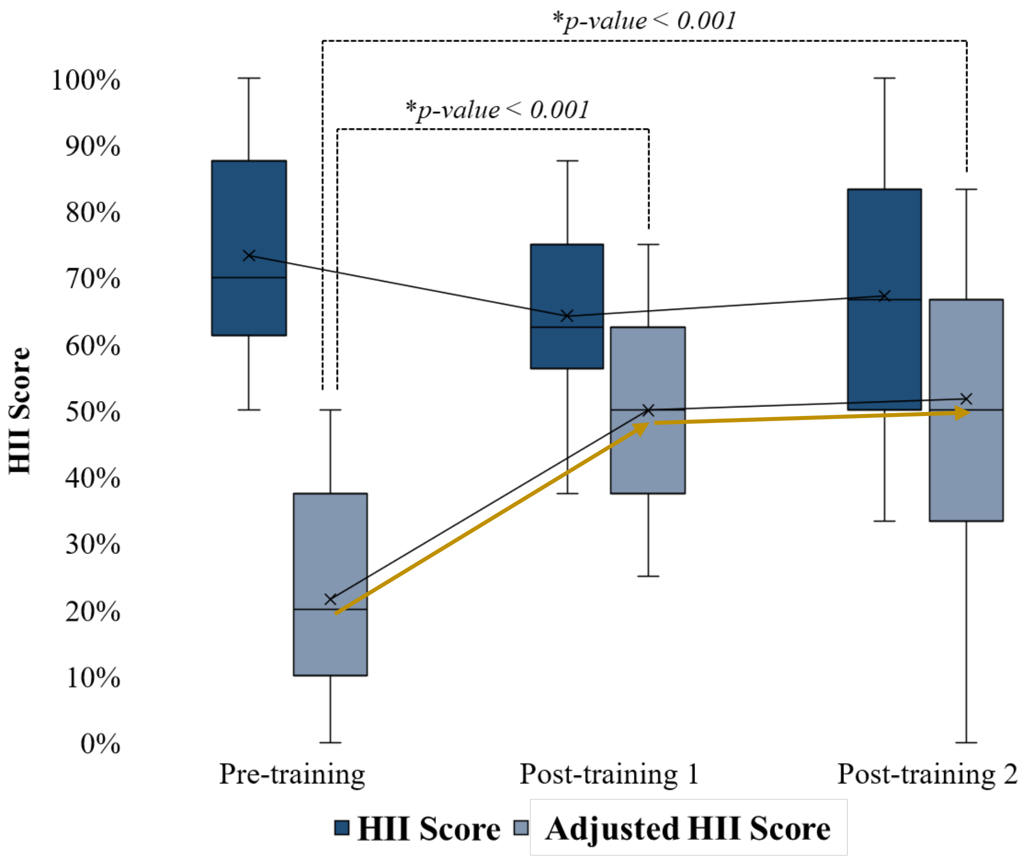
Validation Process



Assessment criteria

1. Hazard recognition performance
2. Visual scanning ability (i.e., 360 spatial attention)
3. Reduction of cognitive failures
4. Neural dynamics

- **Improvement in hazard Identification performance**

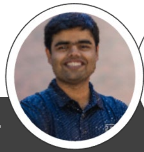


Original HII score:
The ratio of identified hazards to the total number of hazards

vs.

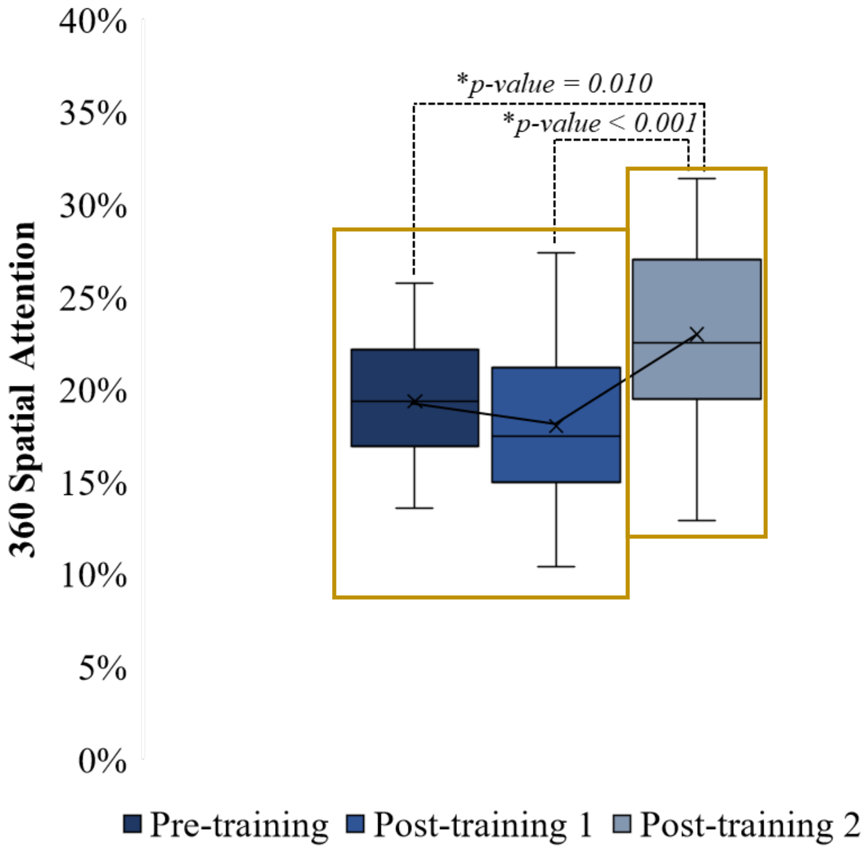
Adjusted HII score:
The ratio of identified hazards (***excluding improper identification***) to the total number of hazards

Adjusted hazard identification scores were significantly increased in post-training sessions



Objective 5

- **Improvement in visual search strategies**



Subjects showed slightly lower 360 spatial attention abilities in Post-training session 1

