Measuring Attention, Working Memory, and Visual Perception to Reduce the Risk of Injuries

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SARMAD
Safety, Risk Management, And Decision-making Research Group

Overview of Research Group

SARMAD
Safety, Risk Management, And Decision-making Research Group

Mission Statement: We believe that optimal decisions in the construction industry emerge out of scientific evidence and empirical data. To realize such a paradigm shift, SARMAD:

(1) Promotes original, unbiased, and innovative research that addresses the global challenges in today's construction industry;

(2) Integrates multiple scientific perspectives to unearth transformative and breakthrough discoveries; and

(3) Develops state-of-the-art decision-support systems, tools, and applications that enable agile and rapid industrial transformation

Vision Statement: SARMAD envisions a construction industry that is: safe for its workers; sustainable for the environment; ethical for our society; creates value for its customers; on time, on budget, and productive for its project managers; collaborative for its stakeholders; and profitable for its constructors.

Motto: *Set the standard in quality and innovation*!

Construction Safety, Risk Management, & Decision Making

- Data Analytics
- Human Error
- Ergonomics
- Cyber-Physical-Human Systems
- Visualization and Training
- Project Performance

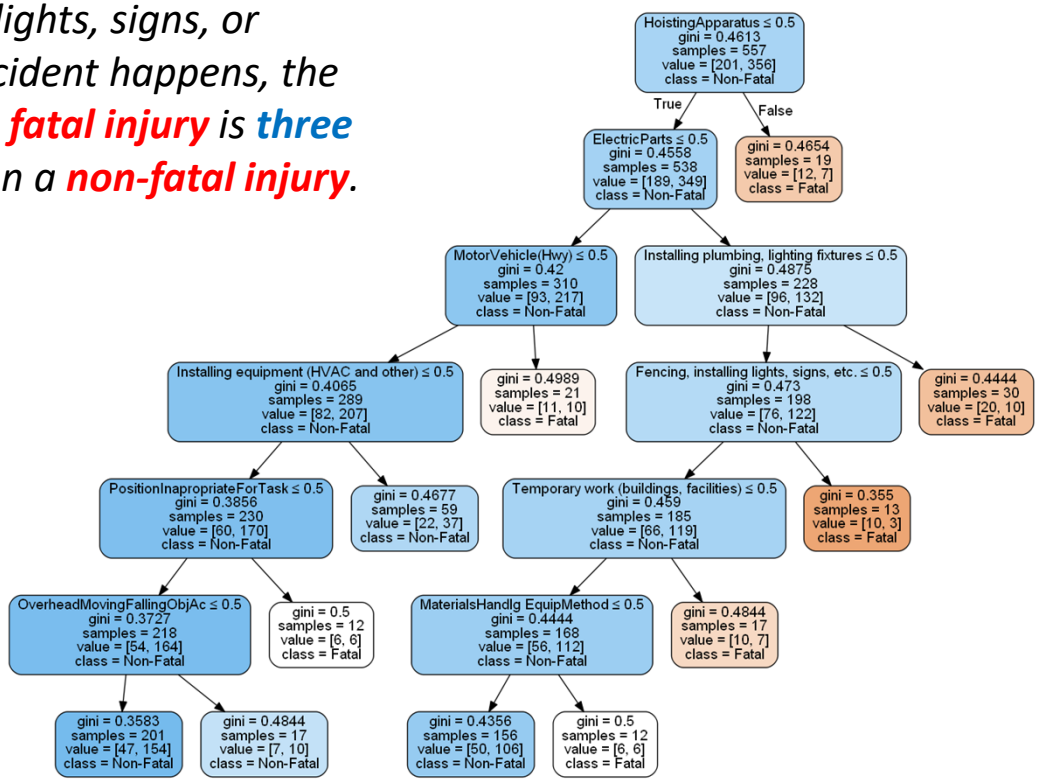
1. Data Analytics

Data Analytics

CPWR THE CENTER FOR CONSTRUCTION RESEARCH AND TRAINING

Accident scenario:

*If an employee is working on electric parts to install lights, signs, or fences, if an accident happens, the probability of a **fatal injury** is **three times** more than a **non-fatal injury**.*



Fatal

Non-fatal

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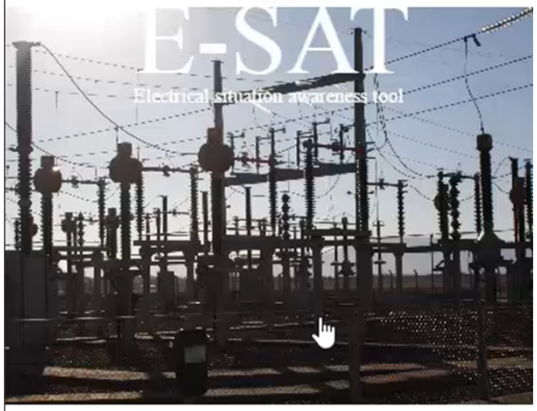
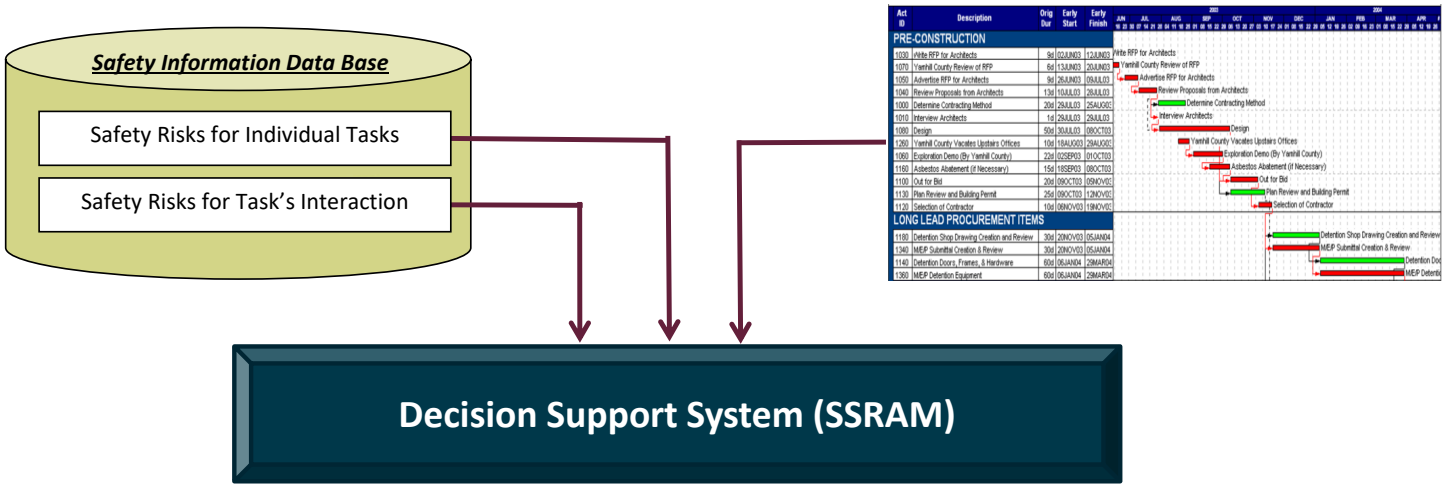
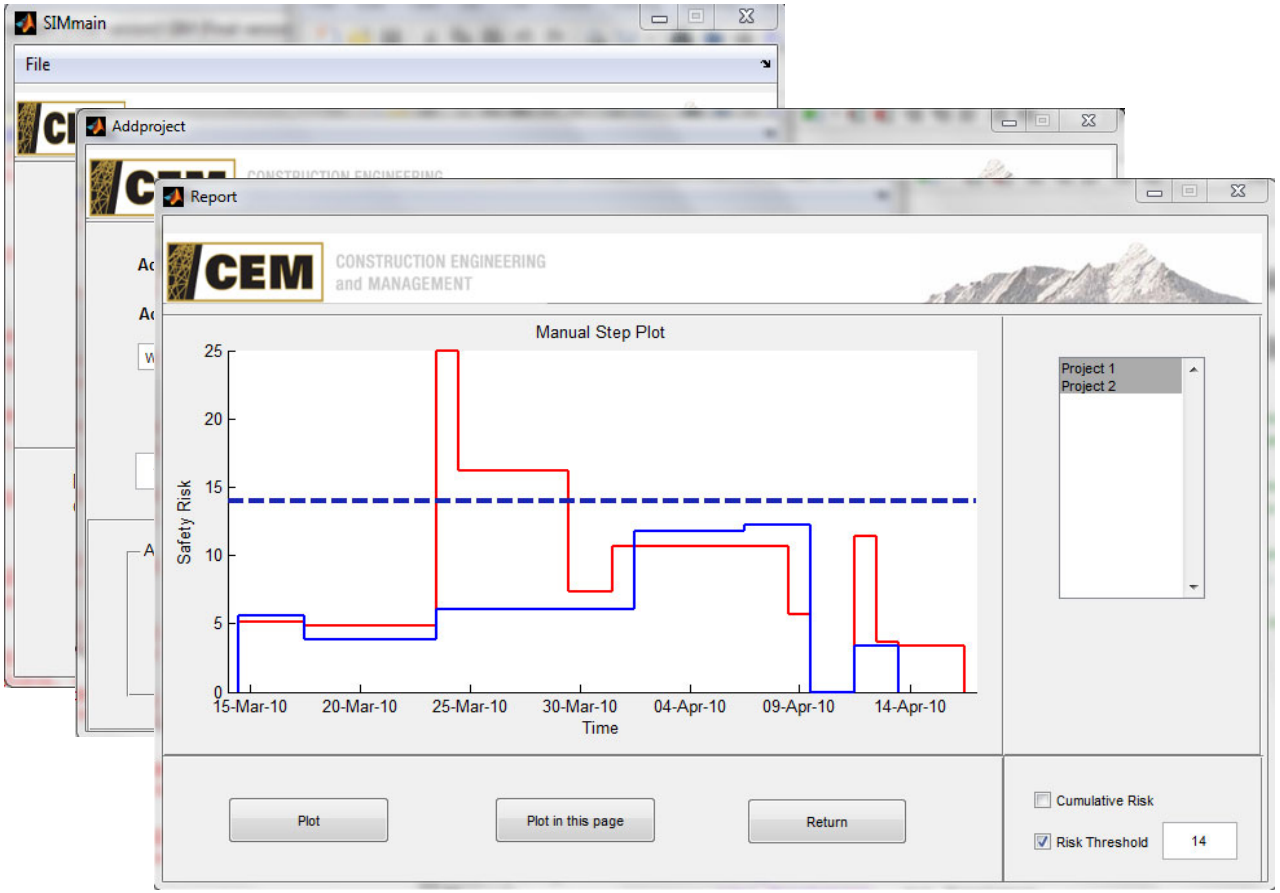


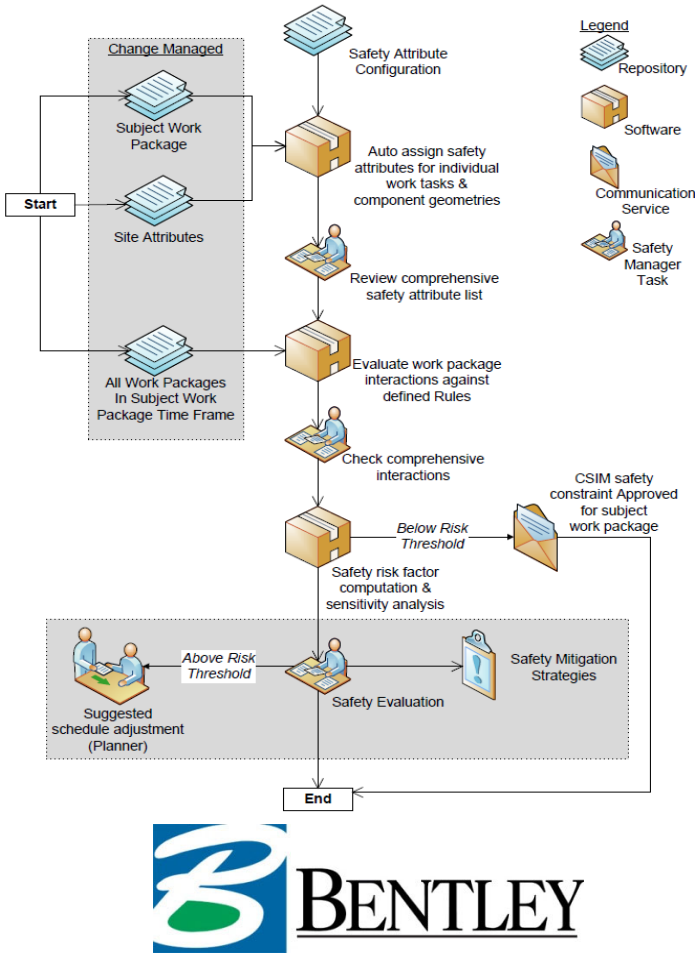
Attribute-Based Risk Management



BENTLEY

Attribute-Based Risk Management





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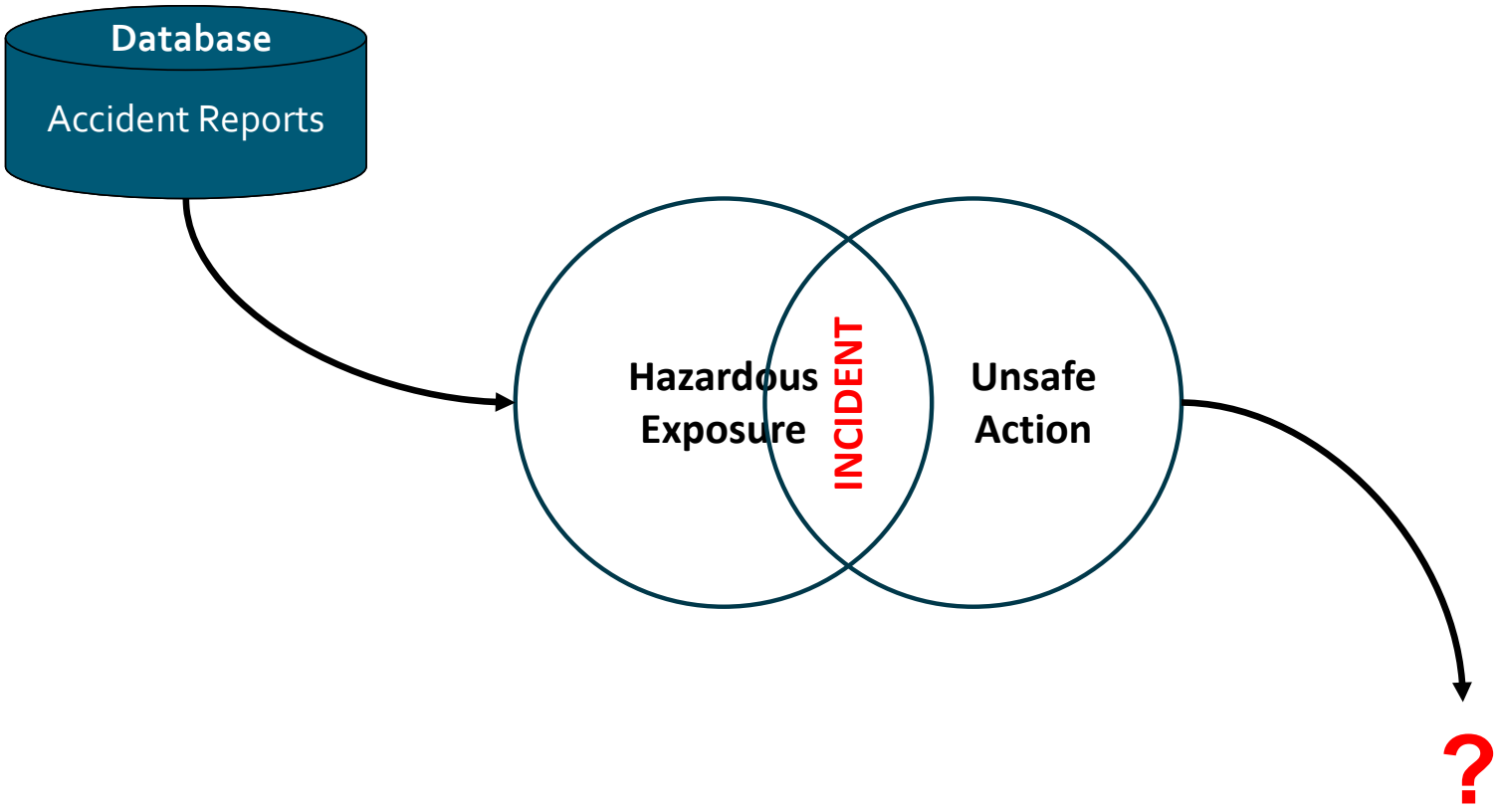
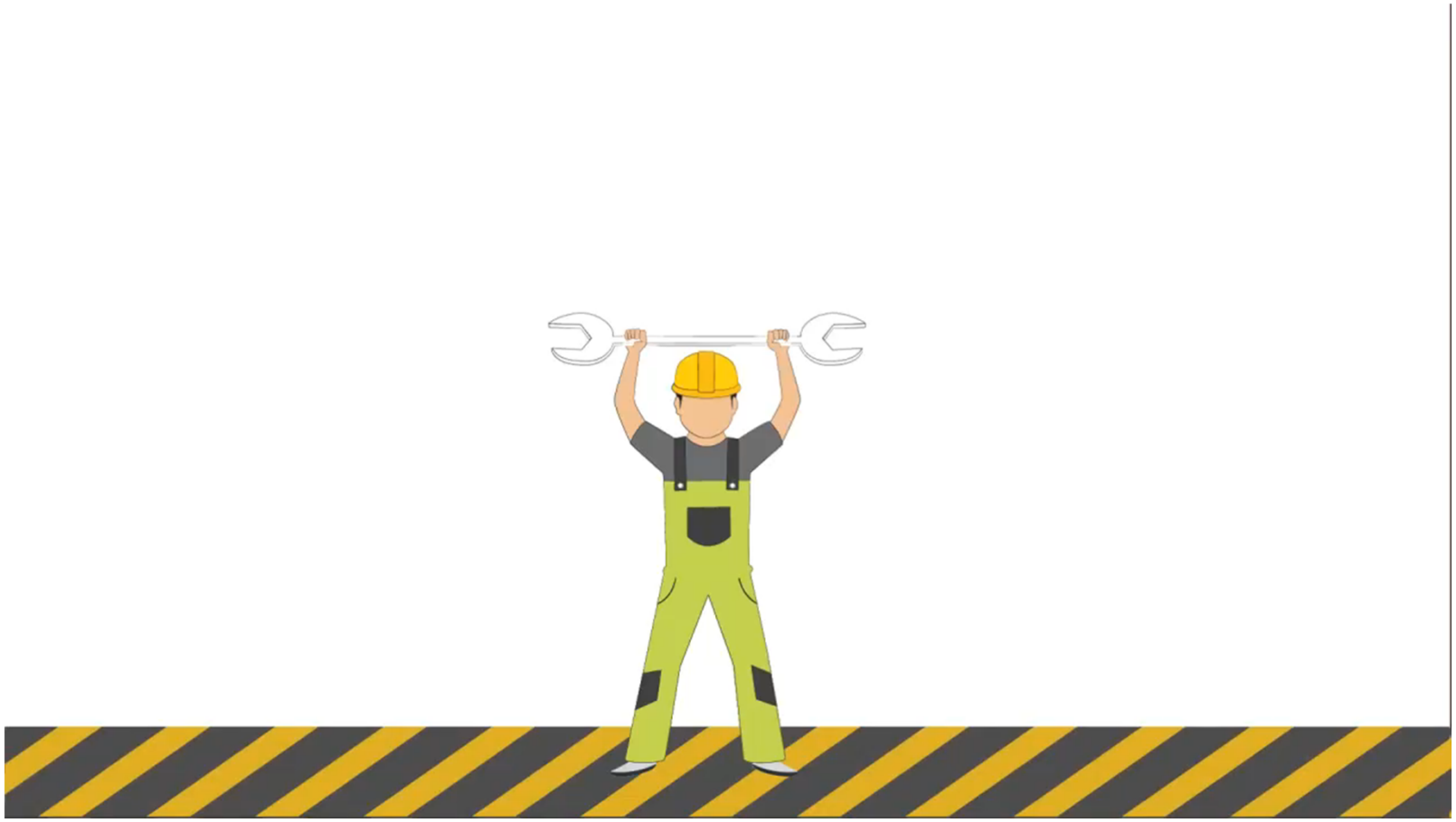
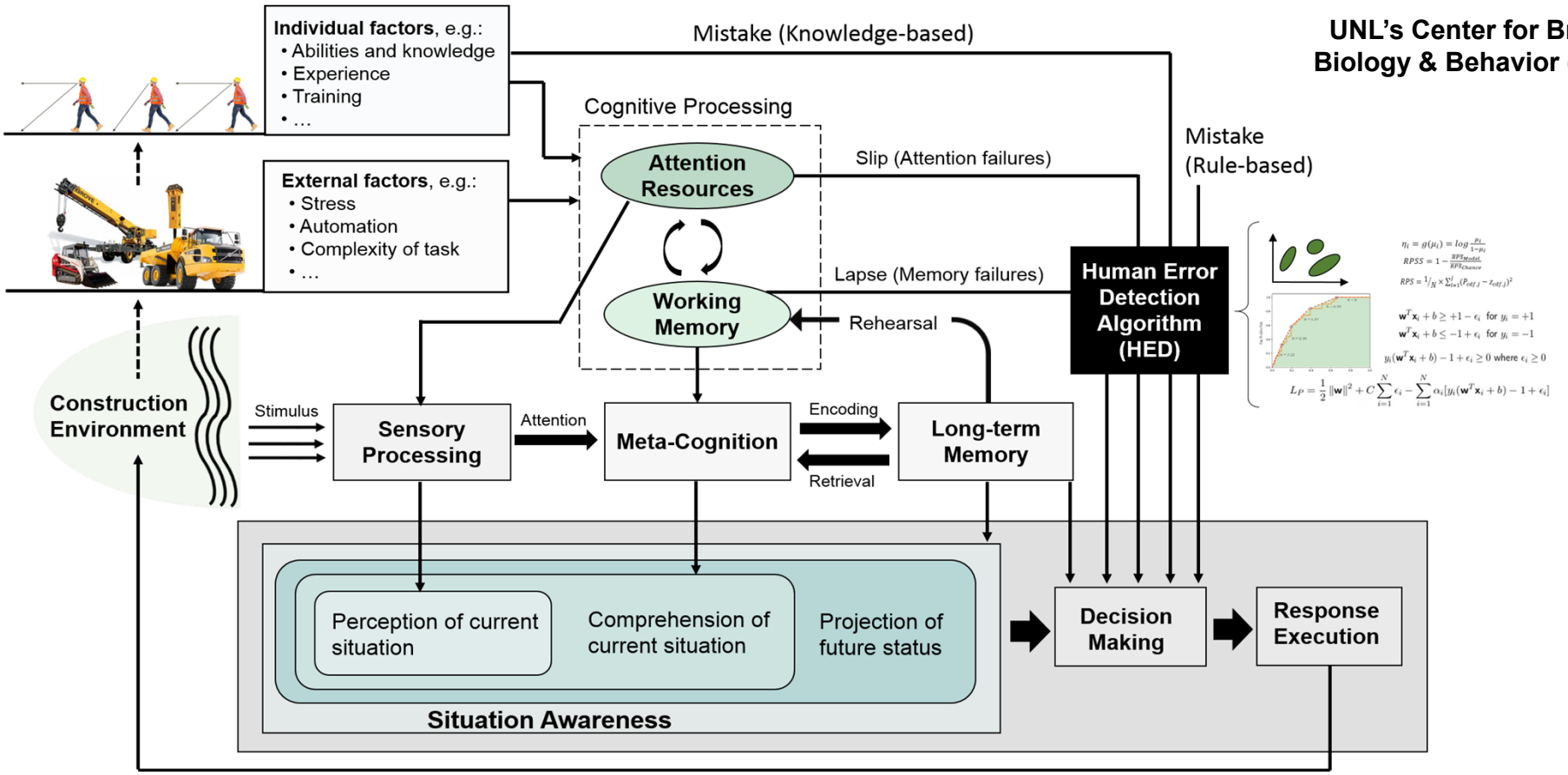

Database
Accident Reports
Hazardous Exposure
INCIDENT
Unsafe Action
?