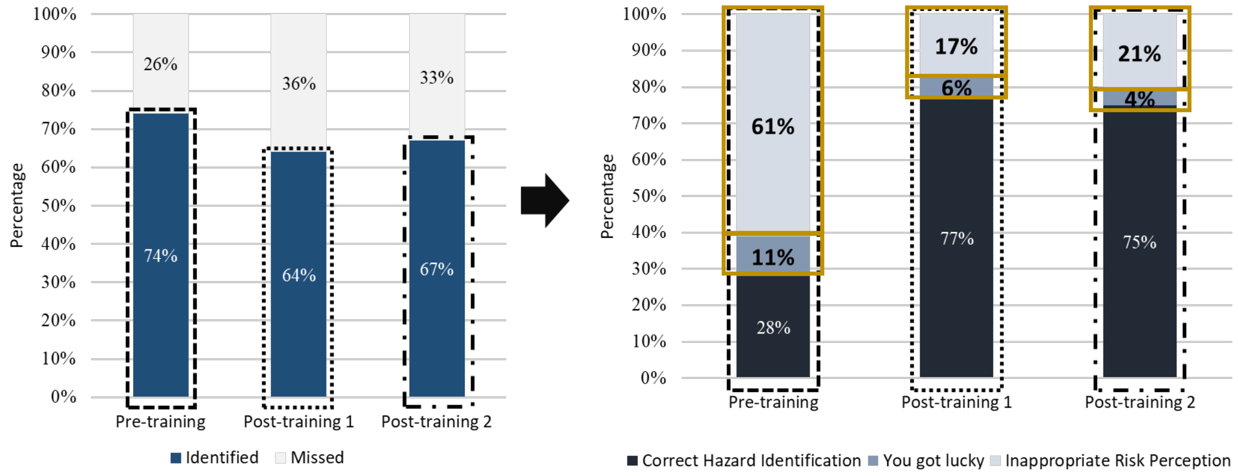
Virtual reality fatigue* *from experimental design

Participants' 360 spatial attention abilities were remarkably improved in Post-training session 2 (*Improvement in visual search skills*)

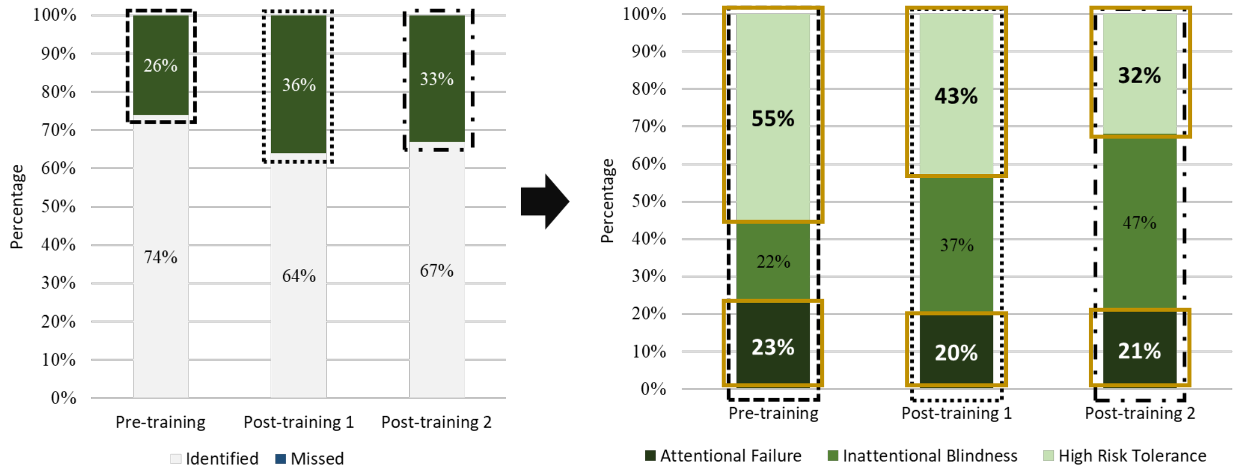
Objective 5

- **Reduction of cognitive failures and improper identification**

Identified Hazards



Missed Hazards



Perceptual-based errors were <u>significantly</u> reduced in post-training sessions

Skill-based errors were <u>marginally</u> reduced in post-training sessions

Knowledge acquisition **VS.** ***Skill development***

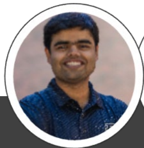
Require repeated training

Takeaways

- The proposed personalized safety training was successful in enhancing not only the **participants' safety knowledge** but also **their visual scanning strategies**.
- Workers need to take **repeated training** to properly improve their visual scanning abilities.

Contributions

- Provide actionable insights into **the development and validation of personalized safety training strategies**.
- Highlight **the importance of understanding root causes of missed hazards** to effectively improve workers' hazard identification capabilities.
- Demonstrate **the significance of integrating interdisciplinary knowledge** to address safety issues in construction industry.



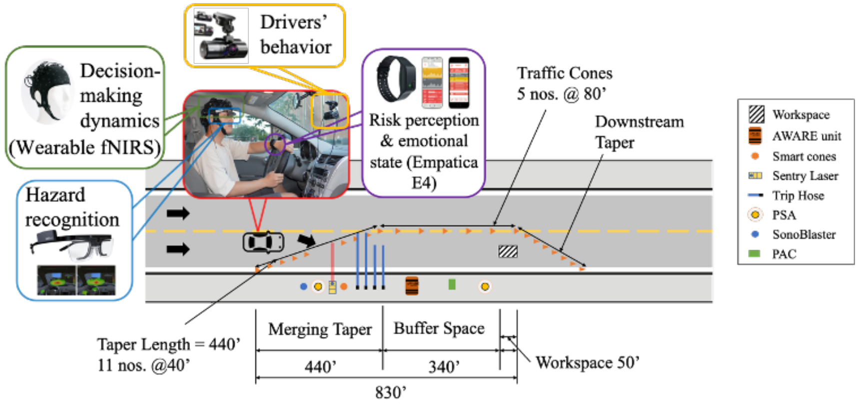

TOWARD AI-INFORMED PERSONALIZED SAFETY TRAINING

- Lee, K., Hasanzadeh, S., and Esmaeili, B. (2022). "Assessing Hazard Anticipation in Dynamic Construction Environments Using Multimodal 360-Degree Panoramas Videos". Journal of Management in Engineering. Sep;38(5):1–16. *DOI: 10.1061/(ASCE)ME.1943-5479.0001069.*
- Lee, K., & Hasanzadeh, S. (2024) "Understanding Cognitive Anticipatory Process in Dynamic Hazard Anticipation Using Multi-modal Psychophysiological Responses". Journal of Construction Engineering and Management. *DOI: 10.1061/JCEMD4/COENG-13896.*
- Lee, K., Pooladvand, S., & Hasanzadeh, S. (2024) "Understanding of Construction Worker's Risk Perception Using Neurophysiological Responses". Journal of Computing in Civil Engineering. *DOI:* 10.1061/JCCEE5.CPENG-5906
- Lee, K., Shinde, Y., Esmaeili, B., & Hasanzadeh, S. (Under-Review) "Multimodal AI-driven Personalized Safety Training for Improving Construction Workers' Hazard Identification: Development and Validation". Automation in Construction
- Lee, K., Hasanzadeh, S., and Esmaeili, B. (2022). "Spatial Exposure to Dynamic Safety Hazards in Construction Sites Through 360-Degree Augmented Panoramas: Ecological Validity in Safety Research". Construction Research Congress 2022. American Society of Civil Engineers, Reston, VA, 715–725. *DOI: 10.1061/9780784483985.073*
- Lee, K., Shinde, Y., Hasanzadeh, S., and Esmaeili, B. (2022). "Toward Personalized Safety Training: Automating the Classification of Construction Workers' Cognitive Failures". International Symposium on Automation and Robotics in Construction (ISARC). Bogota, Colombia. *DOI: 10.22260/ISARC2022/0038*
- Lee, K., Shinde, Y., and Hasanzadeh, S (2023). "Developing a novel computational assessment metric for construction workers' 360-degree spatial attention ability". International Conference on Computing in Civil Engineering. American Society of Civil Engineers, Corballis, OR. *DOI: 10.1061/9780784485248.072*

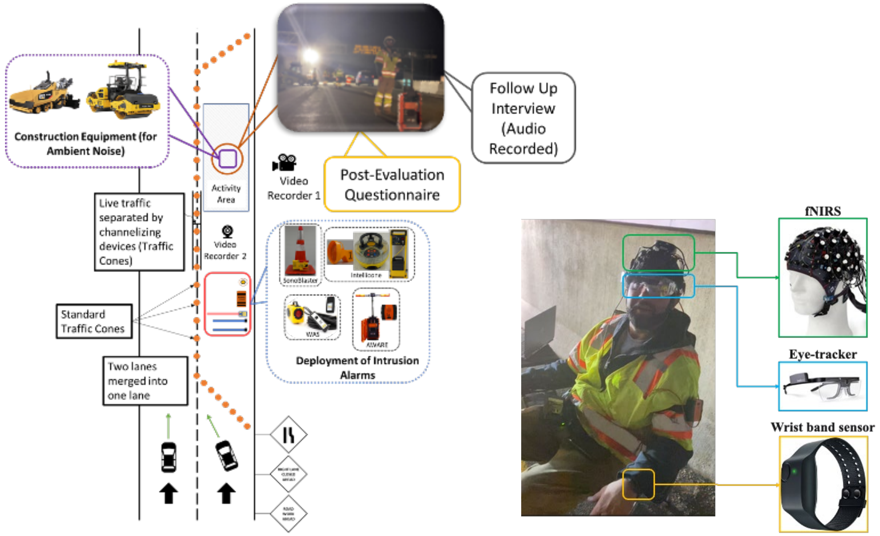

SMART INTERGRATED WORKZONE

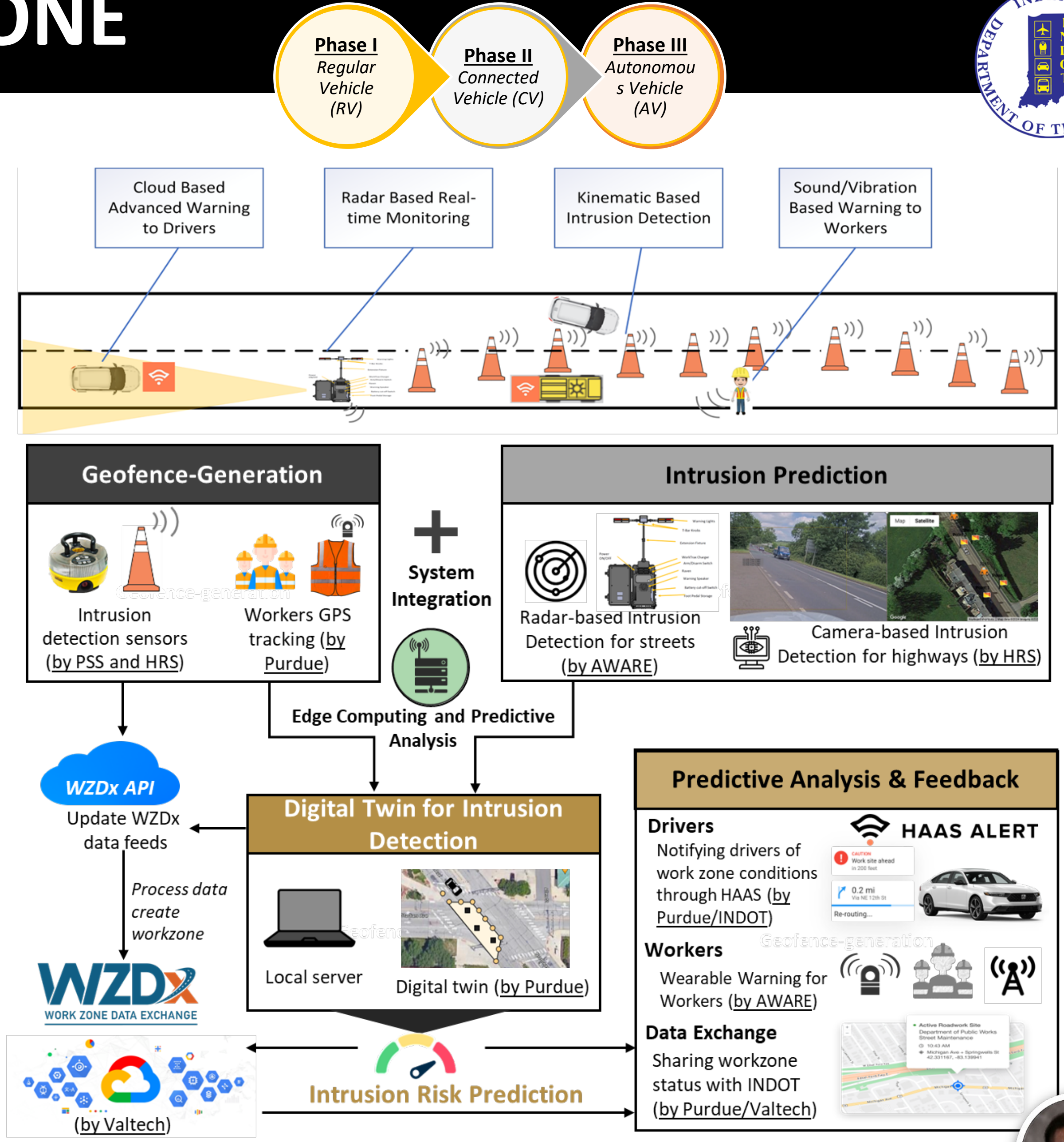
Enhancing Work Zone Safety in through Digital Twin and Sensor Integration