2. Human Error

Problem Statement

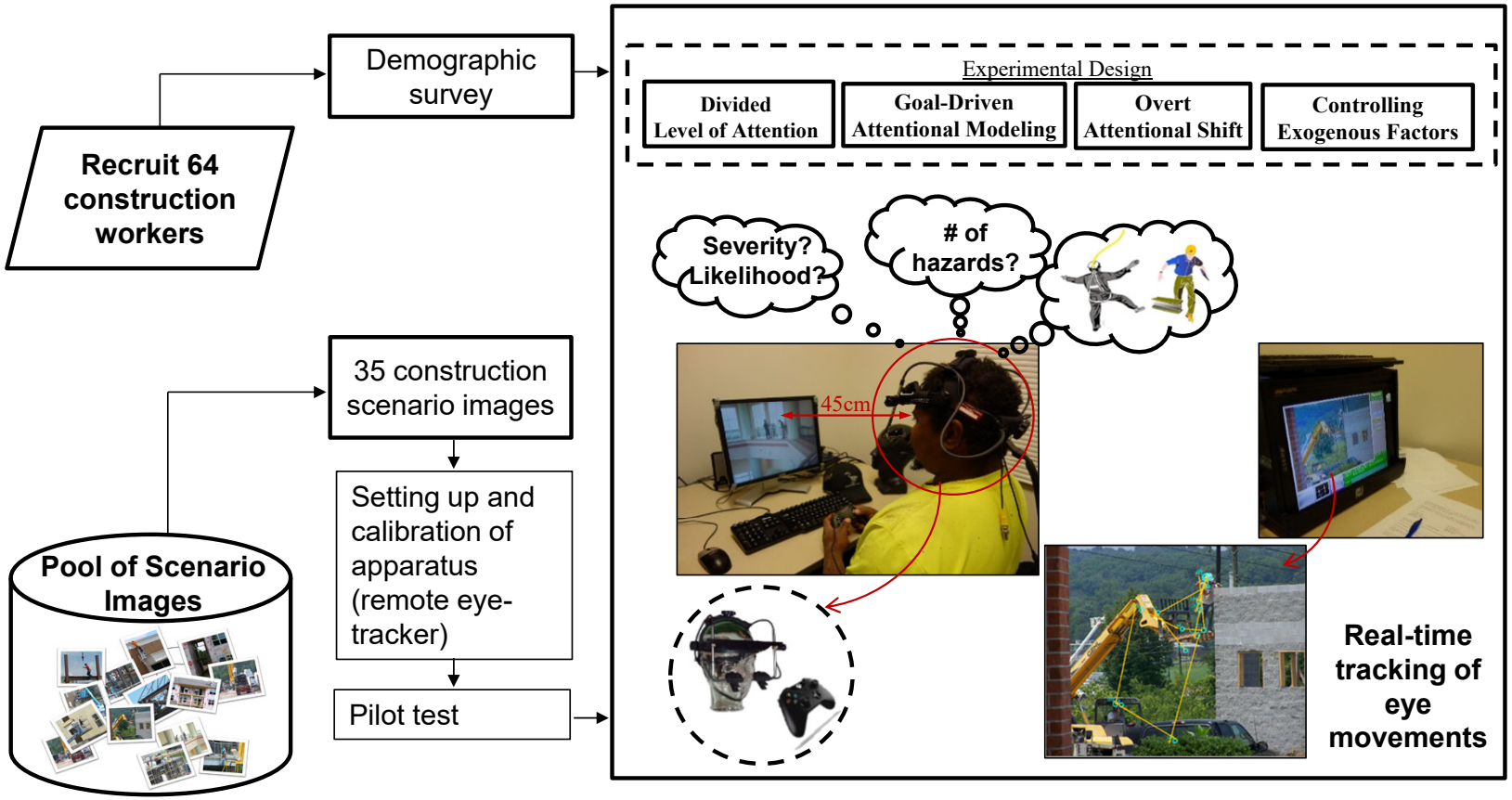


Human Error Detection (HED) Framework



UNL's Center for Brain, Biology & Behavior (CB3)

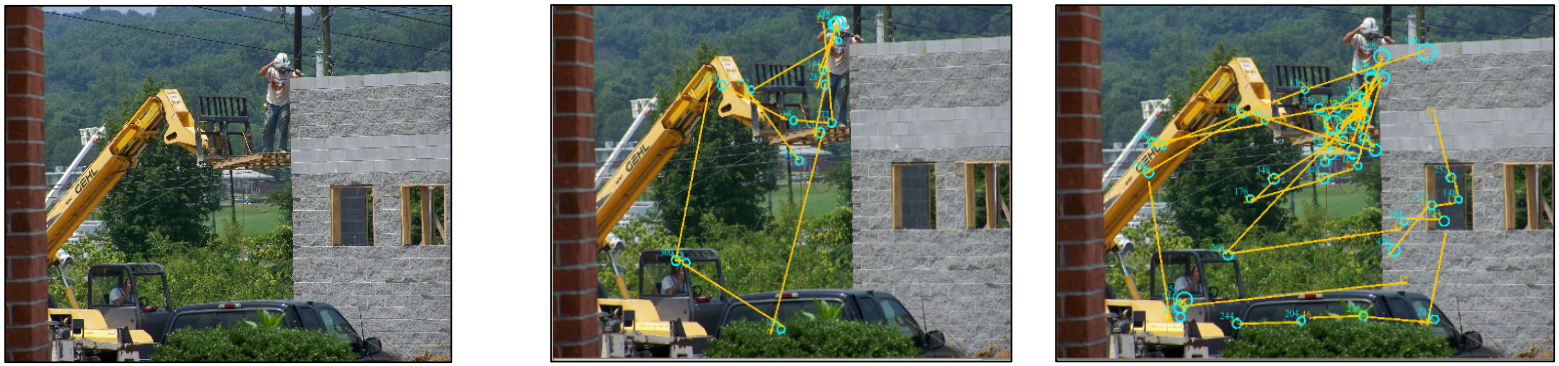
Attention and Human Error



Safety Training: *Receiving traditional safety training has minimal impact on workers' attentiveness to hazards.*

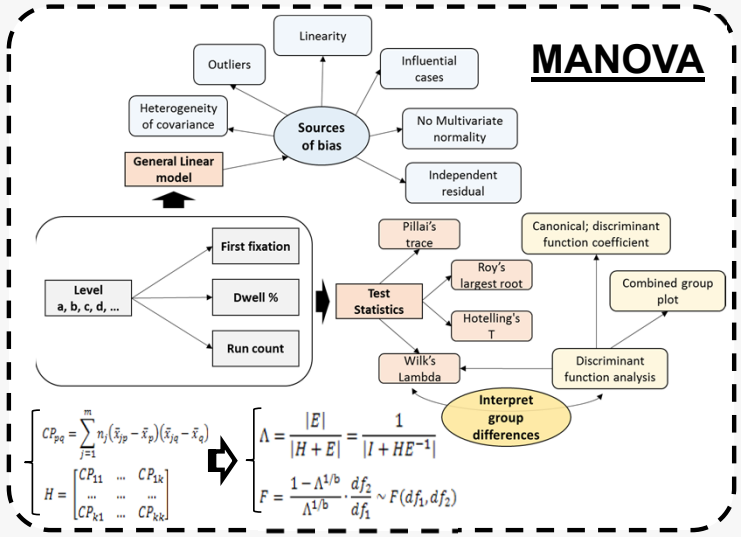
Attentional distribution of groups: with (left) vs. without training (right)

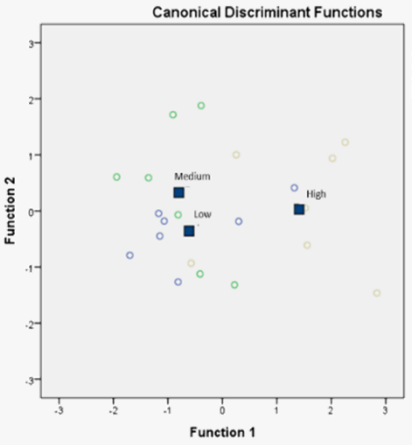
Working Experience: *As a worker gets more experience in construction field, s/he will be more aware of safety requirements in jobsite.*



Cognitive process of: G1=<5 yrs (left), G2: >10 yrs (right) of experience

$$HII_j = \frac{H_i}{H_{tot}} \Longrightarrow HII_{T,j} = Average(HII_j)$$





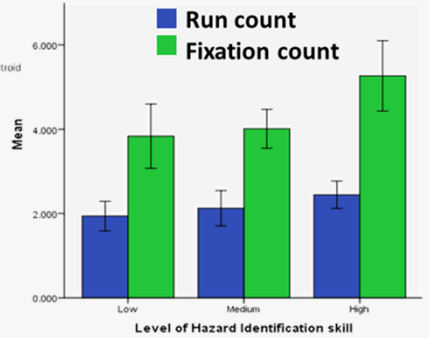


Figure 4. Means and 95% CI between eye movement metrics in each group

Source of Hazard	Value	F	df	Error df	Sig.
Ladder	0.633	2.622	6	34	0.034*
Fall to Lower Level	0.651	2.738	6	34	0.028*
Fall-Protection	0.714	3.149	6	34	0.015*
Struck-By	0.732	3.268	6	34	0.012*
Housekeeping	0.642	2.682	6	34	0.031*
All Hazard Types	0.622	2.559	6	34	0.037*

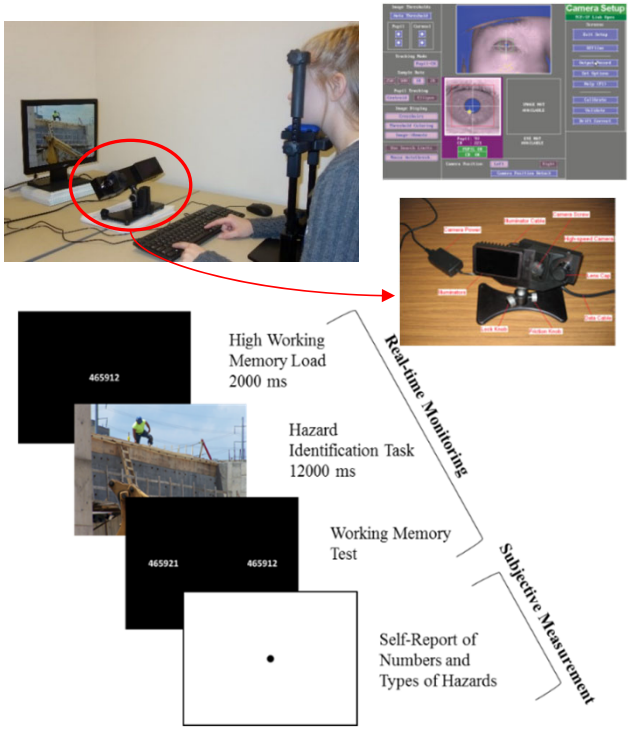
*$p \leq 0.05$

✓ Using Pillai's trace, worker's level of hazard identification skill has significant effect on their eye movements metrics. V= 0.622, F (3, 34) = 2.559, *p*= 0.037.

Working Memory and Human Error

✓ **Goal**: Measuring the Impact of Working Memory Load on the Safety Performance of Construction Workers

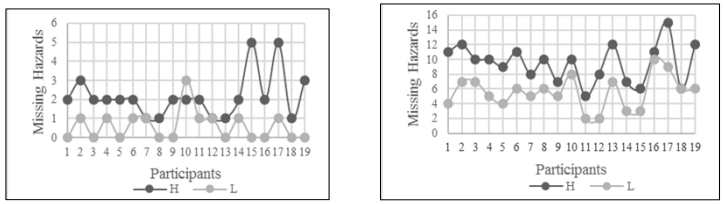
Experiment Procedure



Findings

✓ As working memory load increases, the ability of participants to identify hazards decreases significantly.

✓ Under high-load conditions being **3.8 times** (in fall-to-lower-level hazard) and **1.3 times** (in fall protection-related hazard) **more** likely to miss fall hazards



Distributions of missing (a) fall-to-lower-level hazards and (b) fall protection-related hazards under different memory load

ET metrics	Low memory load		High memory load		Simulation (B=10,000)	
	Mean	*N*	*Mean*	*N*	Welsh statistic	p-value
Fall-to-lower-level						
Dwell time	3173.961	456	2669.671	456	3.342	0.001*
First fixation time	3046.753	445	4062.827	415	-4.678	0.000*
Run count	5.015	456	4.156	456	4.994	0.000*
Fall protection						
Dwell time	1214.555	418	885.263	532	3.124	0.002*
First fixation time	5947.554	312	6755.303	353	-2.447	0.013*
Run count	2.311	418	1.855	532	3.163	0.002*

* $p < 0.05$

Risk Taking Behavior

Safety-Risk Perception Measurement

Phase I

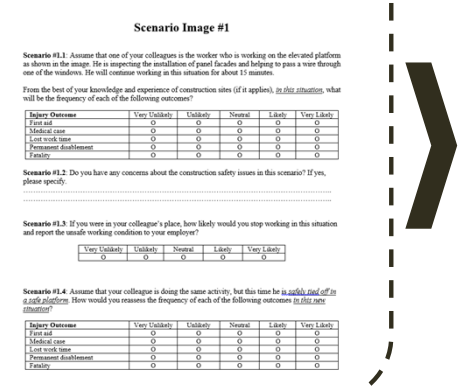
Statement-based questionnaire to measure risk perception of construction workers

Risk statements
1- Working on ladders
2- Working near an unprotected edge (roof)
3- Working near an unprotected opening
4- Working near a skylight
5- Working on a scaffold
6- Working on structural frames (e.g., steel frames)
7- Working on an aerial platform
8- Working/standing on heavy equipment
9- Working on a slippery surface
10- Working on an unsecured or unstable surface
11- Working on an uneven working surface

Risk perception score = (Frequency Score) x (Severity Score)

Phase II

Scenario-based questionnaire to measure risk perception of construction workers



Scenario Image #1

Scenario #1.1: Assume that one of your colleagues is the worker who is working on the elevated platform as shown in the image. He is inspecting the installation of panel facades and helping to pass a wire through one of the windows. He will continue working in this situation for about 15 minutes.

From the best of your knowledge and experience of construction sites (if it applies), *in this situation*, what will be the frequency of each of the following outcomes?

Injury Outcome	Very Unlikely	Unlikely	Neutral	Likely	Very Likely
First aid	O	O	O	O	O
Medical case	O	O	O	O	O
Lost work time	O	O	O	O	O
Permanent disablement	O	O	O	O	O
Fatality	O	O	O	O	O

Scenario #1.2: Do you have any concerns about the construction safety issues in this scenario? If yes, please specify.

Scenario #1.3: If you were in your colleague's place, how likely would you stop working in this situation and report the unsafe working condition to your employer?

Very Unlikely	Unlikely	Neutral	Likely	Very Likely
O	O	O	O	O

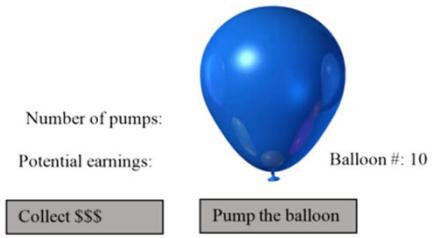
Scenario #1.4: Assume that your colleague is doing the same activity, but this time he *is safely tied off to a safe platform*. How would you reassess the frequency of each of the following outcomes *in this new situation*?

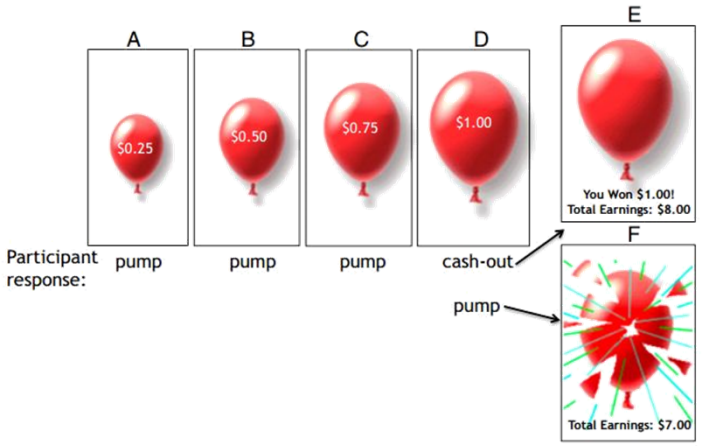
Injury Outcome	Very Unlikely	Unlikely	Neutral	Likely	Very Likely
First aid	O	O	O	O	O
Medical case	O	O	O	O	O
Lost work time	O	O	O	O	O
Permanent disablement	O	O	O	O	O
Fatality	O	O	O	O	O

Risk-Taking Behavior Measurement

Balloon Analogue Risk Task (BART):

Modeling real-world risk behavior through the conceptual frame of balancing the potential for reward versus loss.



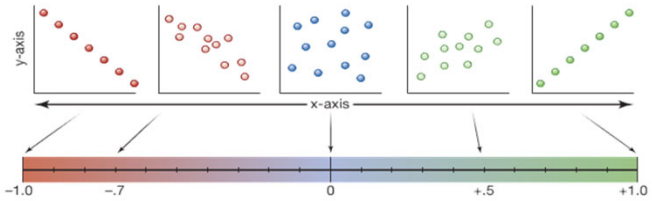


Risk Taking Behavior

***Null hypothesis 1 (H_{01})*:** There is no association between risk perception and the risk-taking behaviors of construction workers.

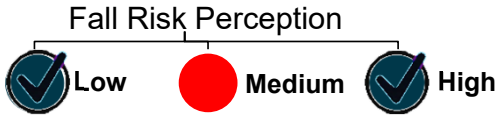
***Null hypothesis 2 (H_{02})*:** There is no significant difference in the risk-taking behaviors of individuals with different risk perception.

Correlational Analysis



- Risk perception is significantly related to risk-taking behaviors (p-value = 0.026 < 0.05).
- Workers who have lower risk perception on construction sites generally engaged in more risk-taking behaviors than those who have higher risk perception.

Permutation Analysis

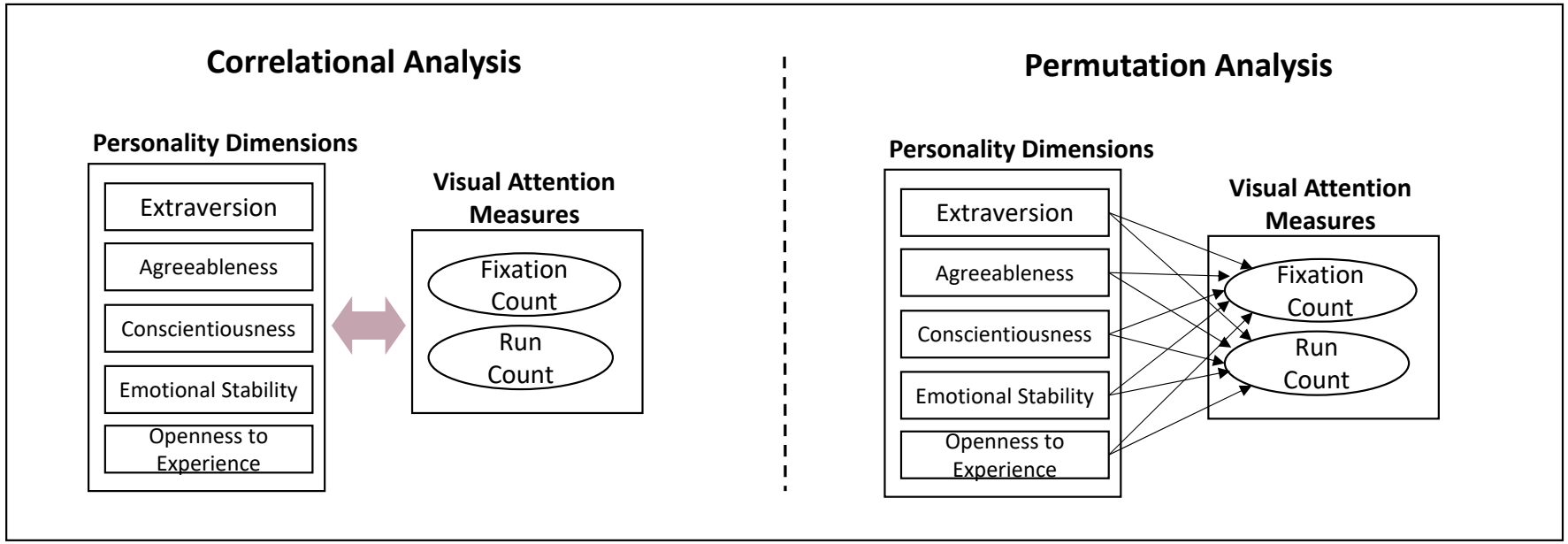


- Risk-taking behavior score of the subjects with high-risk perception was moderately statistically different from the risk-taking behavior score of the subjects with low-risk perception (Welsh t-statistic = 1.91; p-value = 0.08<0.1).

Personality and Human Error

***Null hypothesis 1 (H_{01})*:** There is no association between Big Five personality traits and workers' attentiveness (fixation count or run count) to fall hazards.

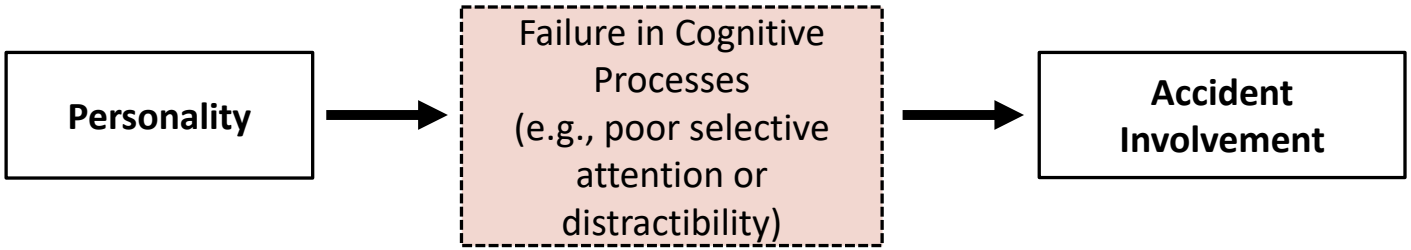
***Null hypothesis 2 (H_{02})*:** Workers' Big Five personality traits have no impact on their attentiveness (fixation count or run count) to fall hazards on a construction site.



Personality and Human Error

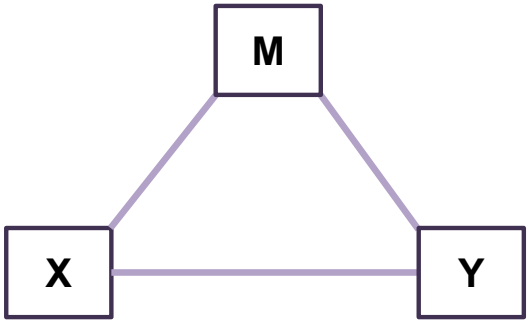
(a) Traditional Approach

(b) Alternative Approach



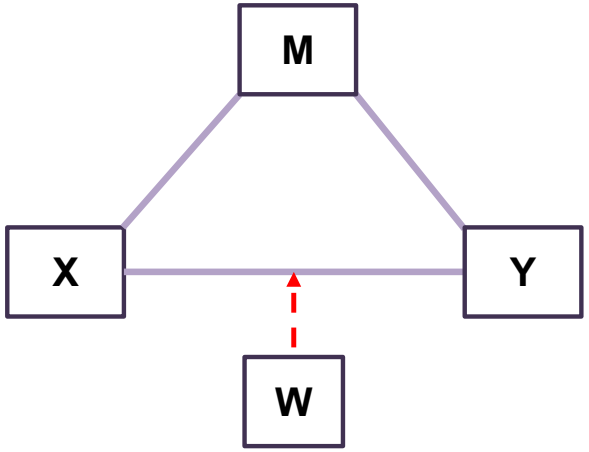
Mediation & Moderation

MEDIATION



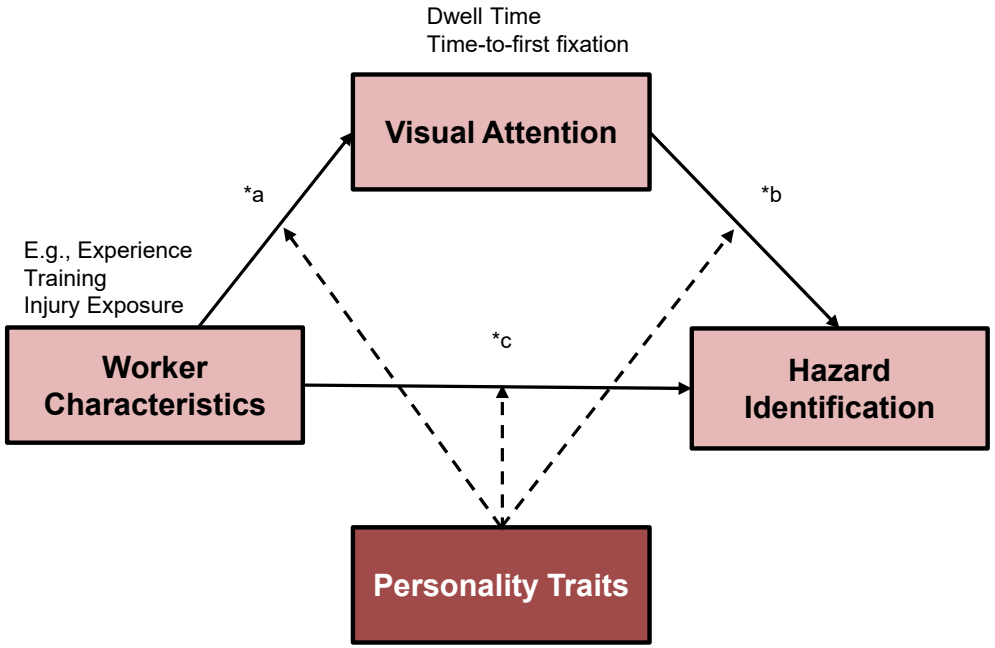
M <u>transmits the effect</u> of X on Y

MODERATION



W <u>influences the strength of association</u> between X and Y

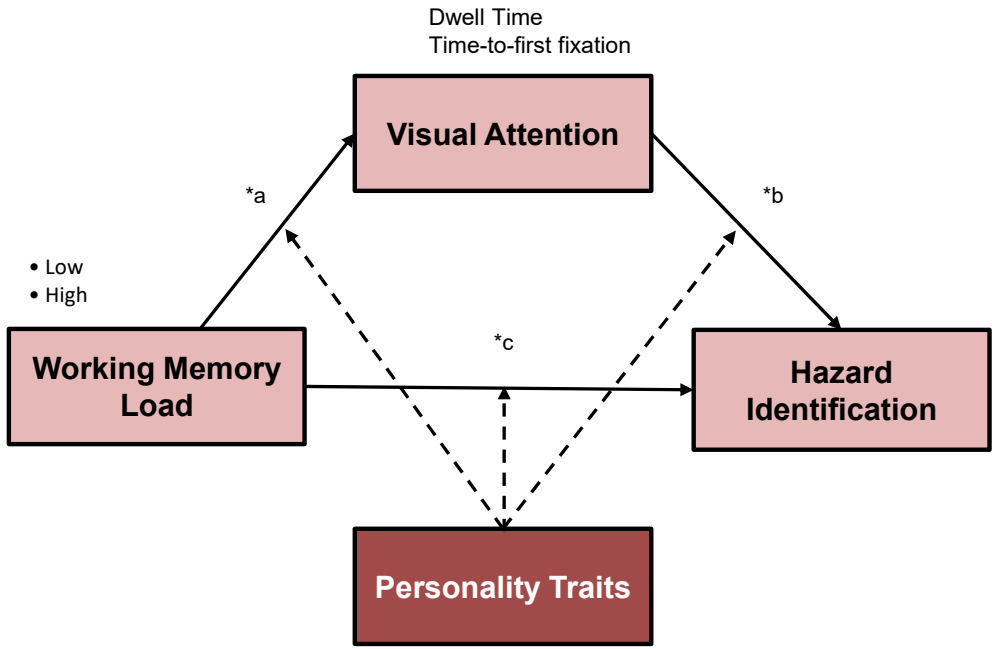
Moderated Mediation



*Paths a, b, c

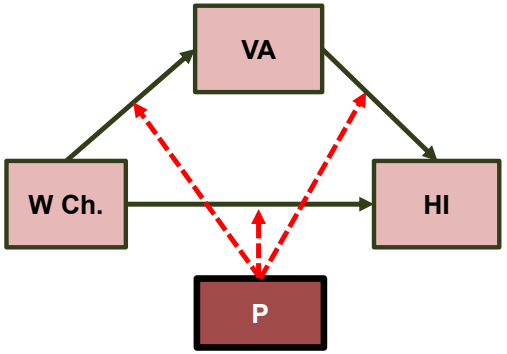
Each participant has a unique entry of variables

Multilevel Modeling

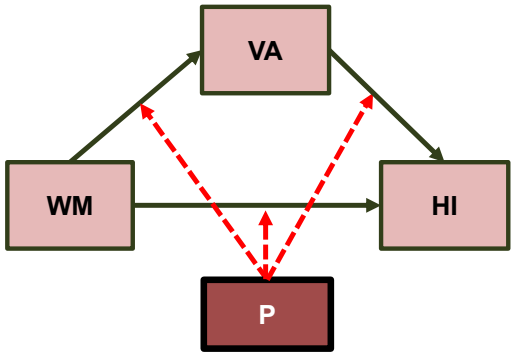


Data from multiple participants nested in both low and high WM groups

Mediation & Moderation



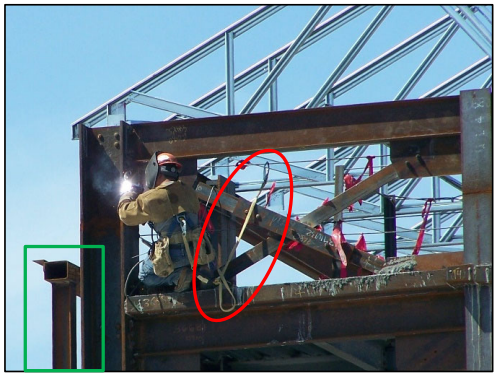
PREDICTOR	OUTCOME	MODERATOR	B	P-VALUE	L-CI	U-CI
Work Exp	TTFF	Consc. (L)	0.024	0.009*	0.006	0.041
Work Exp	TTFF	Open. (H)	0.019	0.018*	0.003	0.034
D. Time	HI	Consc. (H)	0.076	0.020*	0.013	0.139
TTFF	HI	Consc. (H)	0.244	0.010*	0.062	0.427



PREDICTOR	OUTCOME	MODERATOR	B	P-VALUE	L-CI	U-CI
WM	TTFF	Agreeableness	-2991.36	0.005*	-4994.38	-988.34
WM	TTFF	Conscientiousness	-3281.87	0.007*	-5584.53	-979.21
TTFF	HI	Agreeableness	-0.151	0.012*	-0.283	-0.046
TTFF	HI	Conscientiousness	-0.165	0.015*	-0.314	-0.049

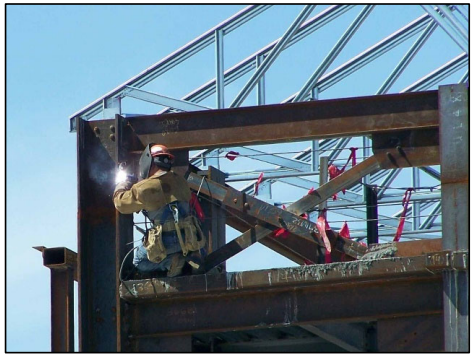
W Ch.: Worker Characteristics **VA**: Visual Attention **HI**: Hazard Identification **WM**: Working Memory

Change Blindness: *Examples*

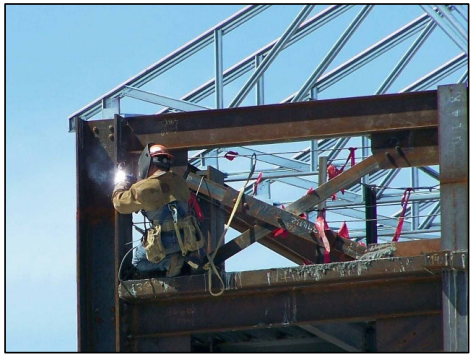


Safety relevant
Safety irrelevant

Safety relevant
Safety irrelevant



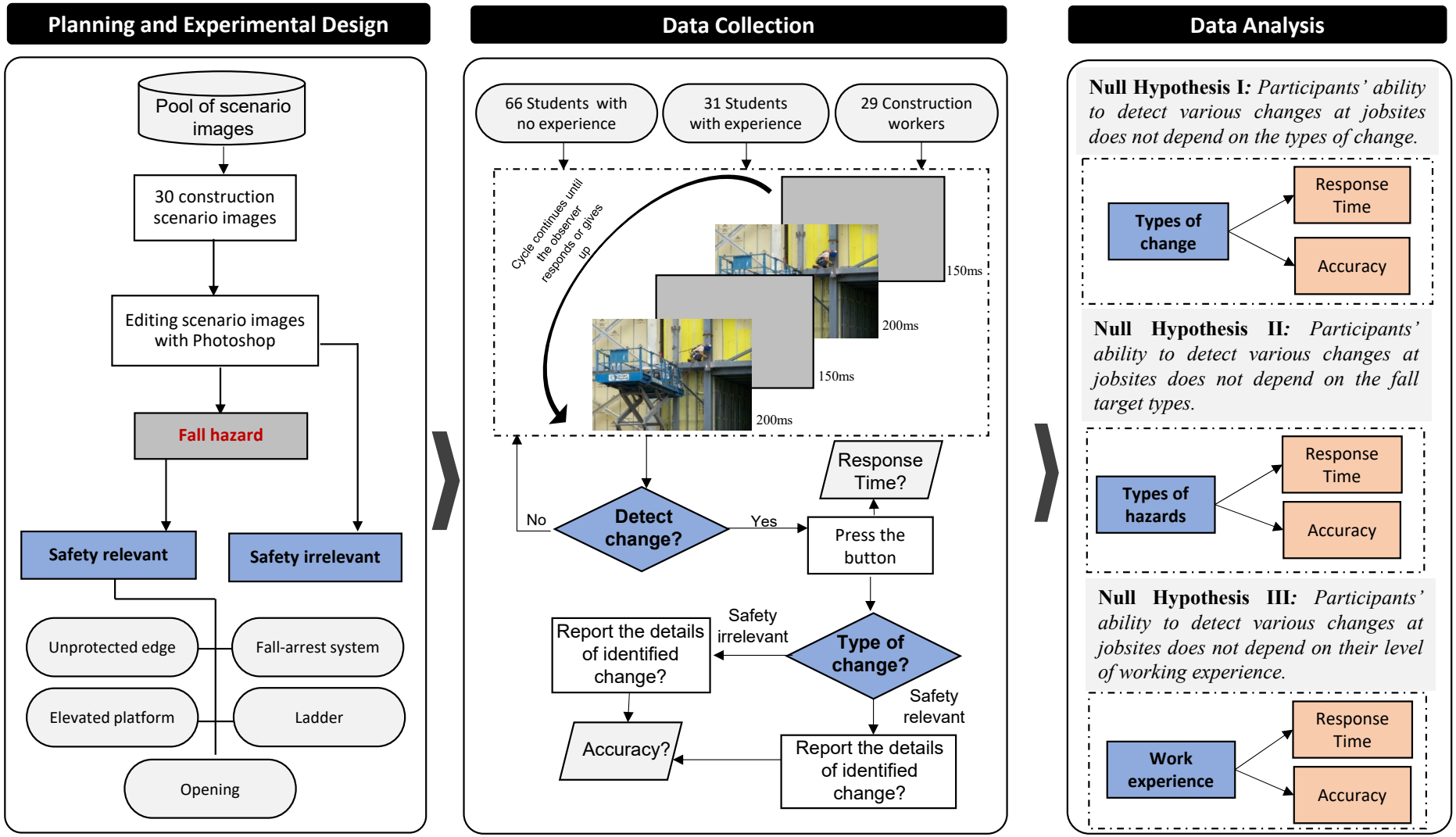
Safety relevant change



Safety irrelevant change

Safety relevant change

Safety irrelevant change

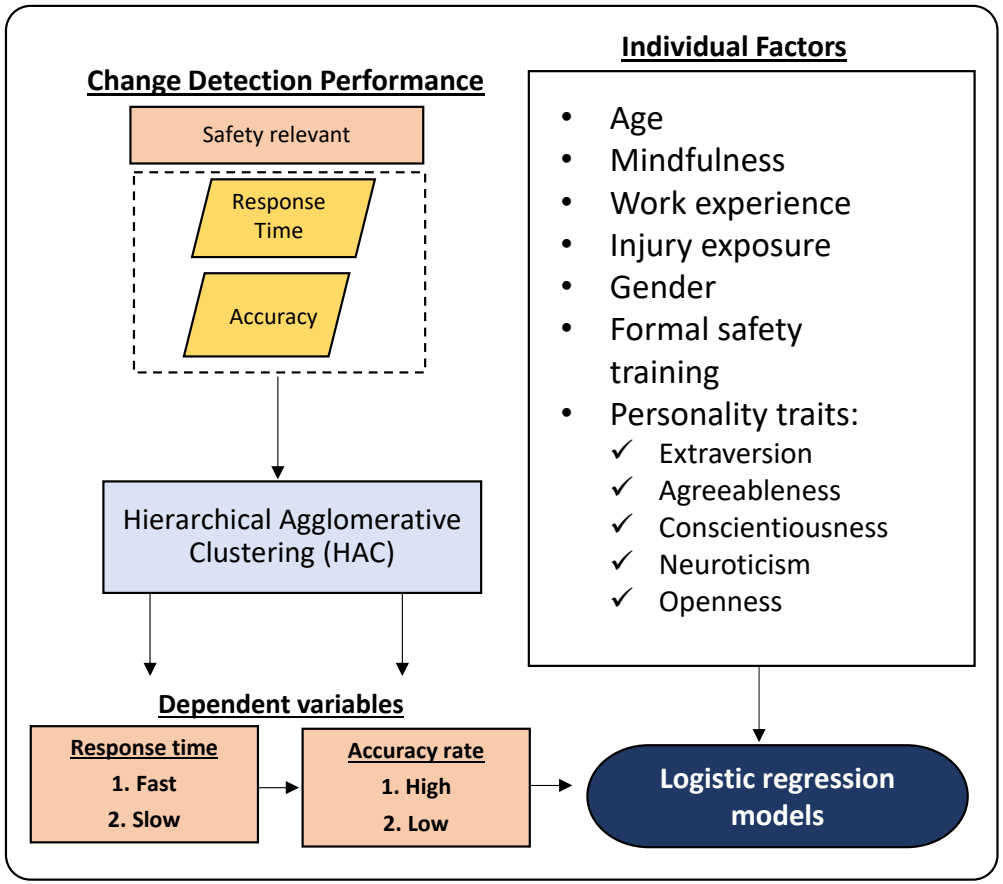

Planning and Experimental Design
Pool of scenario images
30 construction scenario images
Editing scenario images with Photoshop
Fall hazard
Safety relevant
Safety irrelevant
Unprotected edge
Fall-arrest system
Elevated platform
Ladder
Opening
Data Collection
66 Students with no experience
31 Students with experience
29 Construction workers
Cycle continues until the observer responds or gives up
150ms
200ms
150ms
200ms
Response Time?
No
Detect change?
Yes
Press the button
Report the details of identified change?
Safety irrelevant
Type of change?
Safety relevant
Accuracy?
Report the details of identified change?
Data Analysis
Null Hypothesis I: Participants' ability to detect various changes at jobsites does not depend on the types of change.
Types of change
Response Time
Accuracy
Null Hypothesis II: Participants' ability to detect various changes at jobsites does not depend on the fall target types.
Types of hazards
Response Time
Accuracy
Null Hypothesis III: Participants' ability to detect various changes at jobsites does not depend on their level of working experience.
Work experience
Response Time
Accuracy

Can you see the change between these two almost identical images?