Drivers' behaviors



Workers' behaviors





Human-AI Teaming in Construction

Experiential Learning in Smart Construction Education

WORKER-AI TEAMING TO ENHANCE INCLUSIVITY IN THE CONSTRUCTION INDUSTRY OF THE FUTURE

Collaborators:

Sarah Karalunas
Behzad Esmaeili
Vincent Duffy
Craig Yu
Brenda Bannan
Maurice Kugler

Research Background

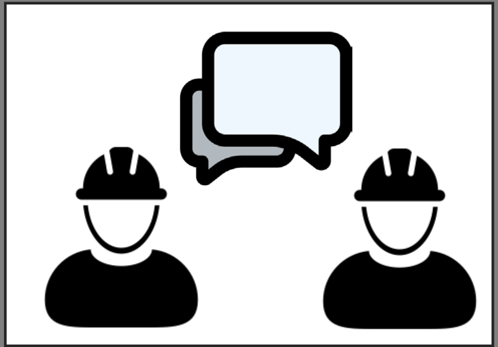
Critical Components of Successful Worker-Worker Teaming

Trust-building

Trust has been discerned as an essential element in any successful relationships

+

Communication



Worker-worker teaming necessitates seamless and comfortable communication

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Safety Management

Workers should maintain situationally aware of hazards to ensure safety

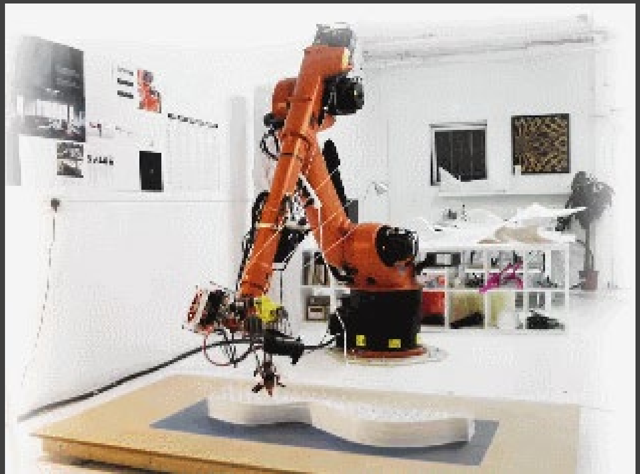
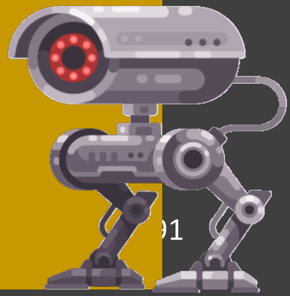
Robotics in Construction

- The application of robotics to construction has yet to catch up with other industries
- Construction presents a unique challenge for robotic applications



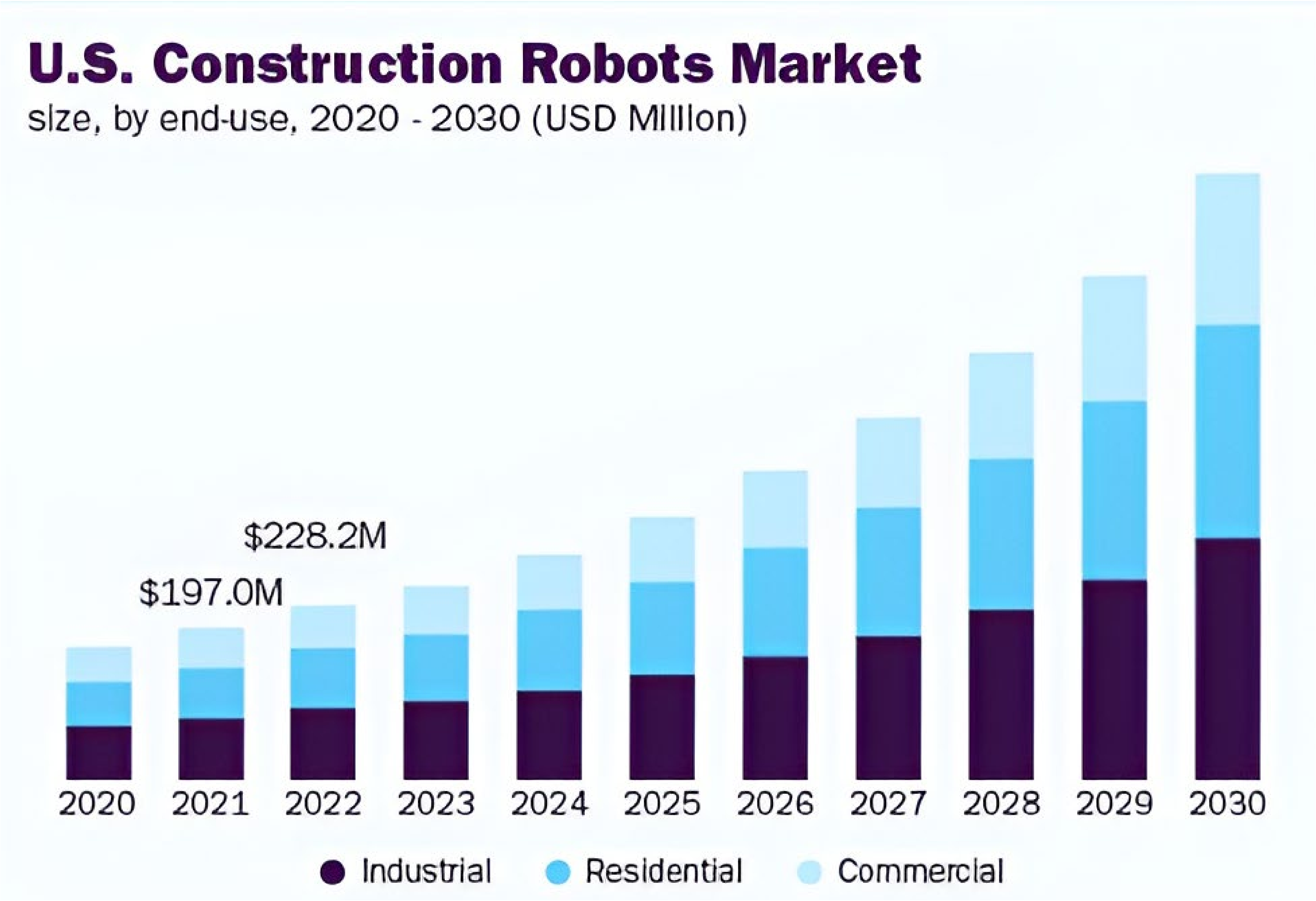




Research Background

Uptrend in Construction Robotics



https://market.us/report/construction-robot-m

Will workers still exist on future construction sites?

Research Background

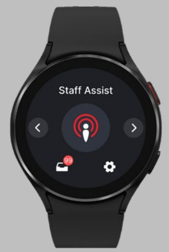
The Envisioned Future Construction Workplaces

Future construction sites

Robotic dog

Drones

Autonomous vehicles



AI-based devices

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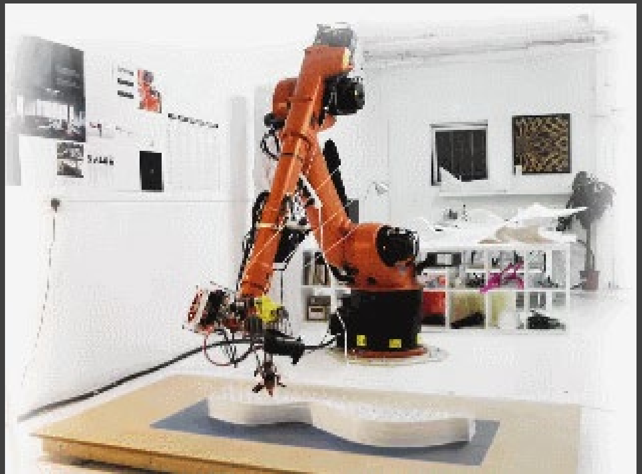
Autonomous technology **(AI)** [1]

Workers [2]

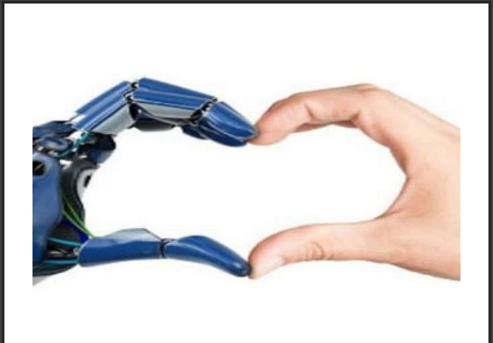
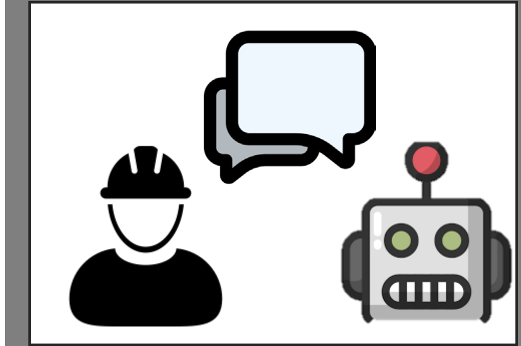
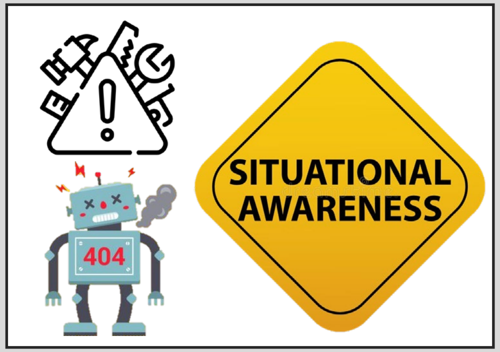
Robotics in Construction

- The application of robotics to construction has yet to catch up with other industries
- Construction presents a unique challenge for robotic applications