Null Hypothesis IV: *There is no association between the dependent variables (percent accuracy and mean response time) and the individual factors*

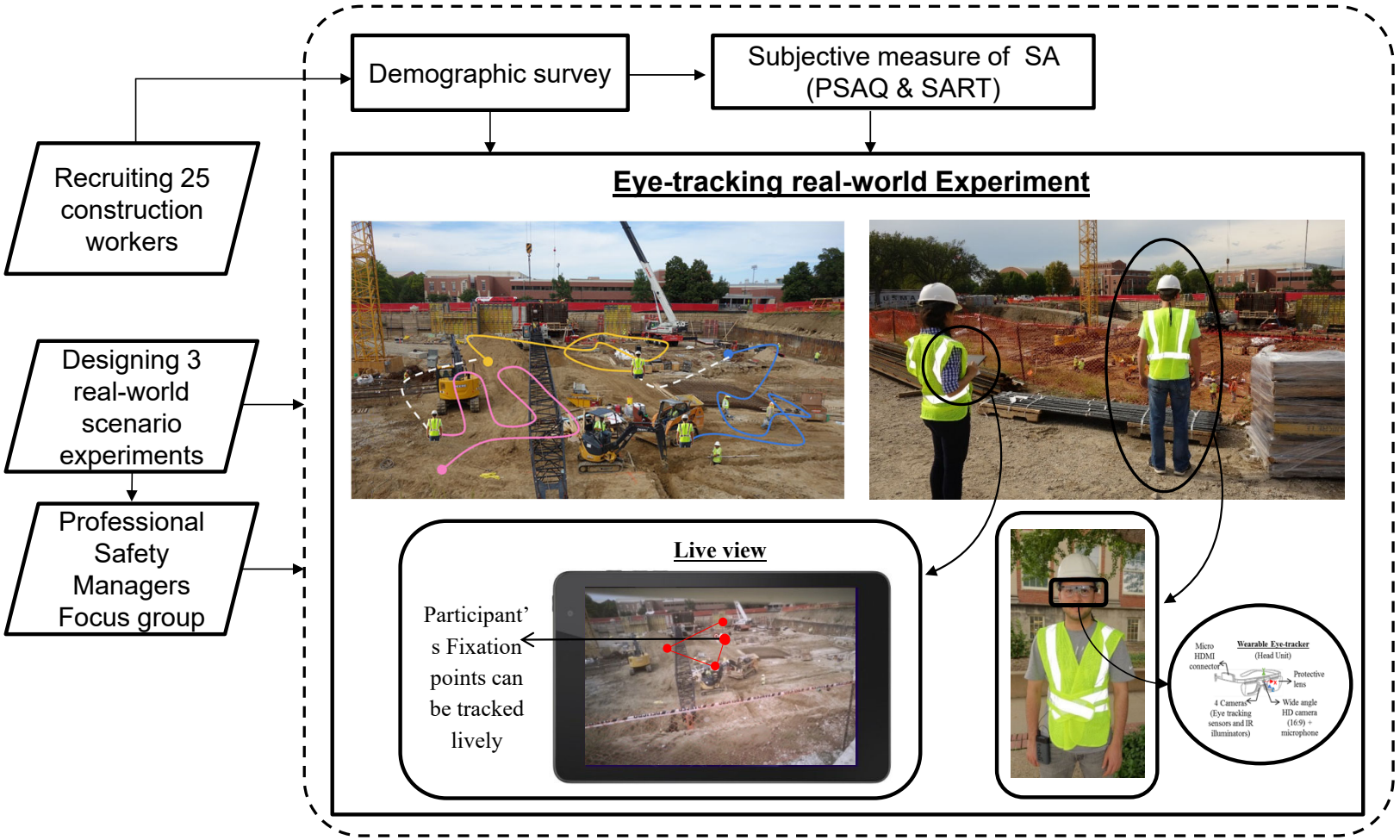
Null Hypothesis V: *There is no difference in attentional allocation (i.e., fixation metrics) of observers towards a type of changes (i.e., safety-relevant versus safety-irrelevant changes)*

Null Hypothesis VI: *There is no difference in attentional allocation (i.e., fixation metrics) of observers towards the various types of fall hazard changes*




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

Real-time Situation Awareness Using Wearable Technology



Real-time Situation Awareness Using Wearable Technology

Scene 4

Scene 3

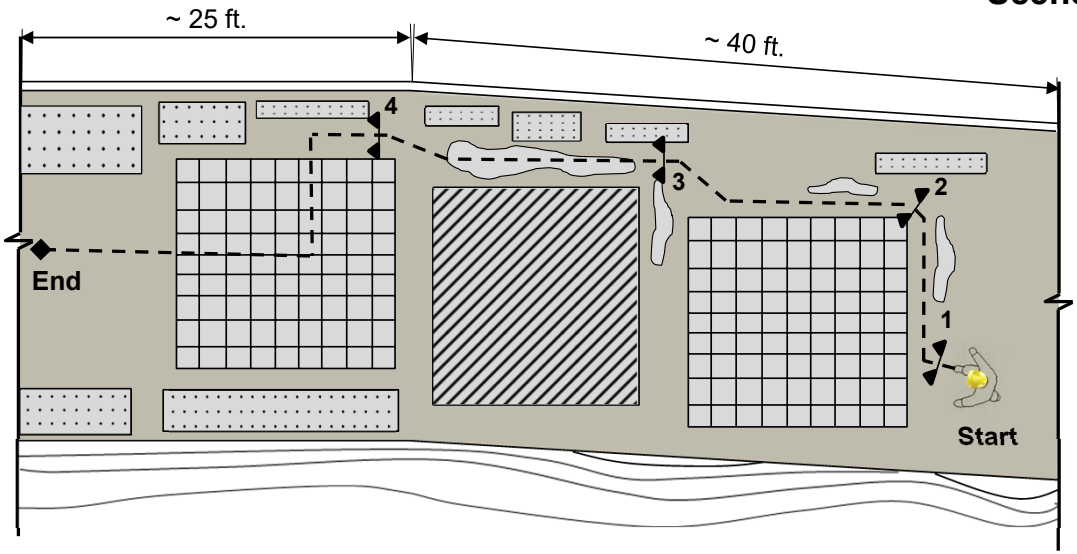
Scene 2

Guide:

Wall formwork

Supporting panel

Stored materials

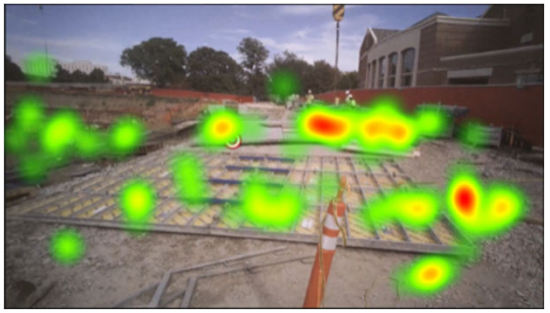


Scene 1

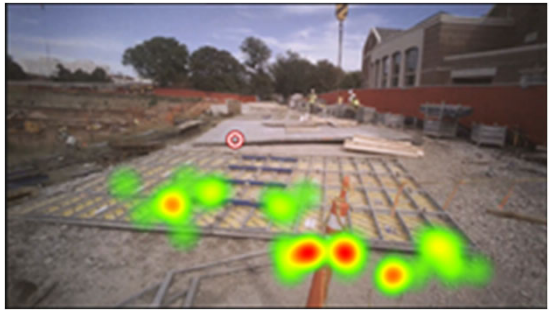
Real-time Situation Awareness Using Wearable Technology

Scene 1

High SA



Low SA



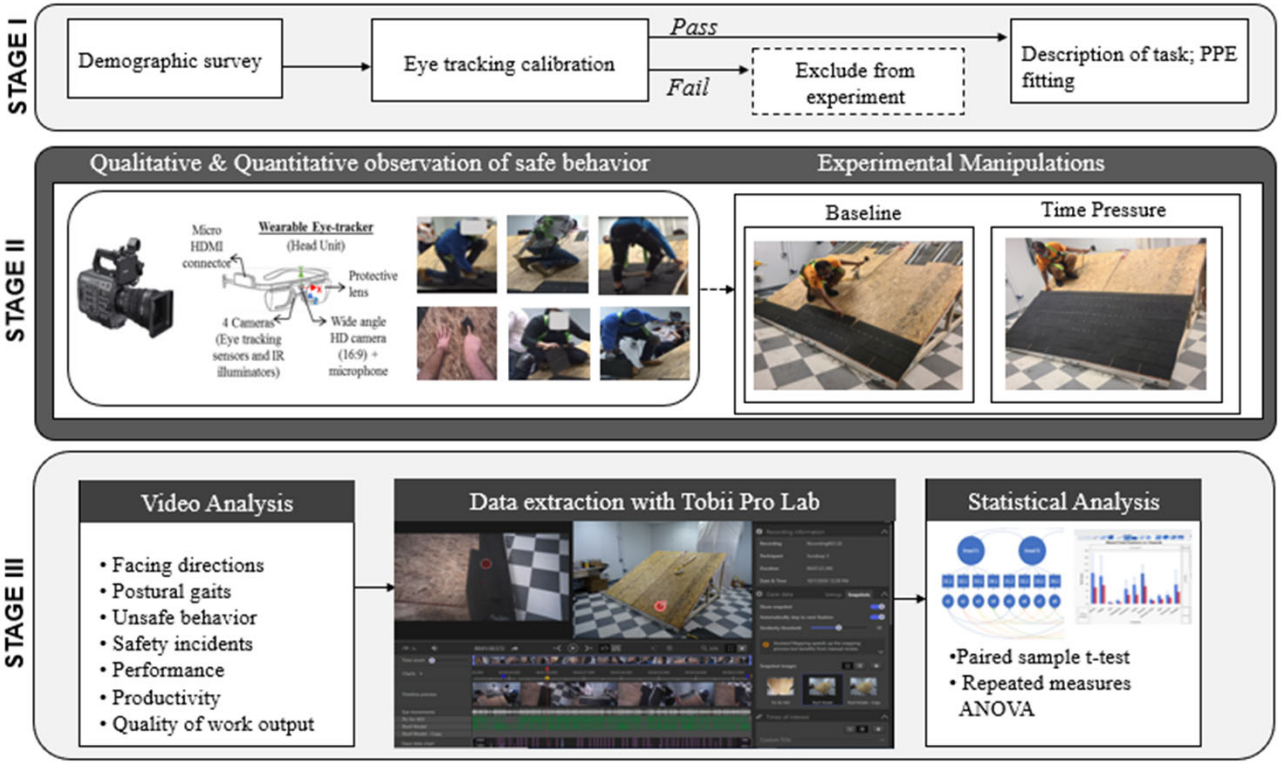
ET metrics	AOI	High SA		Low SA		Permutation results	
		Mean	SD	Mean	SD	Welch's t	*p*- value
Run count	Scene 1	2.167	1.941	0.000	0.000	2.735	0.10**
	Scene 4	8.000	4.099	4.500	2.887	1.584	0.15
Fixation count	Scene 1	2.000	2.898	0.000	0.000	1.690	0.25
	Scene 4	42.667	29.248	11.000	9.764	2.455	0.05*
Fixation duration	Scene 1	0.144	0.188	0.000	0.000	1.709	0.00*
	Scene 4	0.853	0.585	0.220	0.195	2.457	0.05*
Dwell duration	Scene 1	0.143	0.186	0.000	0.000	1.891	0.10**
	Scene 4	0.857	0.583	0.220	0.195	2.475	0.05*

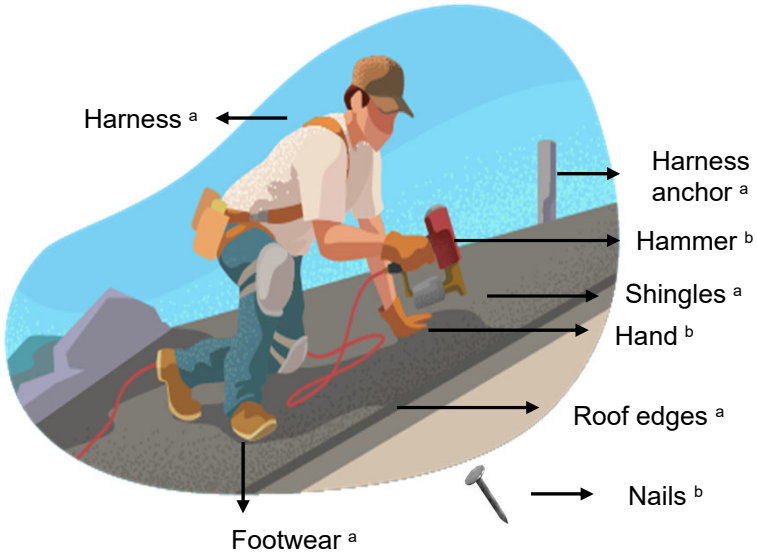
*$p < 0.05$, **$p < 0.1$

The Influence of Time Pressure on Safety Performance

Null Hypothesis I*: Time pressure does not impact attention to safety hazards (e.g. slips, trips, falls, hand injuries)*

Null Hypothesis II*: Time pressure does not impact unsafe behavior of construction workers*





[a] STF AOIs
[b] Hand injury AOIs

Statistical Analysis

Visual indicators

- TFF
- Total Fixation Duration
- Total Visit Duration
- Visit Count

Quantitative Analyses

Statistical Variables

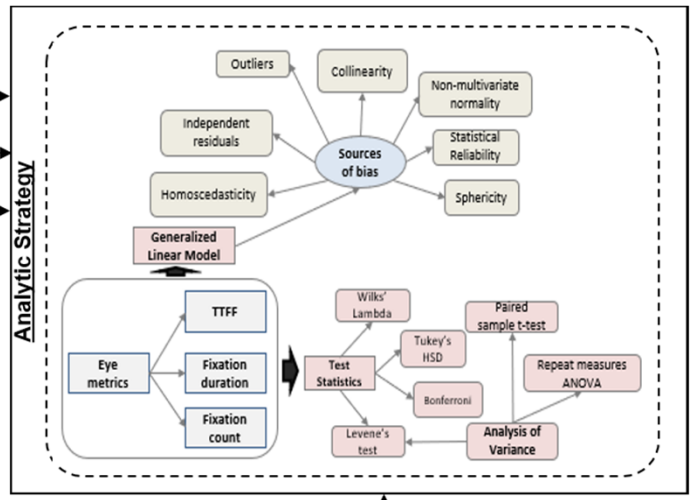
Independent variable
- Time Pressure

Dependent variable
- Hazard Identification

Qualitative Analyses

Visualization

- Heat maps (attentional distribution)
- Scanpath (cognitive process)
- Real-time mapping of eye movements
- Video examination



Areas of Interest

- Safety harness
- Nails
- Roof edges
- Hammer
- Hand
- Shingles
- Safety boots
- Harness hook point

Statistical Analysis

- Paired sample t-test
- Repeated measures ANOVA

Attention and Unsafe Behavior

AOIs	TTFF	TFD	TVD	VC
Harness	7.726*	9.604*	16.431*	28.367*
Edges	8.408*	9.197*	15.478*	26.029*
Footwear	13.968*	8.920*	15.043*	27.695*
Shingles	13.853*	6.081*	8.826*	19.661*
Hand	13.884*	5.471*	8.062*	17.038*
Hammer	19.795*	4.418*	6.137*	15.290*
Nails	42.917*	2.183*	3.009*	7.077*
Harness anchor	68.436*	1.128*	1.404*	4.172*

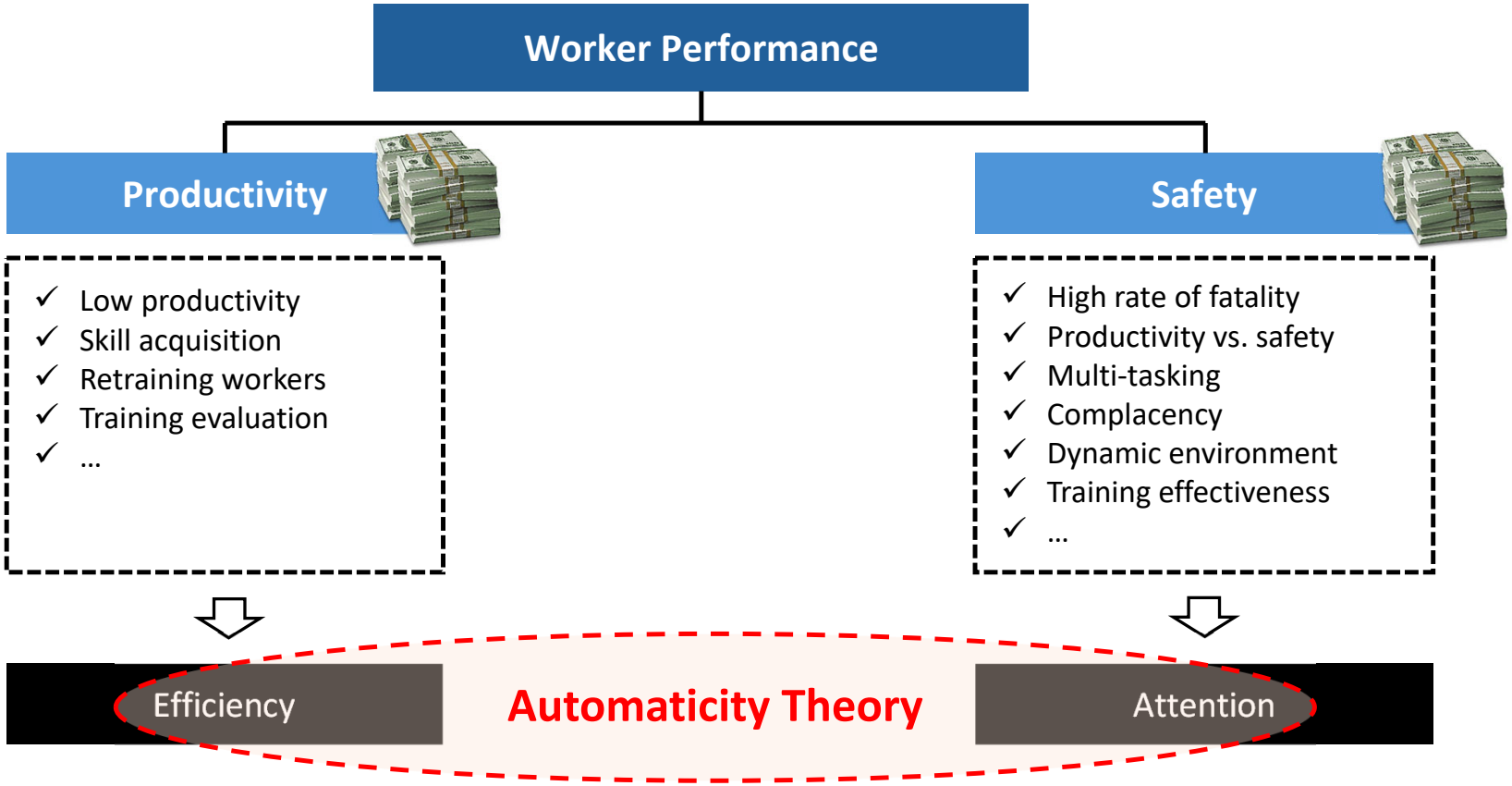
(a) (b) (c) (d)

Unsafe behavior: (a) Sitting close to roof edge; (b) Hammer too close to finger; (c) Poor hand coordination; d) Hammer for support at roof tip

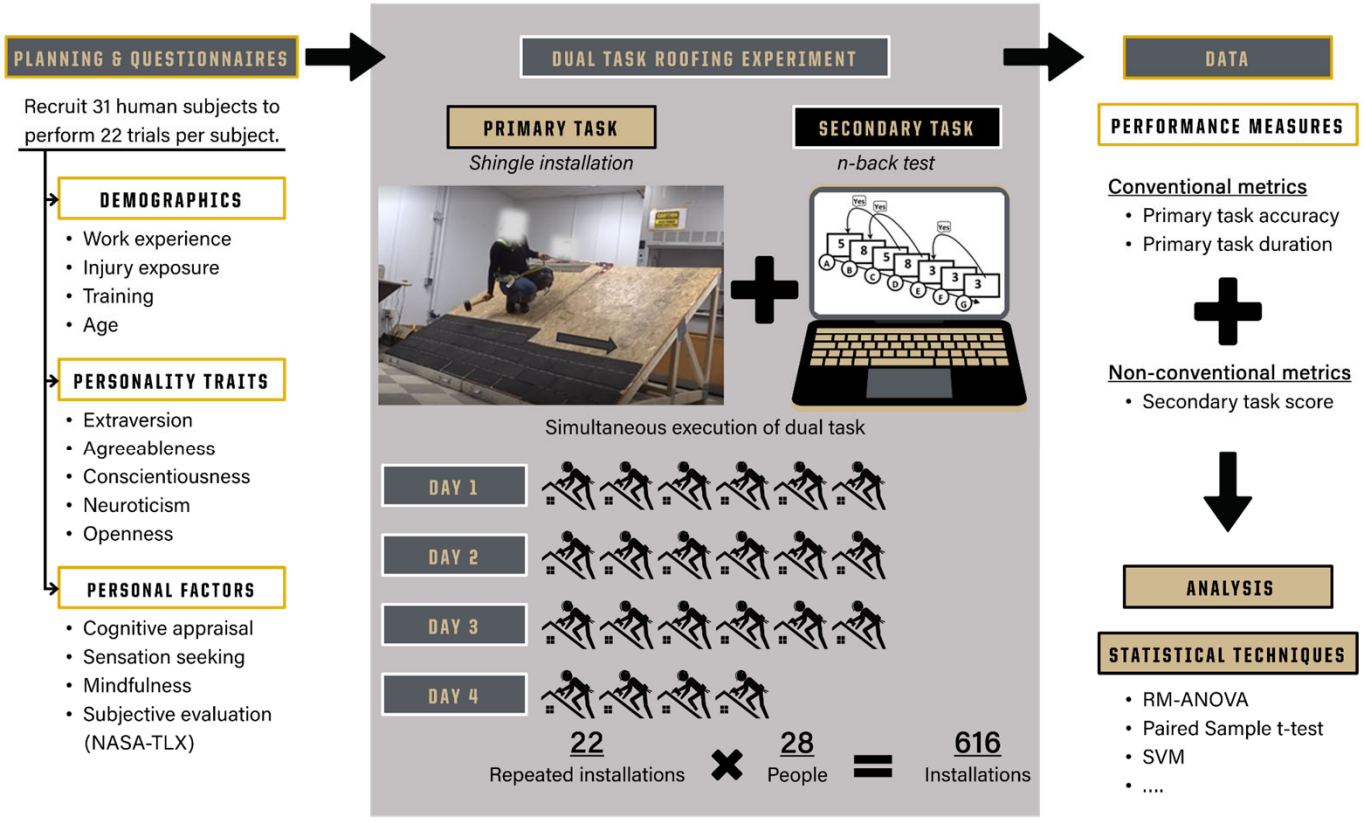
(a) (b) (c) (d)

Safety incidents: (a) Near-skid; (b) Slip hazard; (c) Nail puncture hazard; d) Fall off roof

Automaticity



Automaticity



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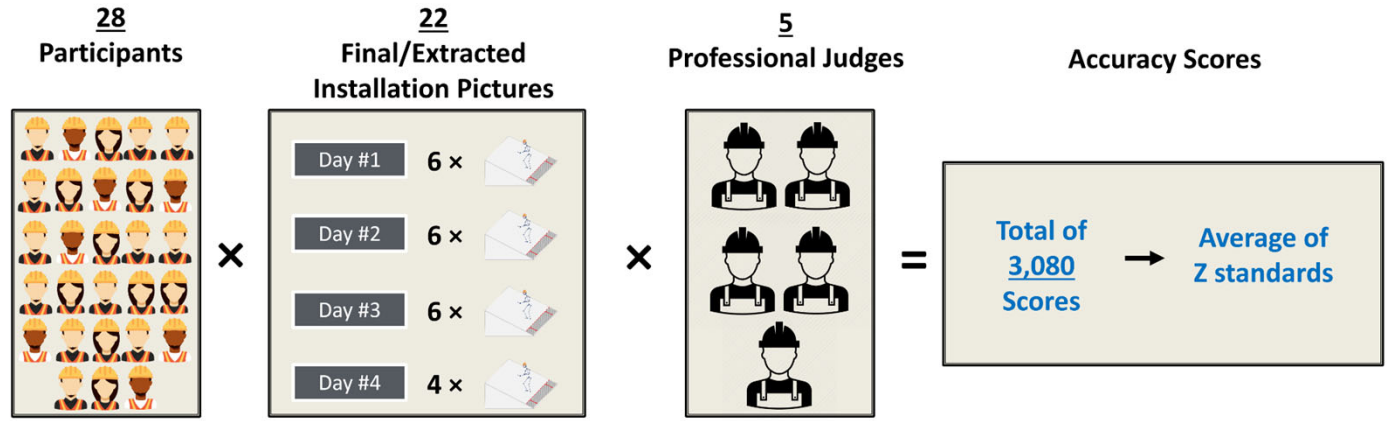

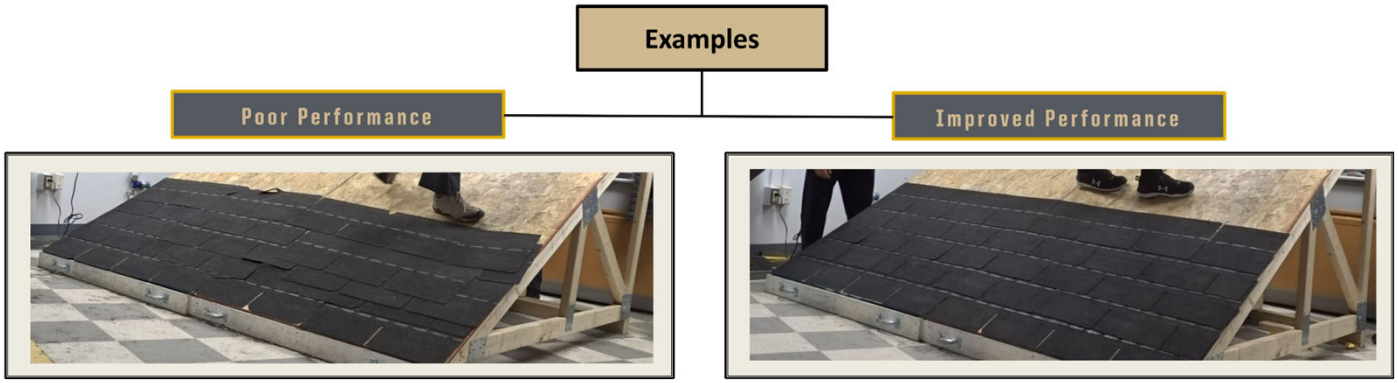

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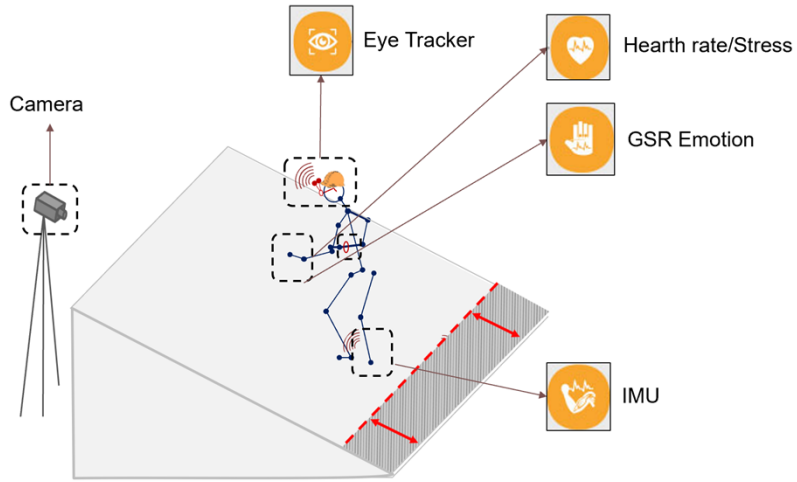
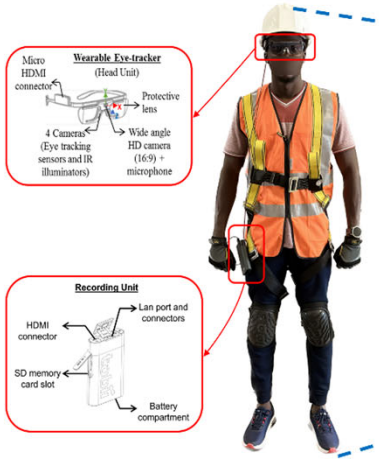
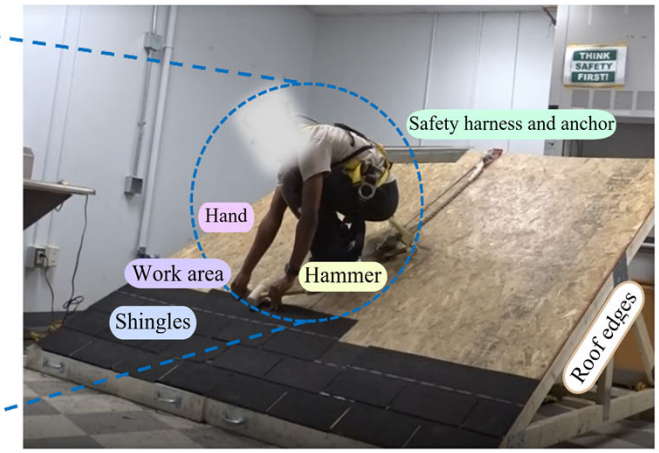
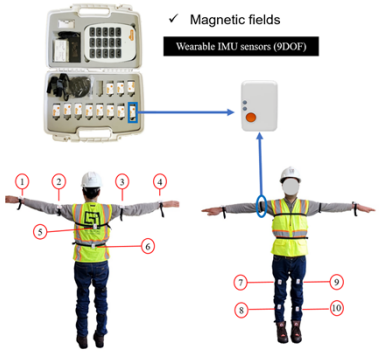








- ❑ **Smart watch**
  - ✓ Heart rate (HR)
  - ✓ Heart rate variability (HRV)
  - ✓ Pulse Ox
  - ✓ Respiration rate
  - ✓ Stress level

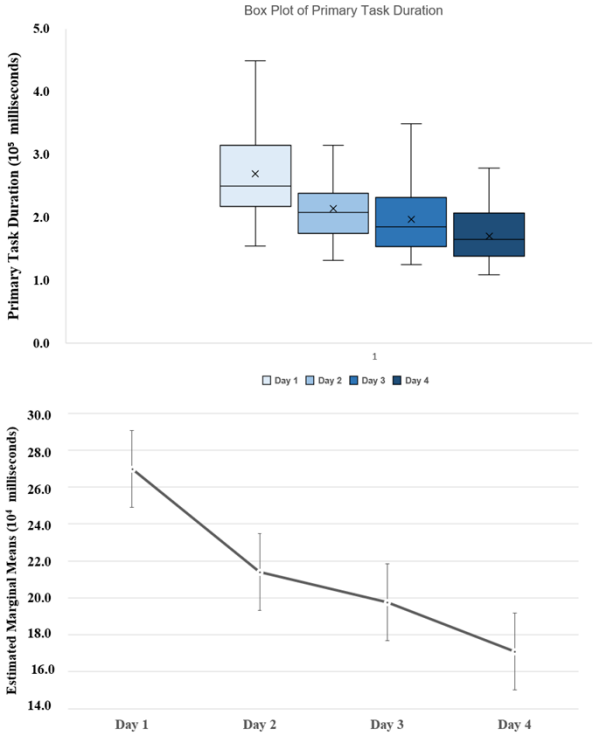
Stage #1 (Unskilled/Nonautomatic)	→	**Repeated practice/training**	→	**Stage #2 (Skilled/Automatic)**
1 ×		20 ×		1 ×

28 participants x 22 installations = **616 installations**

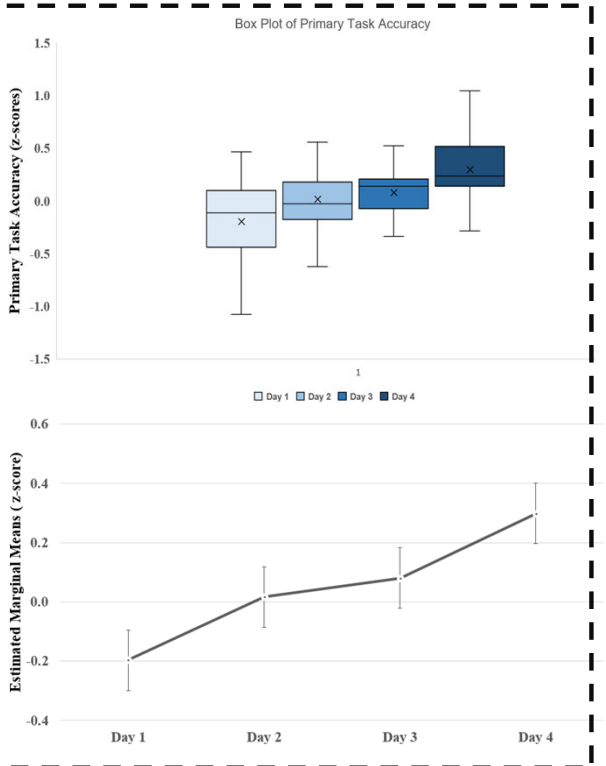
Automaticity

Primary Task

Duration

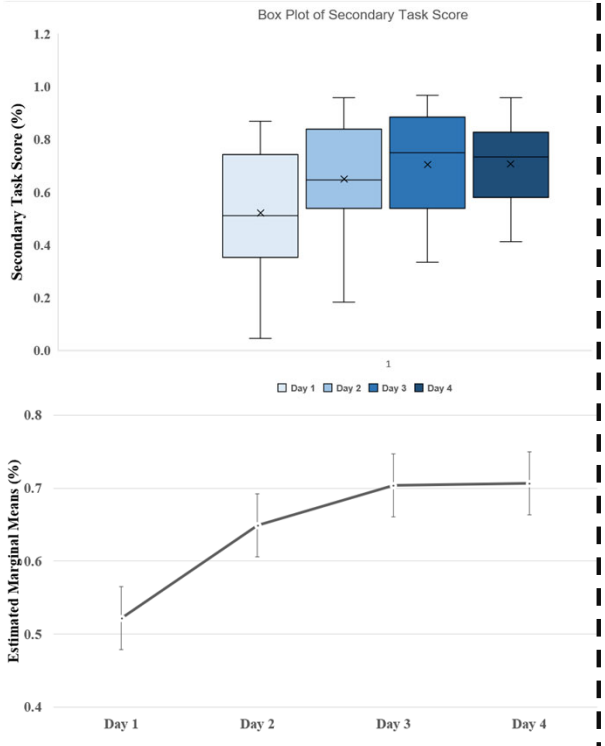


Accuracy



Secondary Task

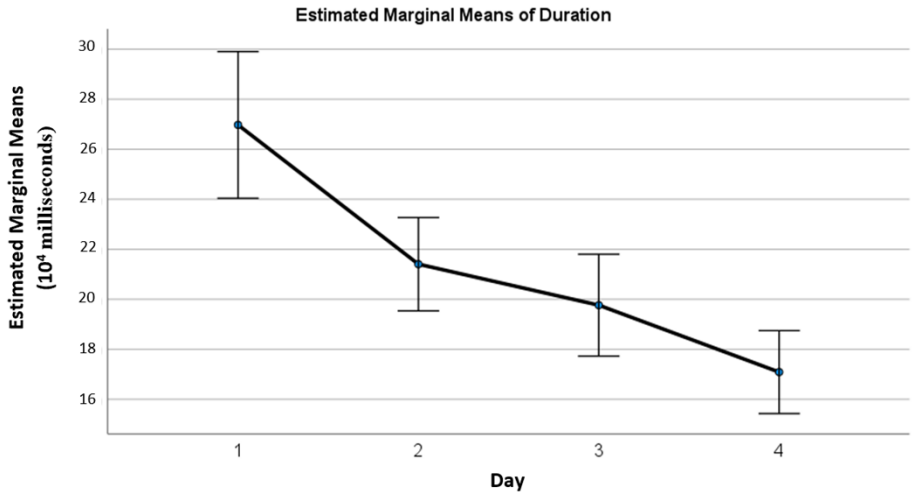
Score



Automaticity

Primary Task Duration

Primary task durations (milliseconds)			
Day	N	Mean (10^4)	Std. Deviation (10^4)
Day 1	28	26.976	7.563
Day 2	28	21.406	4.815
Day 3	28	19.767	5.254
Day 4	28	17.091	4.279



Repeated Measures ANOVA of Primary Task Duration:

Multivariate tests

Effect		Value	F	Hypothesis df	Error df	P-value
Day	Pillai's Trace	0.768	27.529[b]	3.000	25.000	<0.001
	Wilks' Lambda	0.232	27.529[b]	3.000	25.000	<0.001
	Hotelling's Trace	3.303	27.529[b]	3.000	25.000	<0.001
	Roy's Largest Root	3.303	27.529[b]	3.000	25.000	<0.001

** Design: Intercept; Within Subjects Design: Day; b. Exact statistic*

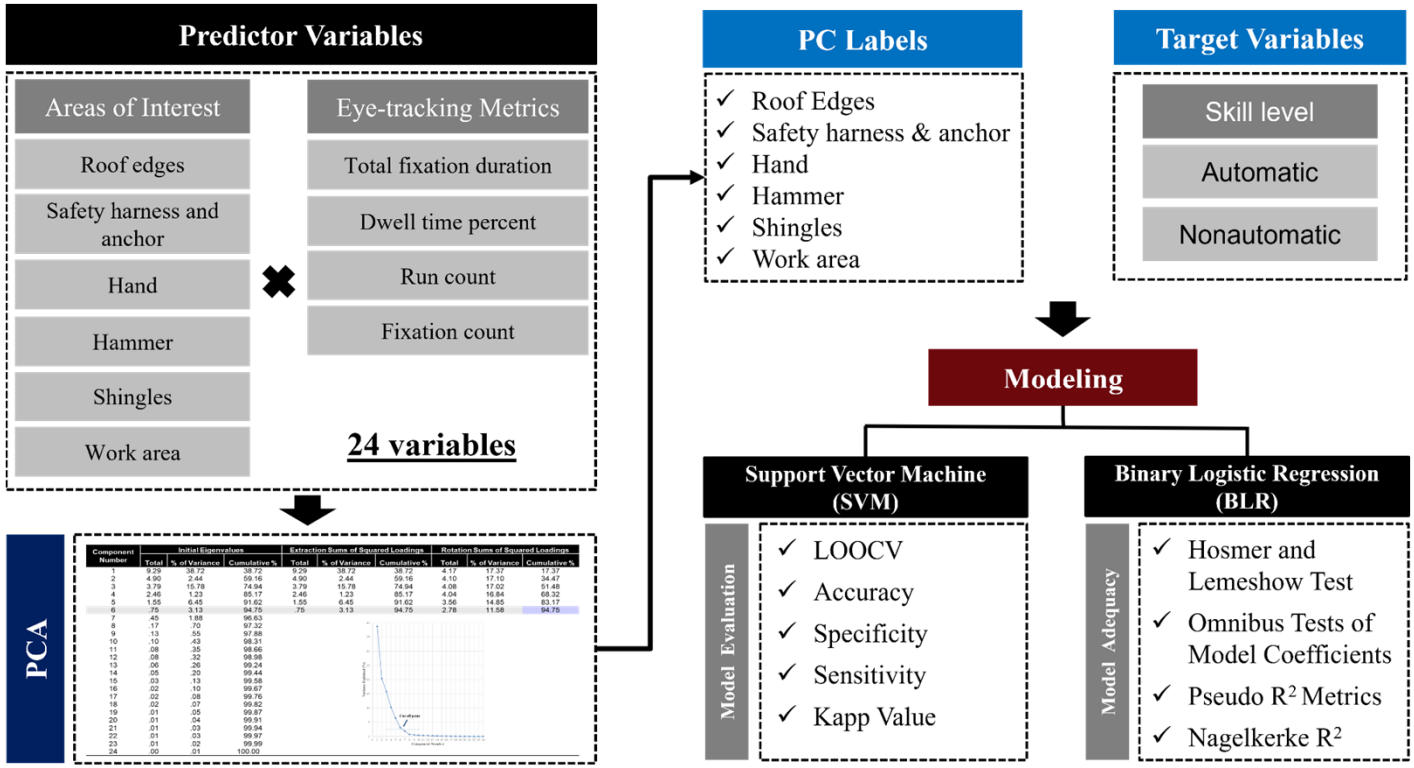
Automaticity

Descriptive Statistics of the Eye-tracking Metrics

AOIs		Total Fixation Duration		Fixation Count		Dwell Time Percent		Run Count	
	Statics	Novice	Expert	Novice	Expert	Novice	Expert	Novice	Expert
Roof Edges	Mean	0.006	0.004	0.037	0.004	0.929	0.528	0.019	0.014
	Std Dev	0.007	0.004	0.040	0.004	1.059	0.623	0.017	0.012
Safety Harness and Anchor	Mean	0.006	0.004	0.040	0.019	0.836	0.457	0.026	0.011
	Std Dev	0.006	0.005	0.036	0.023	0.864	0.583	0.020	0.013
Hand	Mean	0.015	0.014	0.085	0.074	2.117	1.996	0.044	0.043
	Std Dev	0.010	0.015	0.055	0.066	1.545	2.196	0.025	0.033
Hammer	Mean	0.013	0.005	0.075	0.035	1.758	0.677	0.040	0.023
	Std Dev	0.010	0.005	0.055	0.033	1.350	0.676	0.027	0.022
Shingles	Mean	0.067	0.048	0.385	0.314	12.838	9.248	0.117	0.122
	Std Dev	0.036	0.028	0.158	0.161	4.963	4.949	0.036	0.046
Work Area	Mean	0.185	0.125	0.972	0.708	38.704	31.774	0.155	0.134
	Std Dev	0.081	0.066	0.334	0.315	8.247	10.091	0.048	0.049

Automaticity

Data Analysis



Automaticity

Variables in the Proposed BLR Model Equation

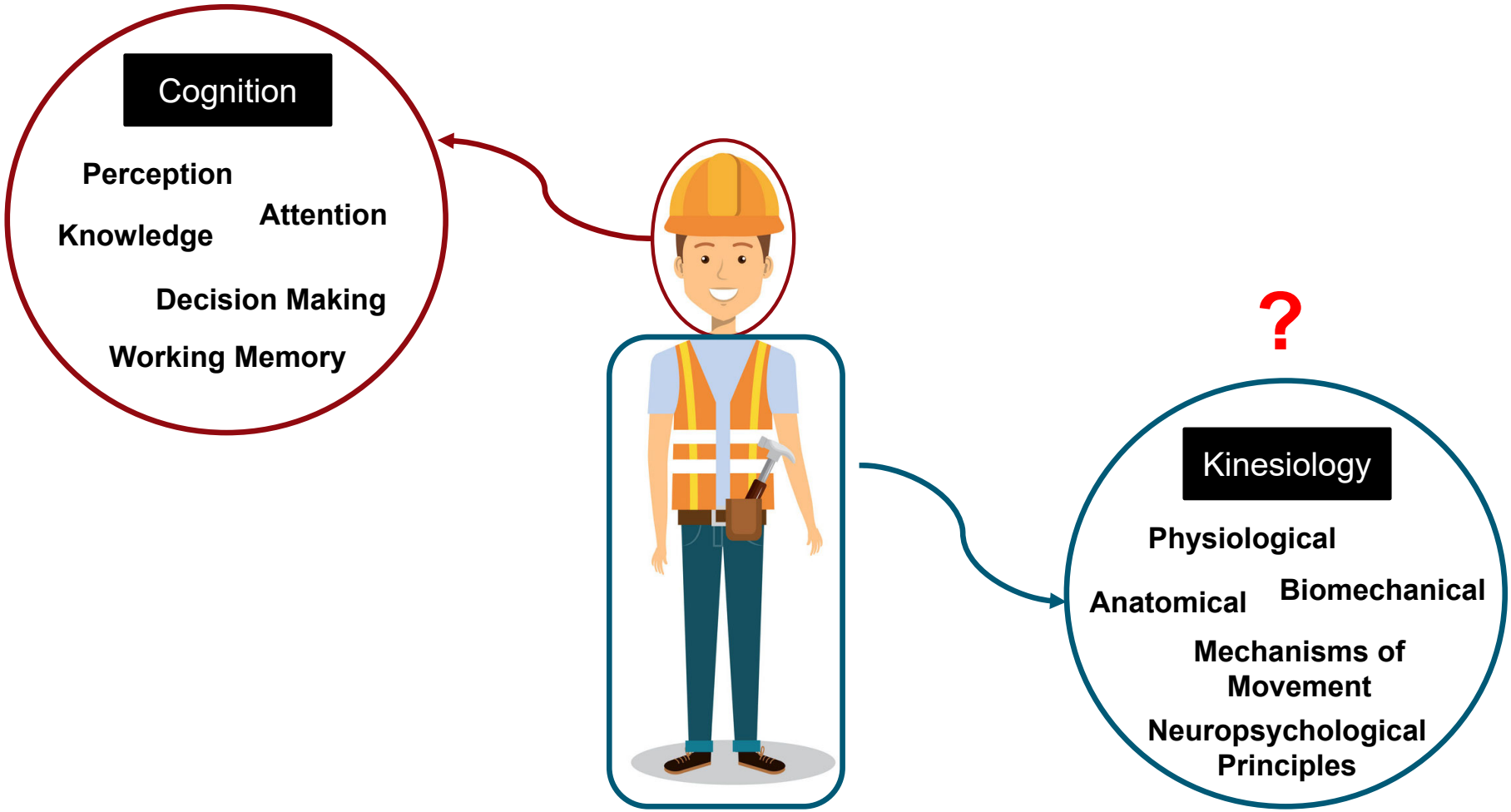
AOIs/PCs	β	S.E.	Wald	*df*	*P-value*	Exp(β)	95% C.I. for Exp(β)	
							Lower	Upper
Roof Edges	-.603	.446	1.832	1	.176	.547	.228	1.310
Safety Harness & Anchor	-1.489*	.484	9.472	1	.002	.226*	.087	.582
Hand	.445	.396	1.265	1	.261	1.560	.719	3.389
Hammer	-1.521*	.511	8.847	1	.003	.219*	.080	.595
Shingles	.248	.379	.429	1	.512	1.282	.610	2.695
Work Area	-.864*	.428	4.080	1	.043	.421*	.182	.975
Constant	-.140	.384	.132	1	.716	.870		