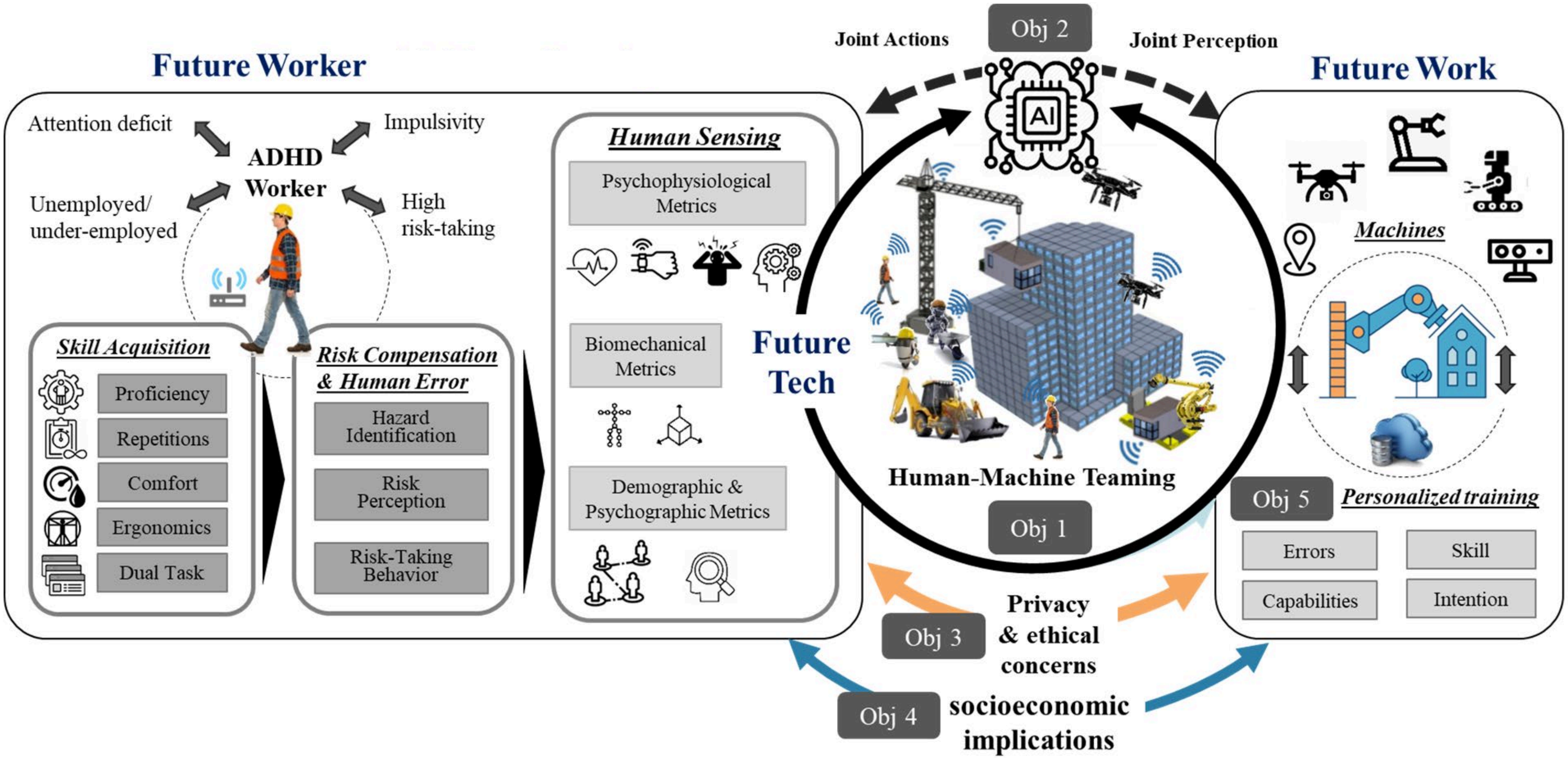
Research Background

Critical Components of Successful Worker-AI Teaming

Trust-building	Communication	Safety Management
		
Trust has been discerned as an essential element in any successful relationships	Worker-**autonomy** teaming necessitates seamless and comfortable communication	Workers should maintain situationally aware of **autonomy** to ensure safety

=> Ensuring **successful worker-AI teaming** in future construction is important.

Point of Departure



Methodology

A Mixed-reality Bricklaying Experiment

Autonomy Agents

Bricklaying Robot

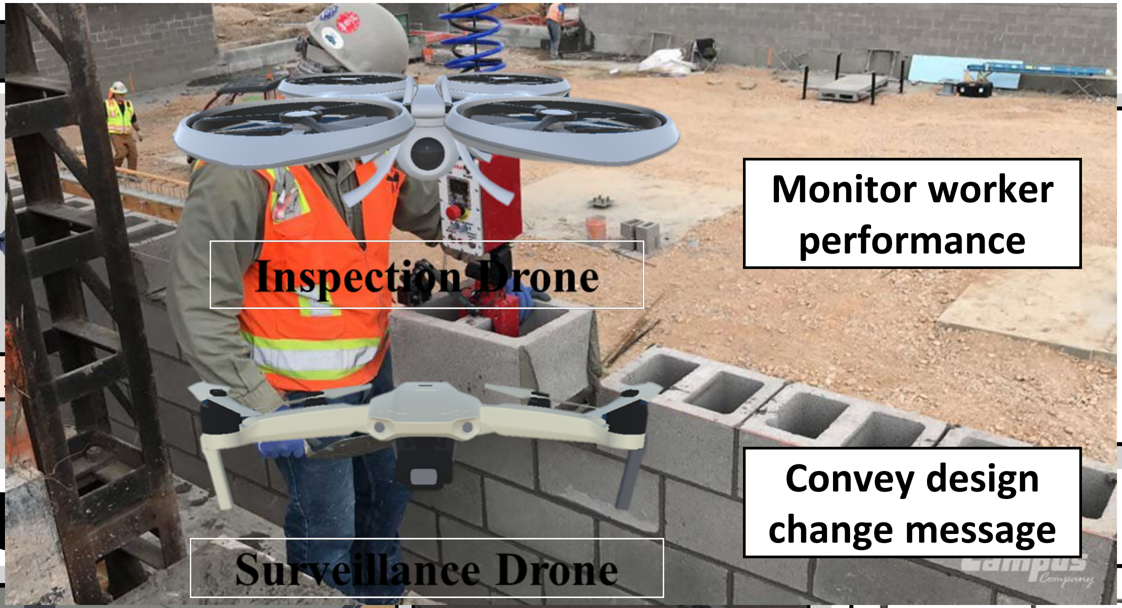
(lift/drop blocks)

Drones

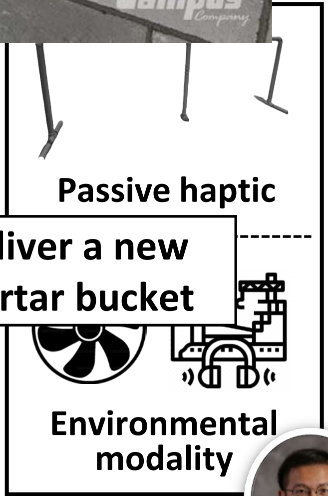
(inspection, survey, delivery)

AI-assistant

(provide drone info.)



Synchronization



Different Modules

1 Baseline
↕
2 Error
↕
3 No AI-assistant
↕
4 Time Pressure
↕
5 Memory Load

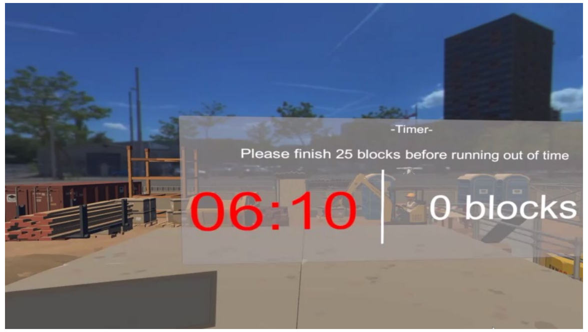
⟷ *Counter-balanced*

2. Error module

This module involves **system failures** of drone and AI-assistant. Workers must maintain **situational awareness**.

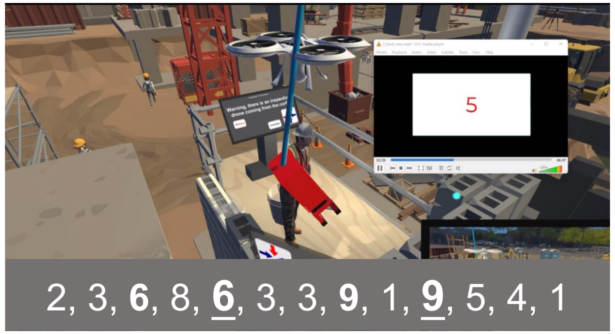
3. No AI-assistant

The AI-assistant is excluded in this module to examine its effectiveness to inform workers of the interruptions.



4. Time Pressure

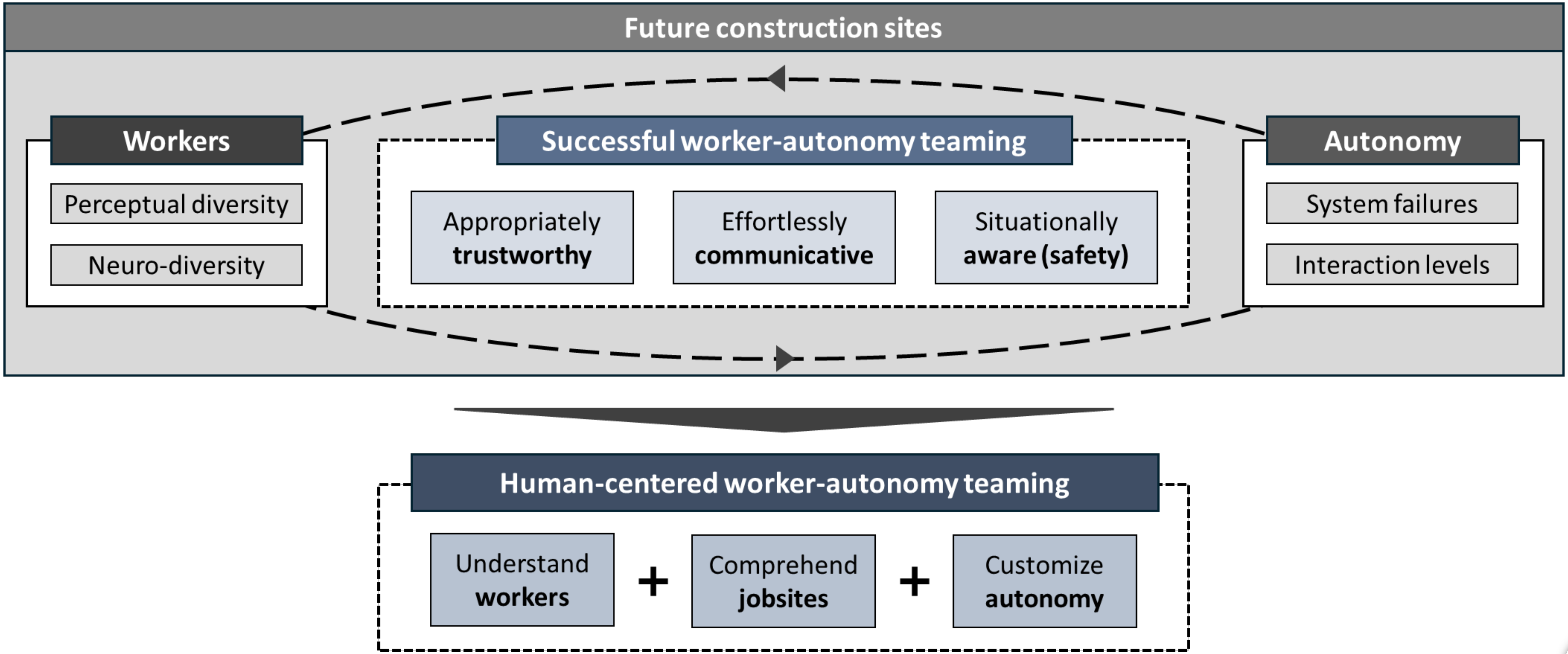
Workers are required to finish the task within a limited time while an **extra compensation** is provided.



5. Memory Load

Workers need to finish the **bricklaying task** and **2-back task** simultaneously in this module.