* The regression coefficient is significant at the .05 level.

$$\ln(odds) = -.140 - .603\text{x}AOI_{\text{Roof Edges}} - 1.489\text{x}AOI_{Safty\ Harness\ \&\ Anchor}$$
$$+ .445\text{x}AOI_{\text{Hand}} - 1.521\text{x}AOI_{\text{Hammer}}$$
$$+ .248\text{x}AOI_{\text{Shingles}} - .864\text{x}AOI_{\text{Work Area}}$$

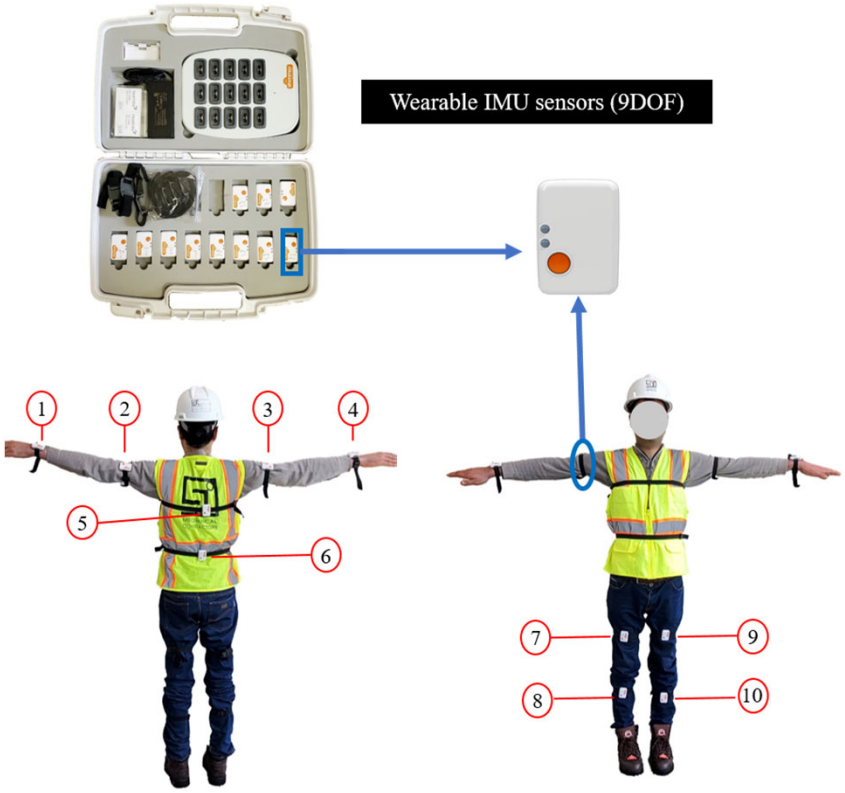
Automaticity

Evaluation Statistics	SVM (LOOCV)	BLR (LOOCV)
Accuracy	.768	.768
95% Confidence Interval	(0.636, 0.870)	(0.636, 0.870)
No Information Rate	0.5	0.5
P-Value [Acc > NIR]	3.667e-05	3.667e-05
Kappa	0.536	0.536
Precision	0.727	0.742
Sensitivity/Recall	0.857	0.821
Specificity	0.679	0.714


Cognition
Perception
Attention
Knowledge
Decision Making
Working Memory
?
Kinesiology
Physiological
Anatomical
Biomechanical
Mechanisms of Movement
Neuropsychological Principles

3. Ergonomics

Assessing Lower Extremity Kinematics of Roofing Tasks



Level-Surface (0°)

Walking

Squatting

Sloped Surface (30°)

30° Wooden Roof Platform

The Effect of Fatigue on Workers' Safety Performance

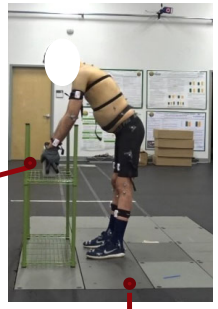
Research Questions

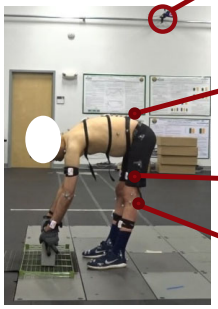
- Is the fatigue pattern different between/within the lumbar flexor and lumbar extensor muscles for cyclical lifting tasks?
- When fatigue starts? How much recovery they need?

Fatigue protocol

Oldcastle 4-in x 4-in x 16-in
Concrete A-Shaped Fence Block

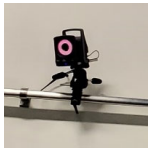
Lifting Activity





Force plate-Bertec:
- ✓ Ground reaction forces (GRF)
- ✓ Ground reaction moments (GRM)

Camera



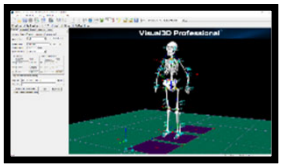
Motion capture systems

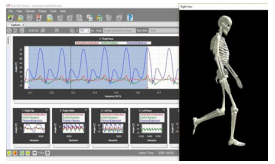
IMU shimmer

EMG Delsys

Passive reflective markers

Exoskeleton





Experiment Conditions:

No.	Factors	Level	
1	Lifting height	Below knee	Waist
2	Weight of Loads	Light	Heavy
3	Working pace	Slow	Fast
4	Fatigue	Yes/No	Yes/No

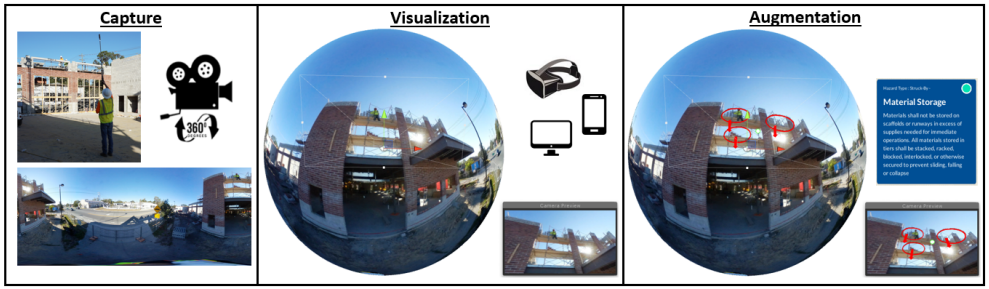
Kinematic and kinetic outputs:
- Median frequency of lumbar muscles
- Peak compressive force and Shear force at joints.
- Joint angles

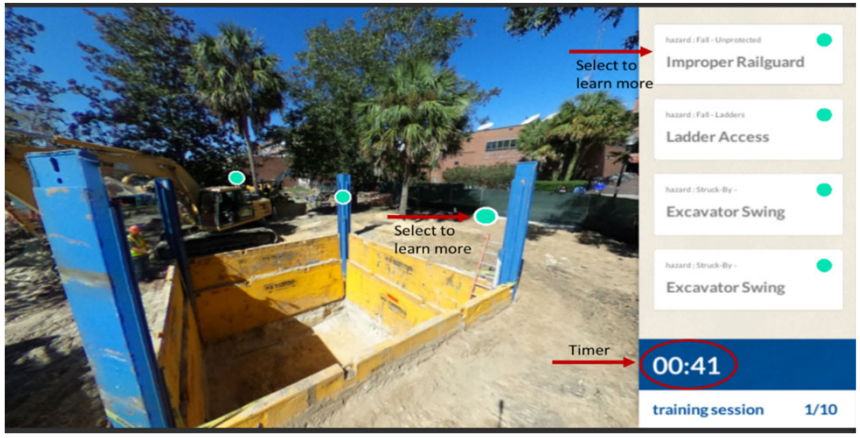
4. Training and Visualization

Visualization for Safety

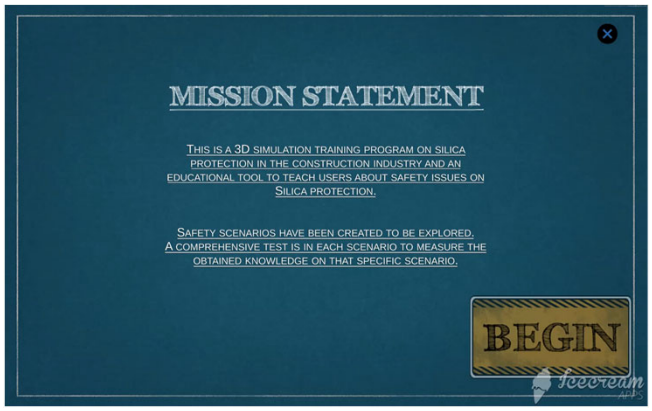
OSHA® Occupational Safety and Health Administration

CPWR THE CENTER FOR CONSTRUCTION RESEARCH AND TRAINING





Silica Hazard in Construction
(SH-05053-SH8)



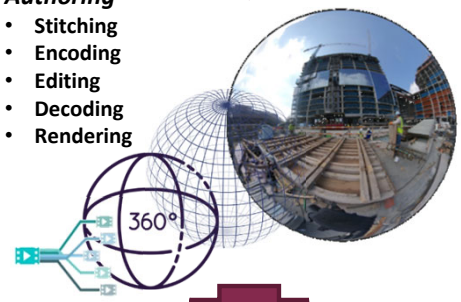
Wind Tower Construction Safety
(SHTG-FY-20-02)

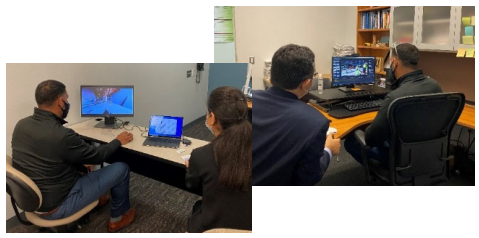
360-degree Dynamic Panorama Augmentation for a Real-Time Safety Warning

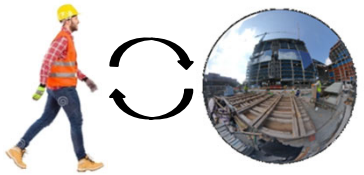
Pool of Scenario

Authoring

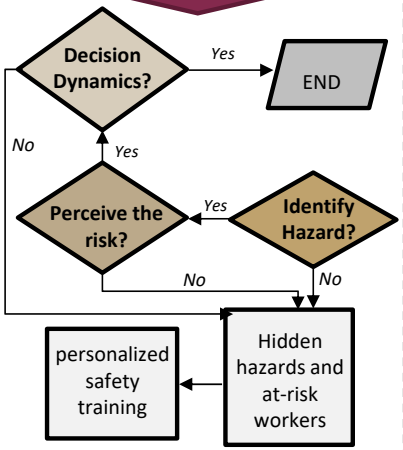
- Stitching
- Encoding
- Editing
- Decoding
- Rendering







Worker-Jobsite Interaction



Assessing Situation Awareness of Workers Under 23 Scenarios

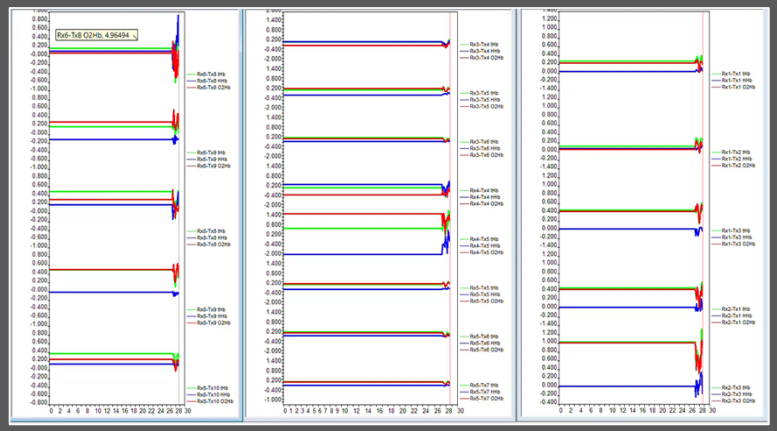
Decision-making and biases

unity ***Immersion***

Risk perception and emotional state

360-degree Dynamic Panorama Augmentation for a Real-Time Safety Warning

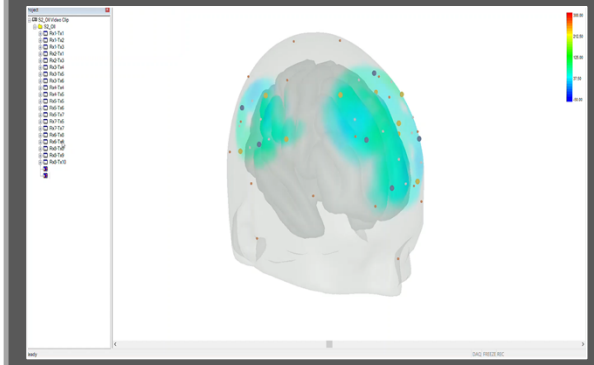
OxySoft Brite-fNIRS



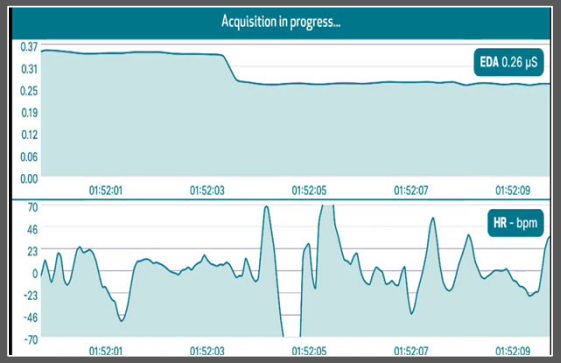
At Jobsite

360 Panoramic Augmentation

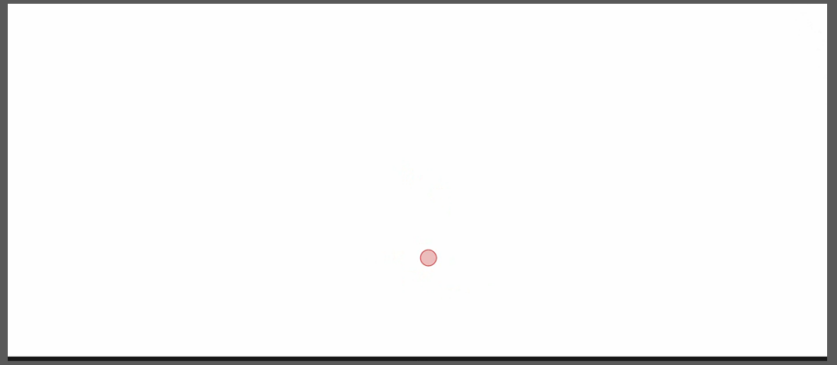
Brain Activation



E4 Empatica (GSR and HR)

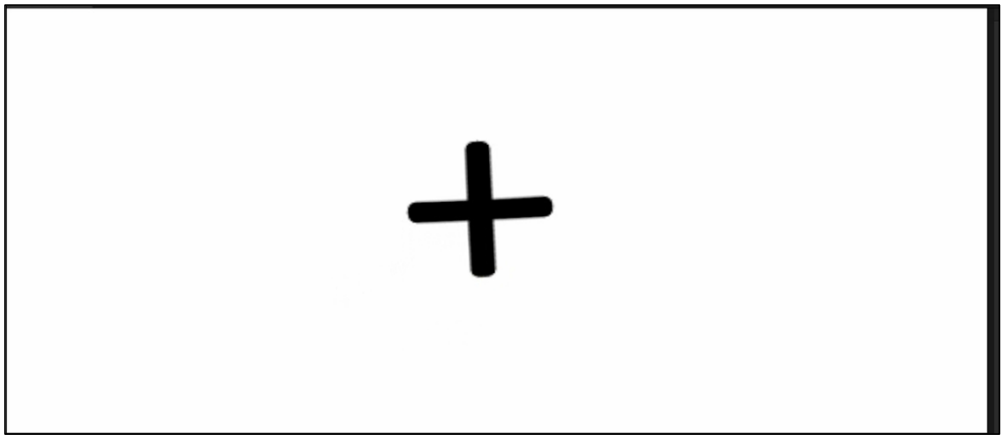


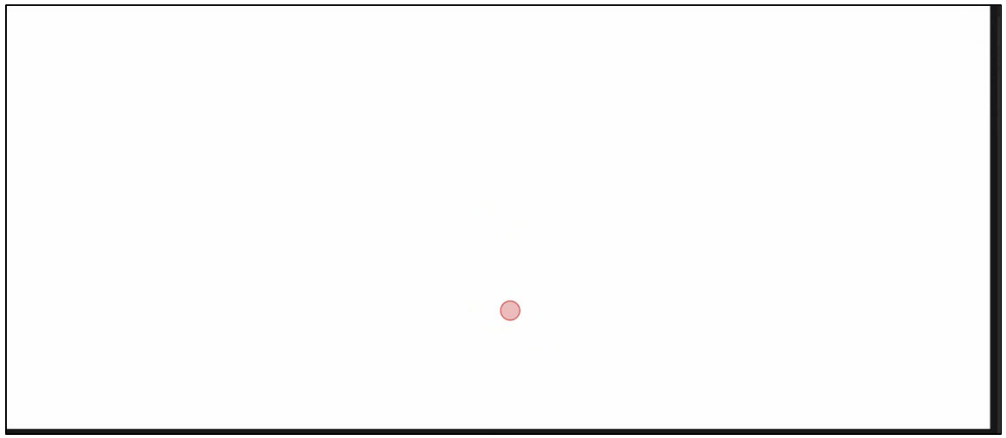
Real-Time Attentional Distribution



360-degree Dynamic Panorama Augmentation for a Real-Time Safety Warning

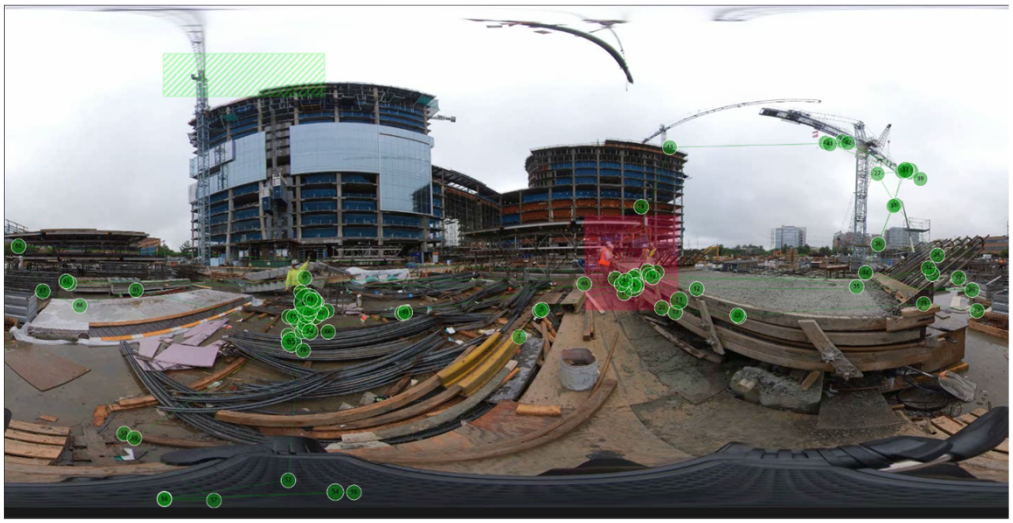
Internal factors (e.g. different abilities of situational awareness)



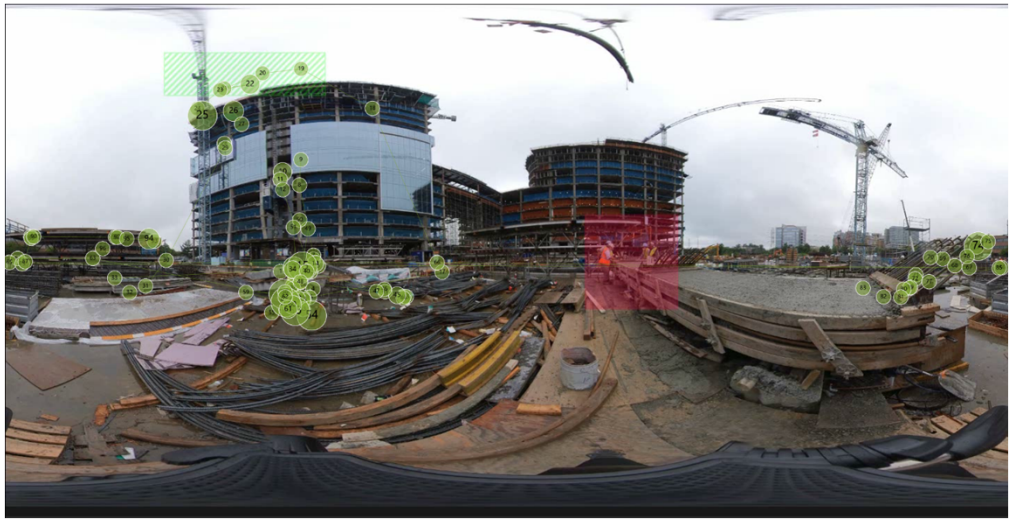


- **Lower situational awareness**
- **Higher situational awareness**

360-degree Dynamic Panorama Augmentation for a Real-Time Safety Warning



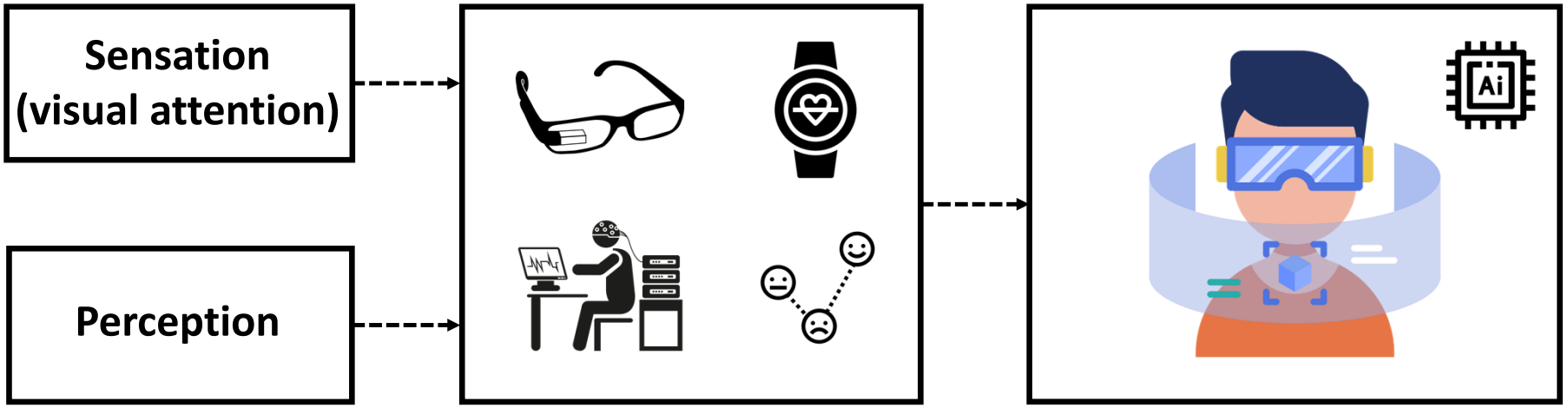
- Lower situational awareness



- Higher situational awareness

Overall Goal

The overall goal of this research is to translate **non-invasive neuro-psychophysiological metrics** (e.g., brain signals, emotional responses, eye movements) into **information personalized AI-based training systems**