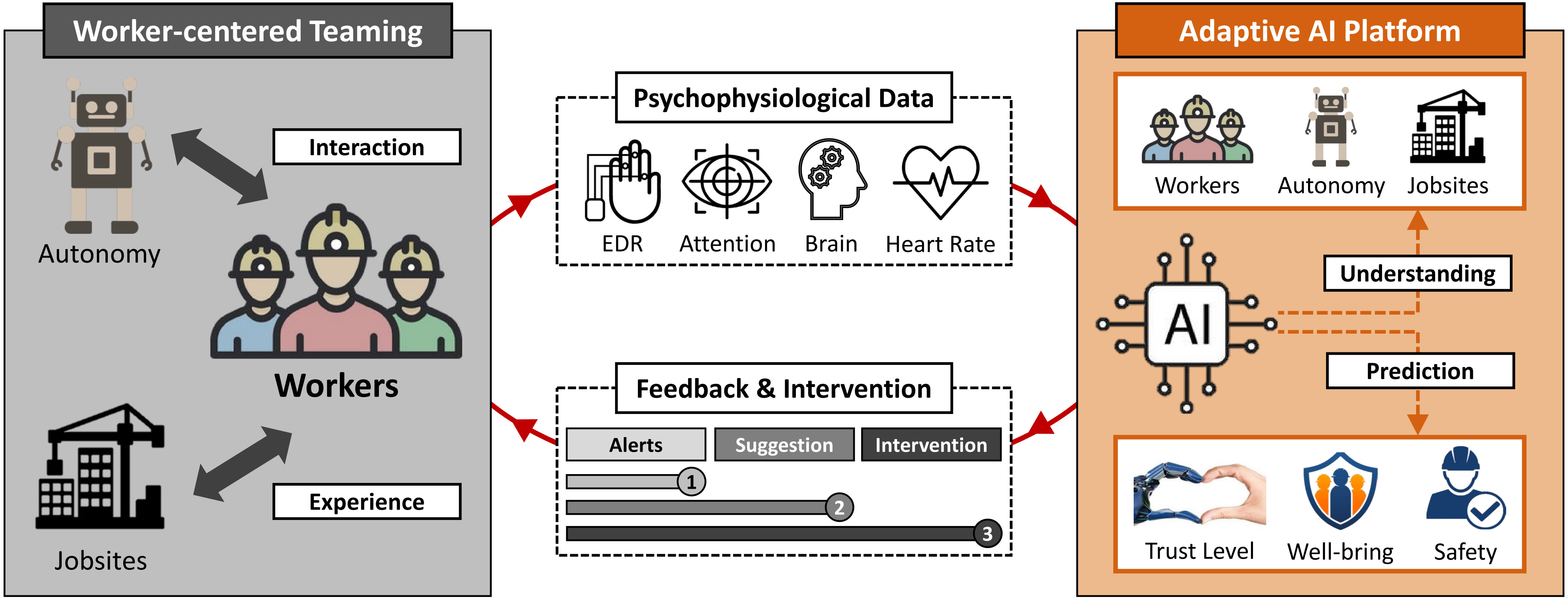
Findings



Future construction sites
Workers
Perceptual diversity
Neuro-diversity
Successful worker-autonomy teaming
Appropriately trustworthy
Effortlessly communicative
Situationally aware (safety)
Autonomy
System failures
Interaction levels
Human-centered worker-autonomy teaming
Understand workers
+
Comprehend jobsites
+
Customize autonomy

Findings

Develop and validate a multimodal adaptive AI platform to predict worker's states and provide personalized feedback based on their trust level, mental comfort, and situational awareness.



WORKER-AI TEAMING TO ENHANCE INCLUSIVITY IN THE CONSTRUCTION INDUSTRY OF THE

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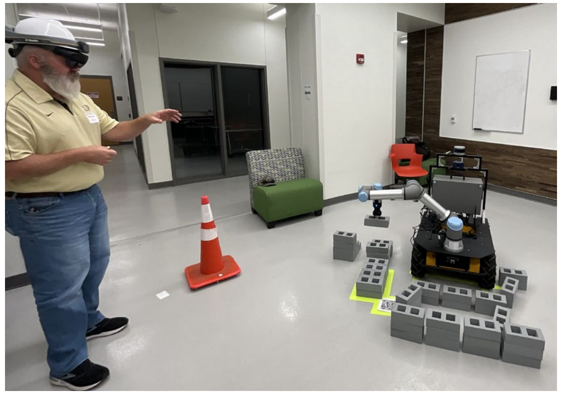
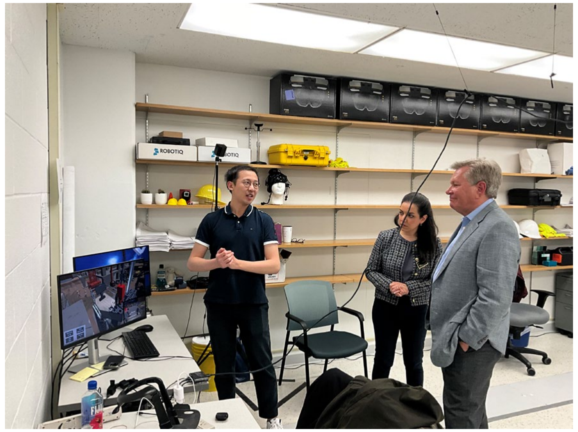
OUTREACH & BROADER IMPACTS

Introduction a Girl to Engineering Event
(WiEP and I2Safe collaboration)




Industry demo

Build, Fix, Drive it Event at Imagination Station





Overall Impact of I2SAFE Lab Themes

- ✓ **Enhanced Learning and Workforce Development**: By fostering inclusive learning environments and integrating intelligent technologies, the I2SAFE Lab prepares a diverse and skilled workforce capable of navigating modern construction challenges.
- ✓ **Improved Safety and Risk Management**: The lab's focus on human factors, predictive modeling, and automation not only enhances safety but also creates a culture of proactive risk management on job sites.
- ✓ **Optimized Efficiency through Data and Analytics**: Leveraging big data, digital twins, and AI-driven insights, the lab drives efficiency improvements in construction management, planning, and operations, making construction projects smarter, safer, and more inclusive.

These takeaways underscore the **I2SAFE Lab's commitment to integrating intelligent, inclusive, and safe practices, ultimately transforming how construction processes are managed, learned, and experienced.**

THANKS FOR YOUR ATTENTION

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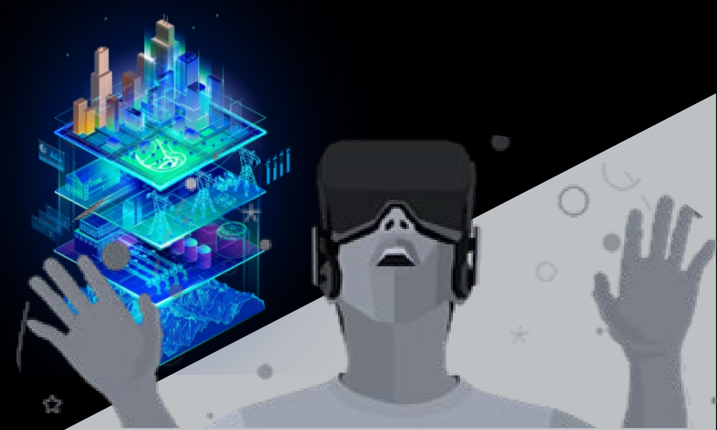

ANY QUESTION?

THANK YOU