Training Development

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

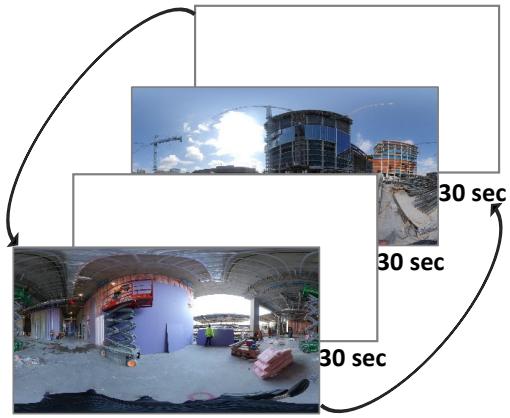
Demographic and psychographic survey

Instruction of whole experimental process

Image-based experiment

Video-based experiment

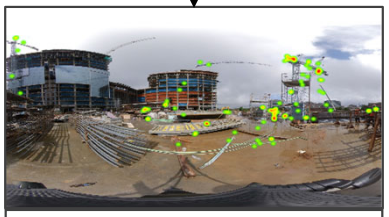
Cycle continues for all 23 scenarios



30 sec

Data Collection and Analysis

Immersion



Embedded Eye-tracking

Number of identified hazards for each scenario

Hazard identification performance (calculate HII)

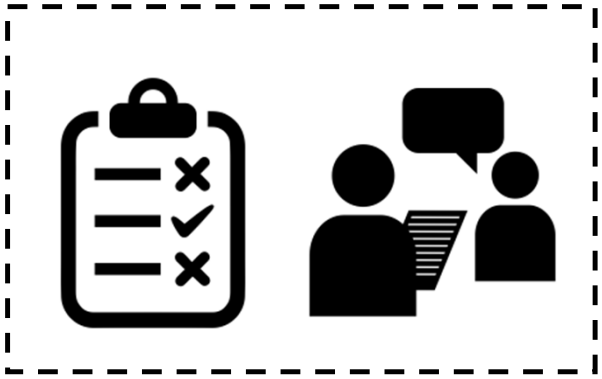
Visual search strategies

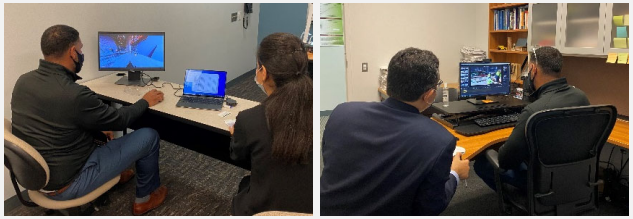
Assess an impact of the hazard delivery methods on worker's hazard identification ability and visual search strategies

Training Development

- **Hazard identification index (HII)**

- **Subjective hazard identification and demographic data**





- **Identifying hazards by safety professional**

- **Predefined hazards**

- **Worker's subjective hazard identification by using surveys and interviews**

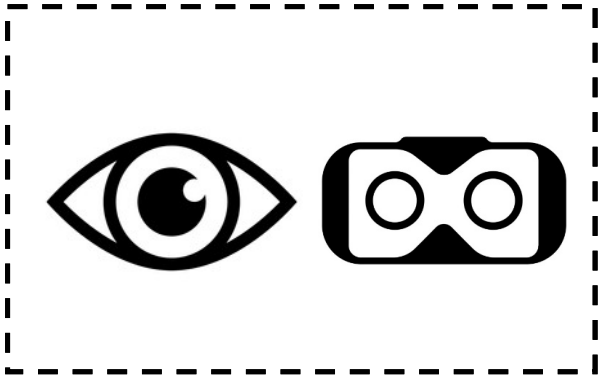
- **Individual hazard identification index (HII) score**

$$0.5 = \frac{2 = (number\ of\ identified\ hazards)}{4 = (total\ number\ of\ hazards)}$$

Training Development

- **Eye-tracking data**

- **Various eye-tracking metrics (e.g., fixation duration and count)**

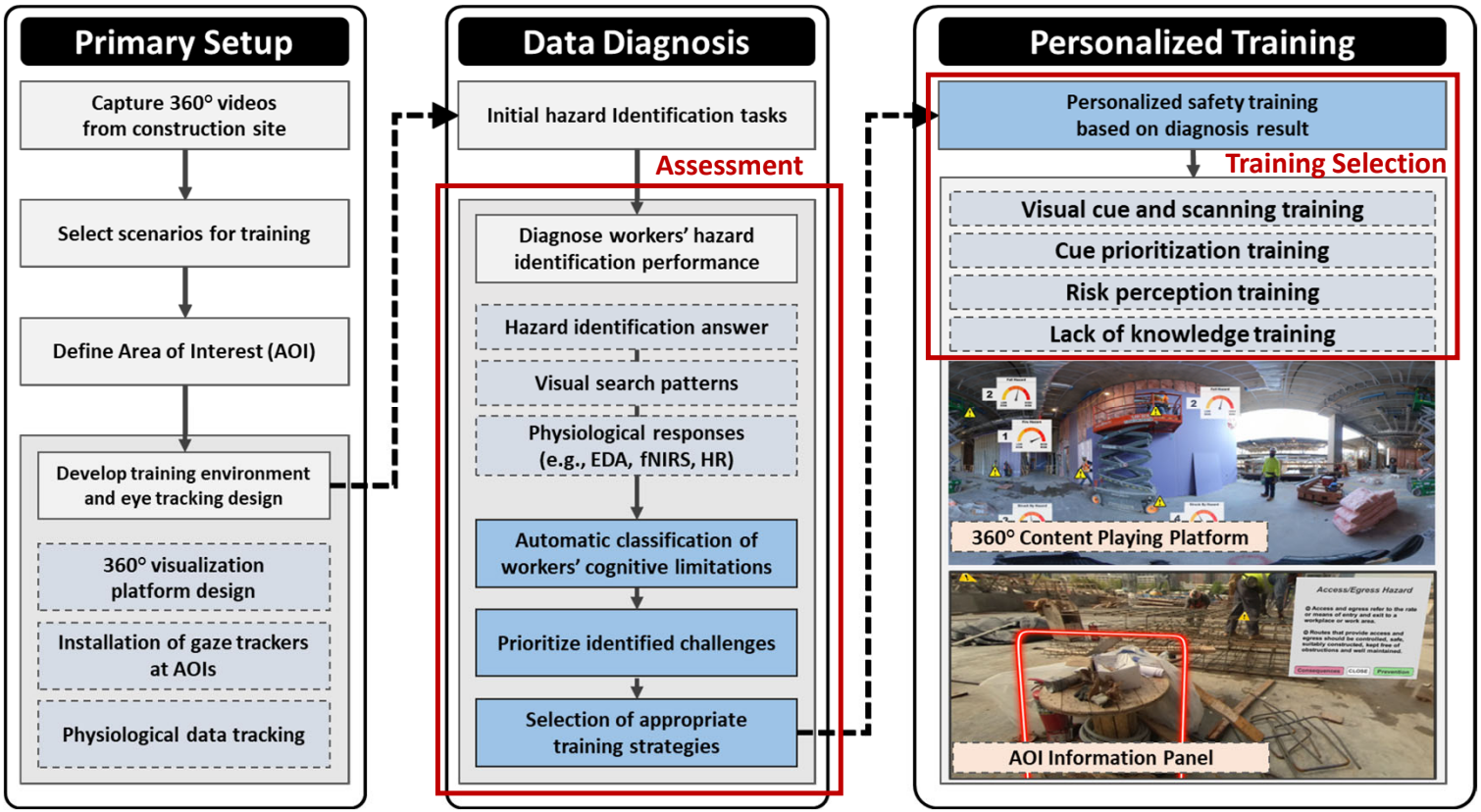


- **Area of Interest (AOI) was marked in each scenario based on predefined hazards**

Embedded eye-tracker

Training Development

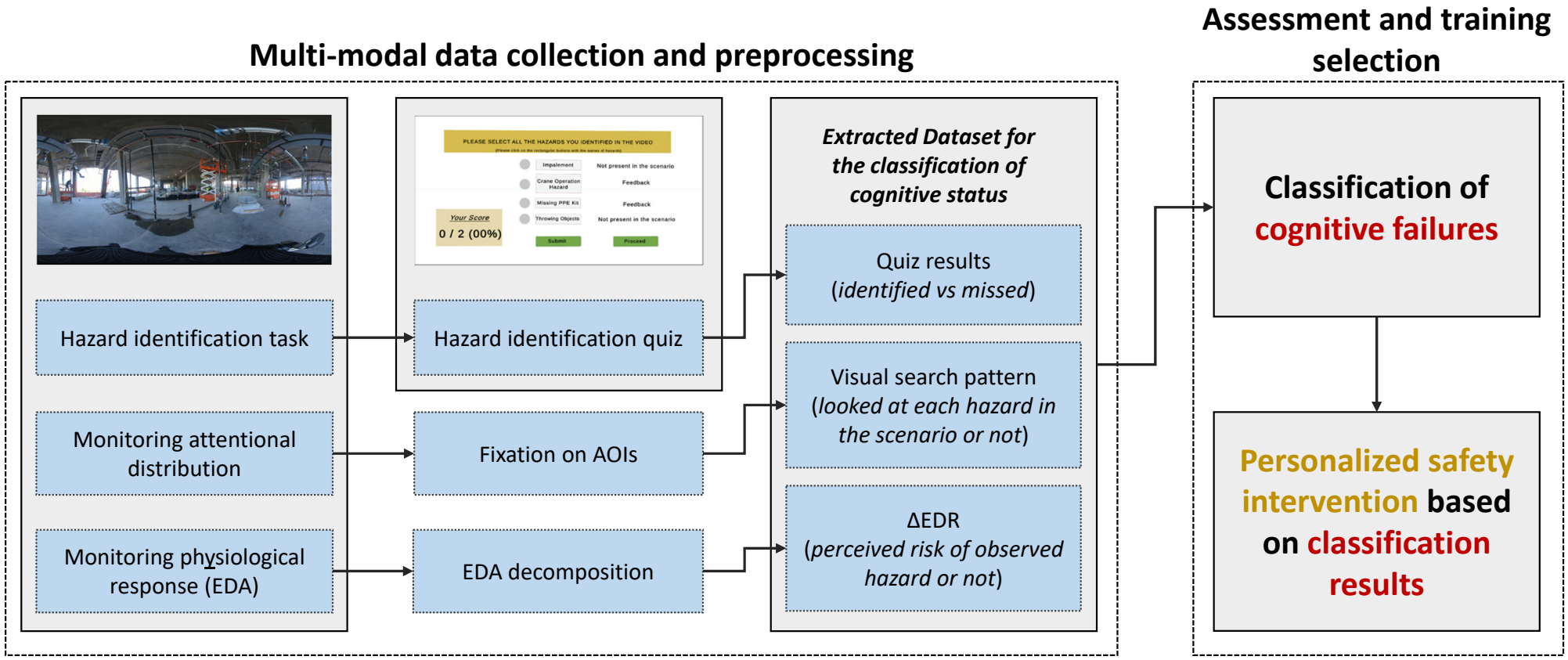
- **Framework of the proposed safety training**



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**



Training Development

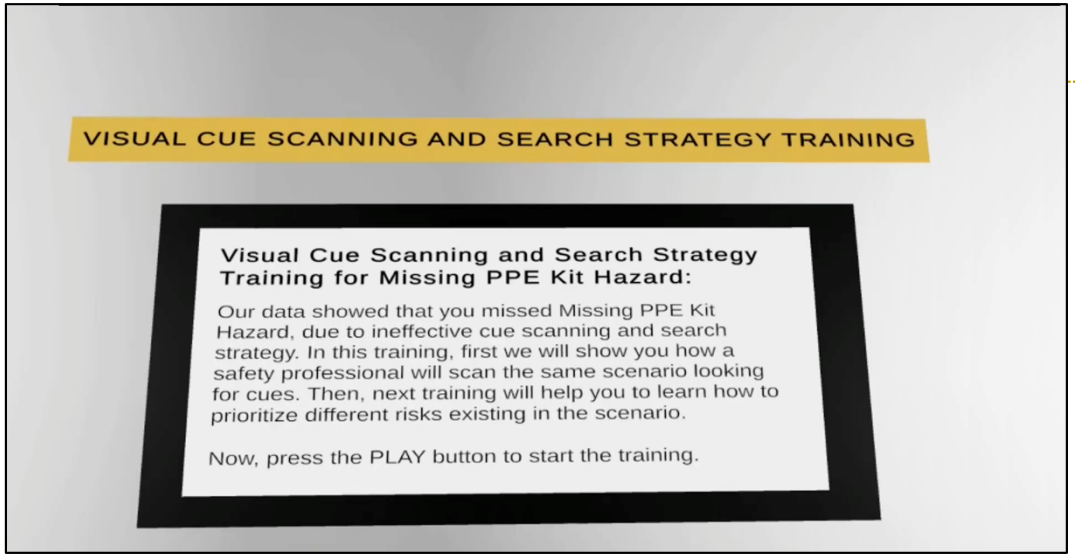
- **Cognitive failures and classification mechanisms**

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

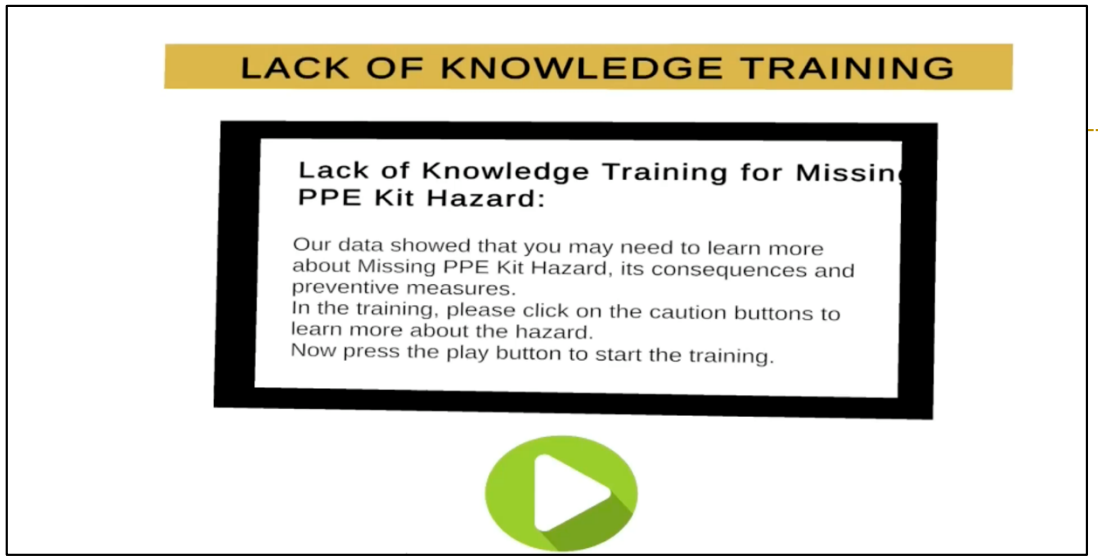
- **Cognitive failures and recommended interventions**

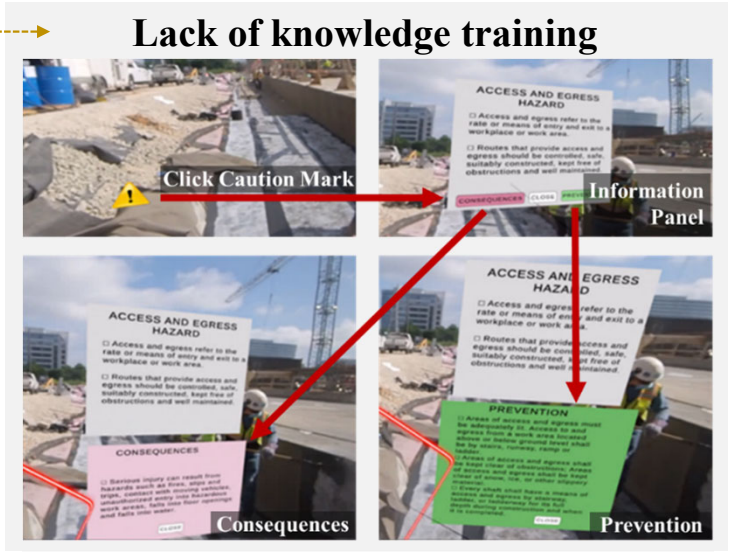


Aiming to enhance workers' fundamental visual scanning abilities by showing an expert's visual search patterns

Training Development

- **Cognitive failures and recommended interventions**

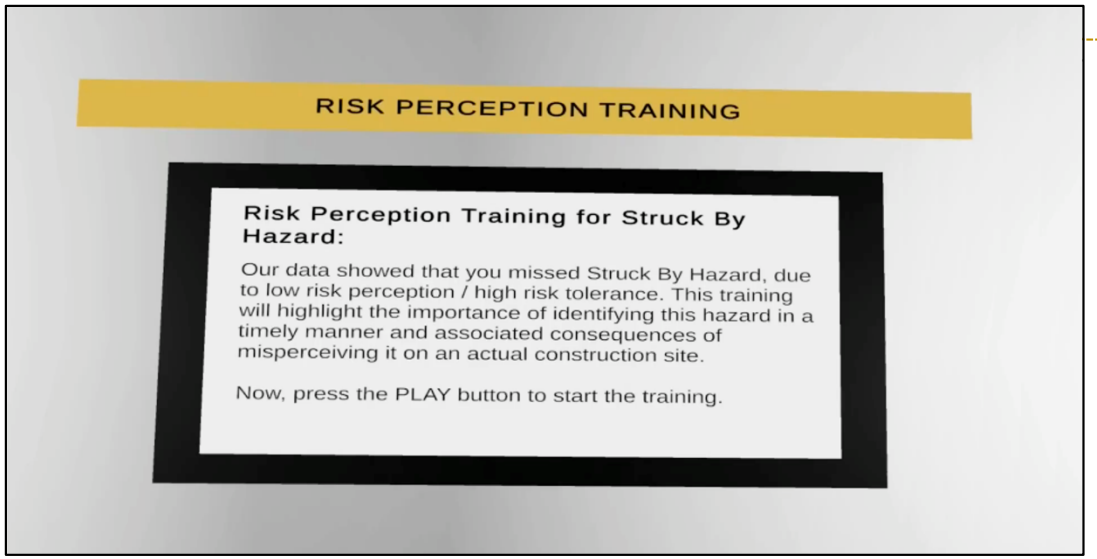




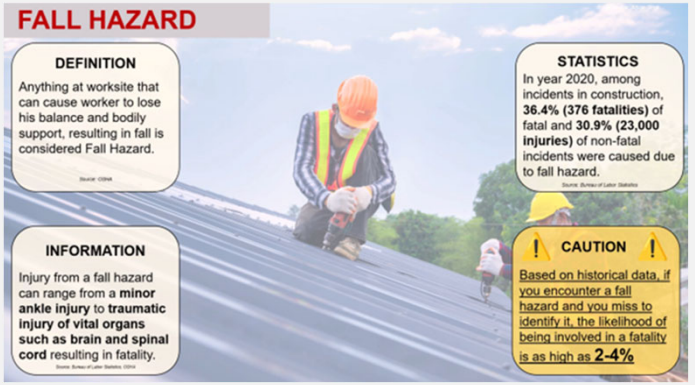
Aiming to enhance workers' safety knowledge by providing relevant information regarding different hazards

Training Development

- **Cognitive failures and recommended interventions**



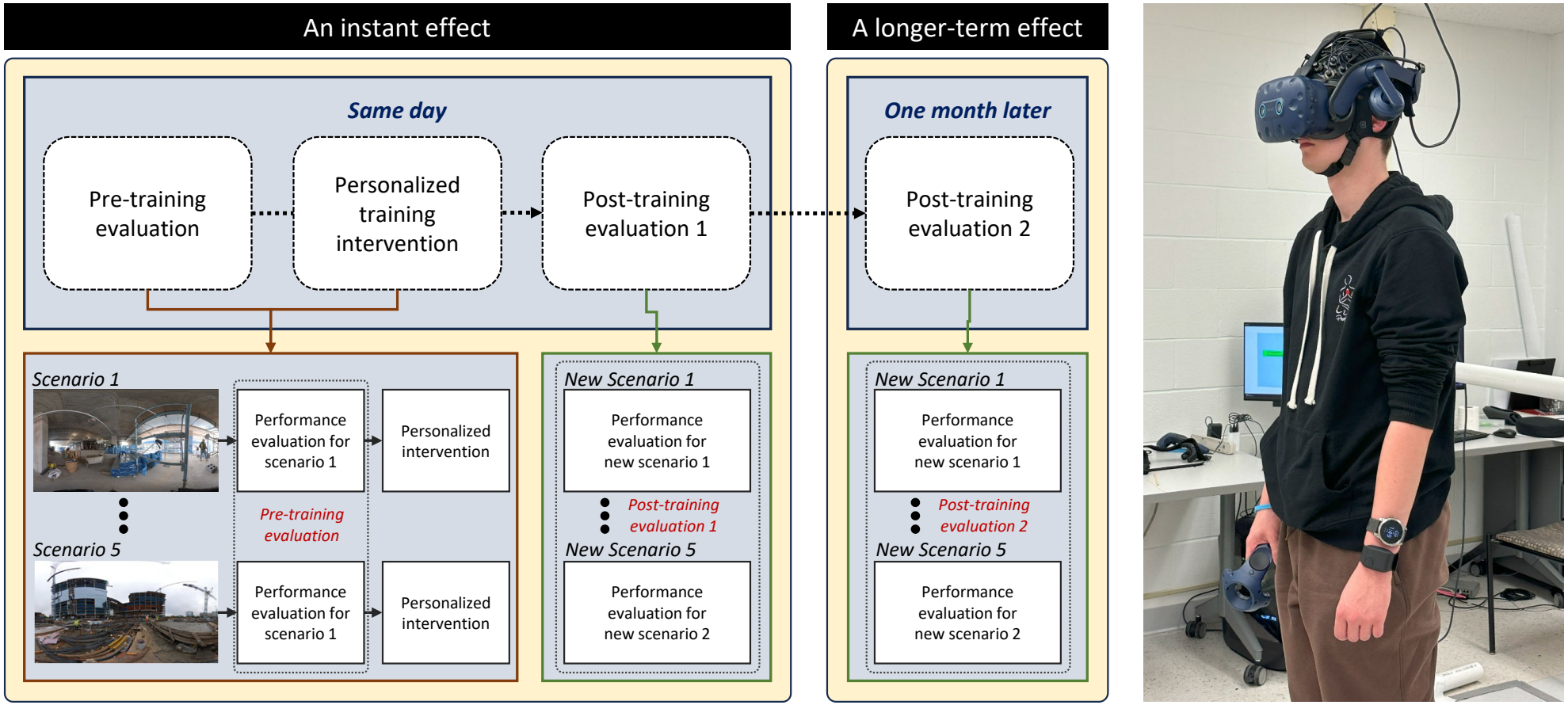
Risk perception training



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

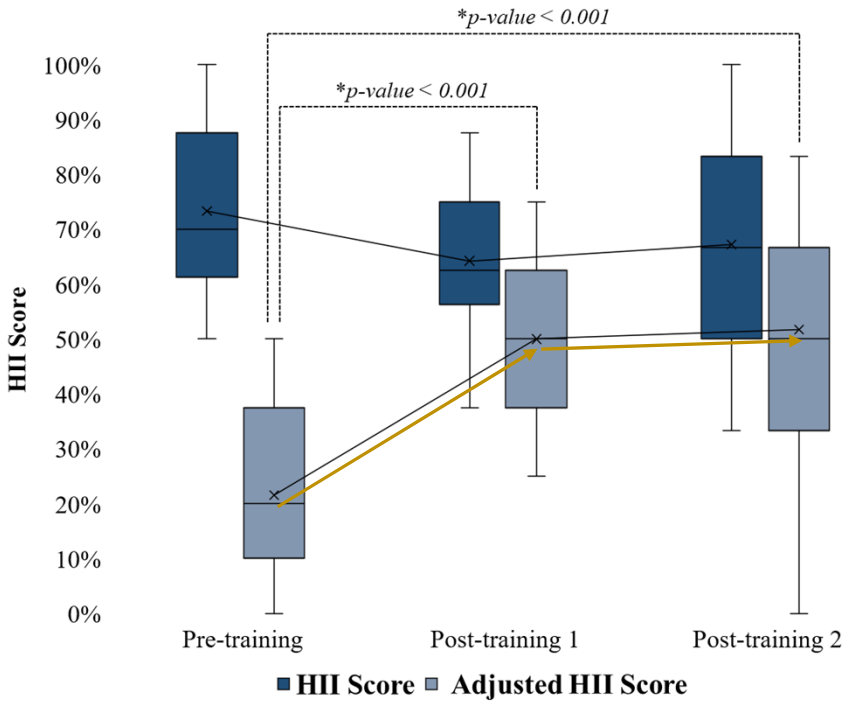
Training Development

- **Overview of the validation process**



Training Development

- **Improvement in hazard Identification performance**



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

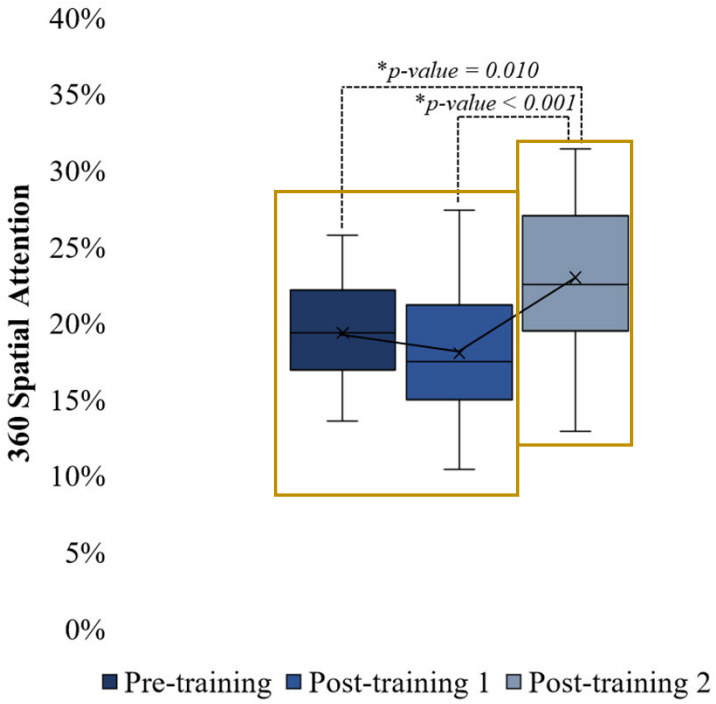
vs.

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

Training Development

- **Improvement in visual search strategies**



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

↑

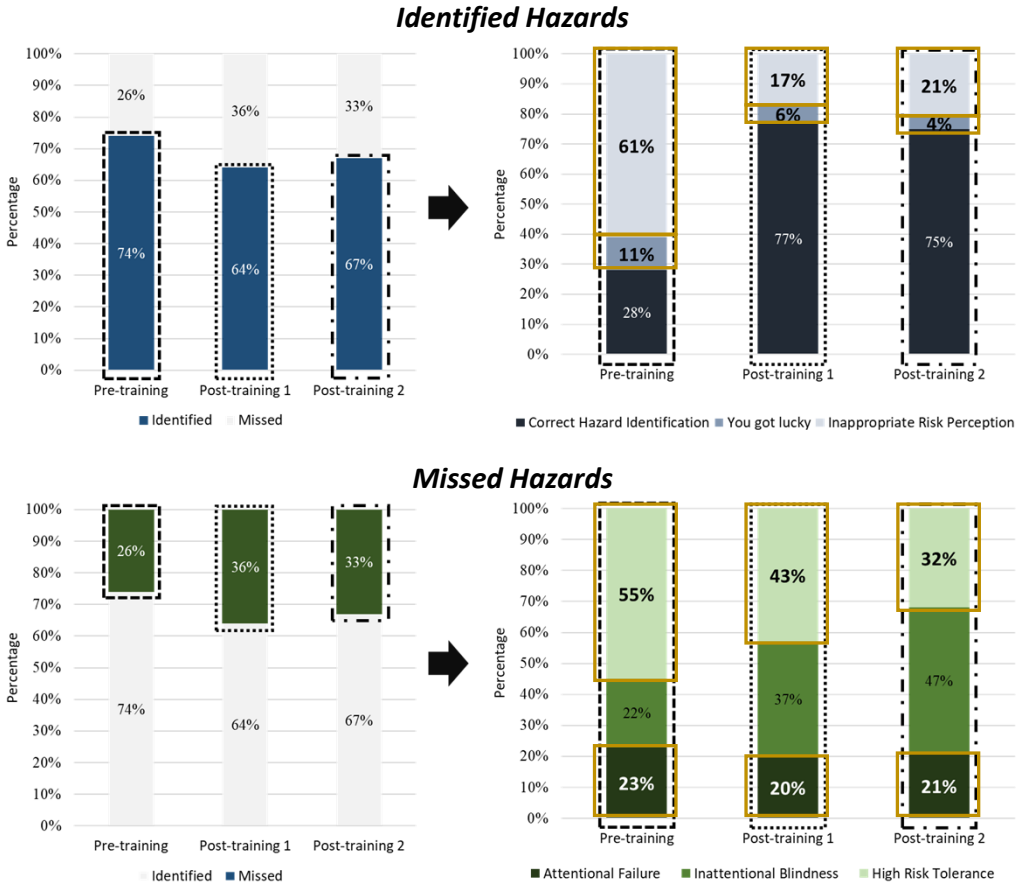
***Virtual reality fatigue* from experimental design**

Participants' 360 spatial attention abilities were remarkably improved in Post-training session 2

(Improvement in visual search skills)

Training Development

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



Perceptual-based errors were **significantly** reduced in post-training sessions

Skill-based errors were **marginally** reduced in post-training sessions

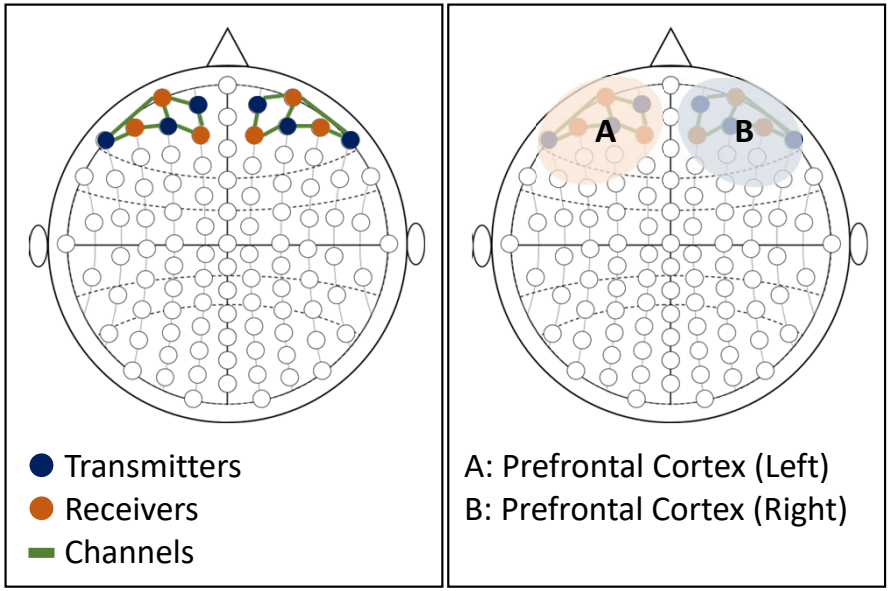
Knowledge acquisition **VS.** ***Skill development***

Require repeated training

Training Development

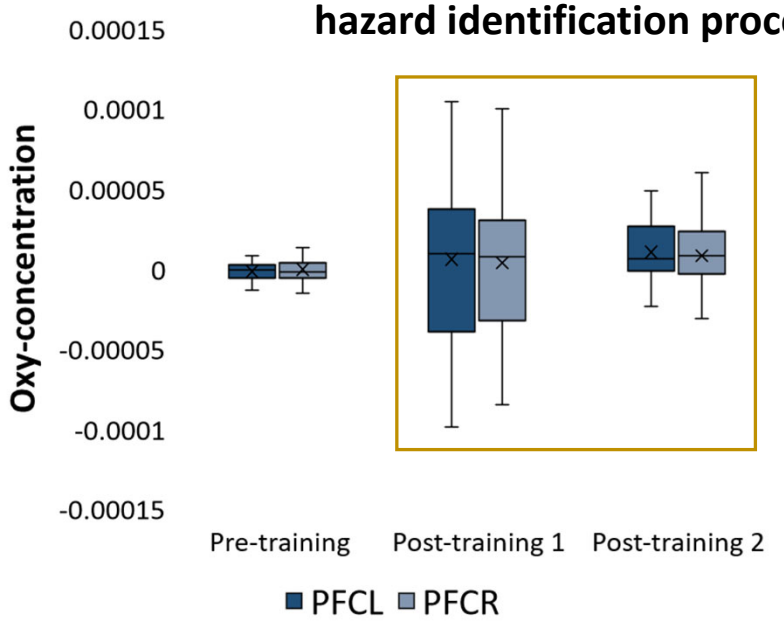
- **Changes in brain activation**

Optodes' arrangement **Defined ROIs**



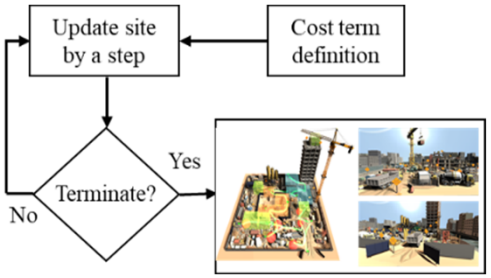
Functionality of PFC: Decision-making / Integrating sensory information

More actively engaged in hazard identification process

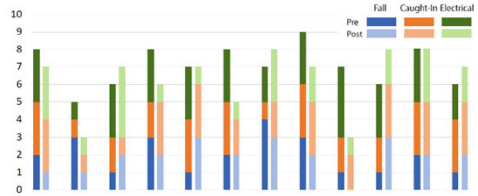


Slightly higher activation of prefrontal cortex in Post training sessions

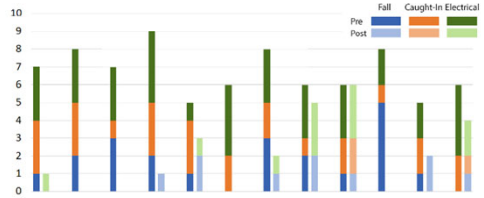
Synthesizing and Personalizing Safety Training Scenarios



$$C_{\text{total}}(R,H) = w_{\text{D}}C_{\text{D}}(R,H) + w_{\text{S}}C_{\text{S}}(R,H) + w_{\text{T}}C_{\text{T}}(R,H),$$

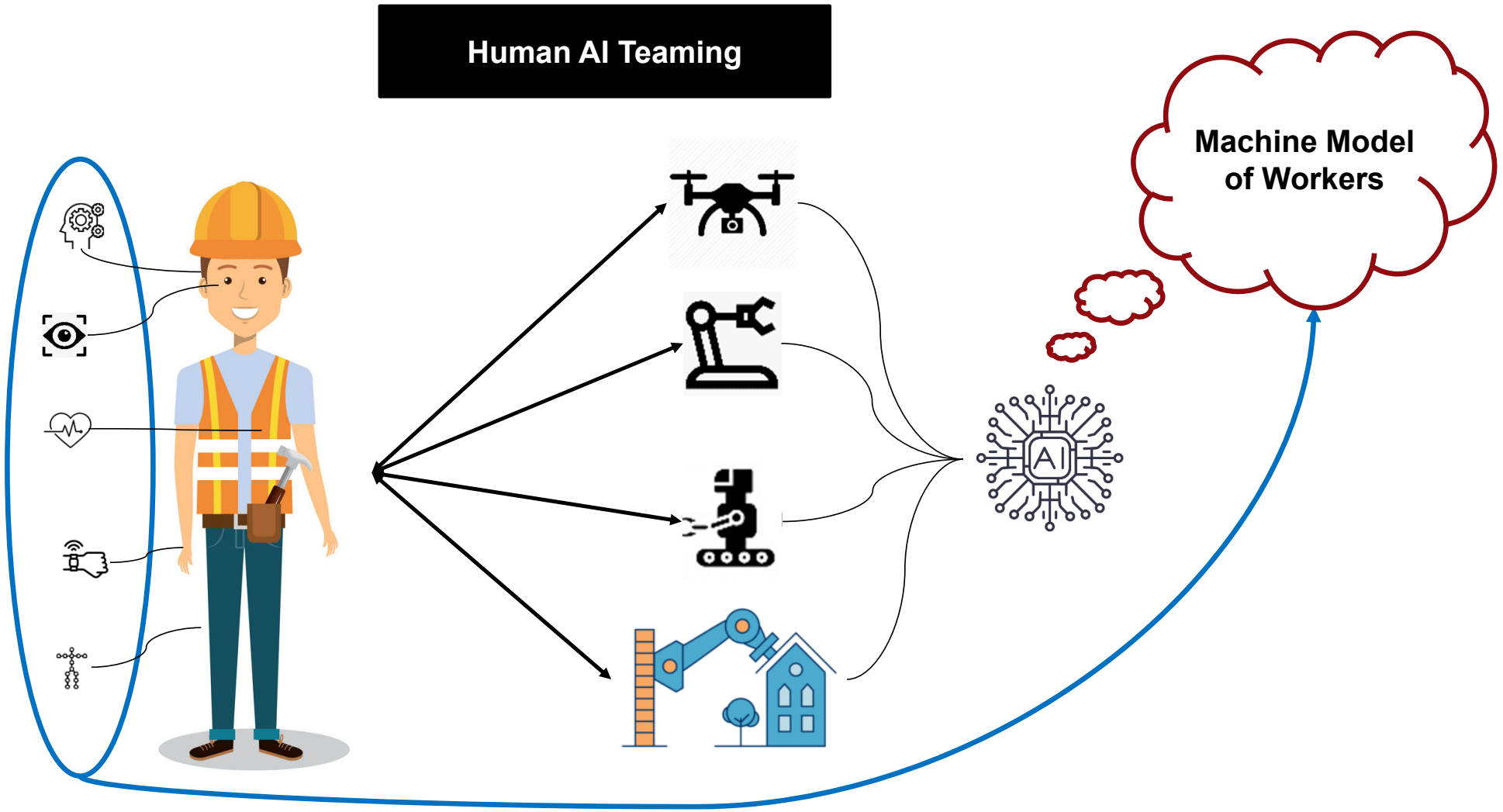


(a) The Control Group.

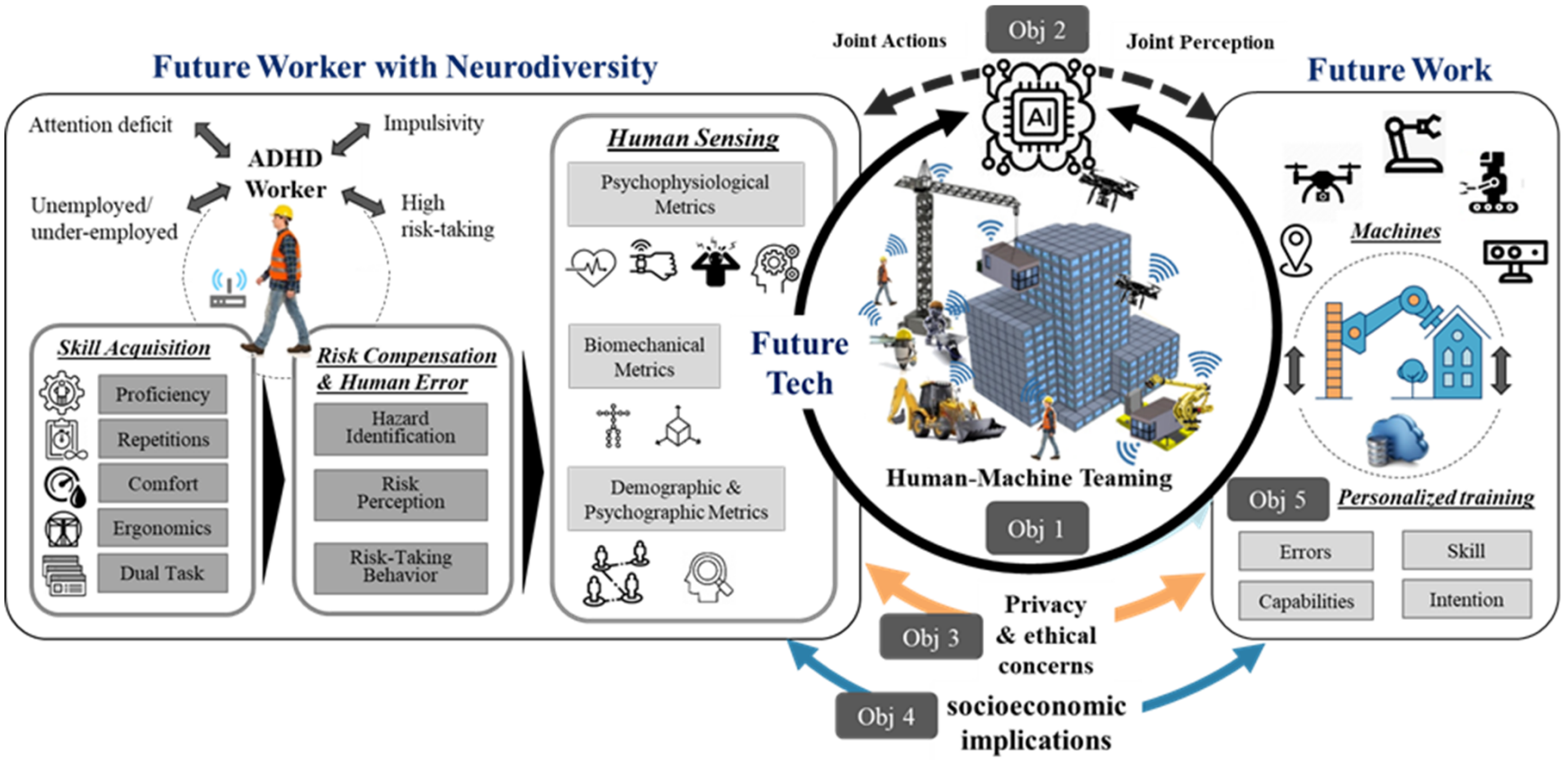


(b) The VR Group.

5. Cyber-Physical-Human Systems


Human AI Teaming
Machine Model of Workers
AI

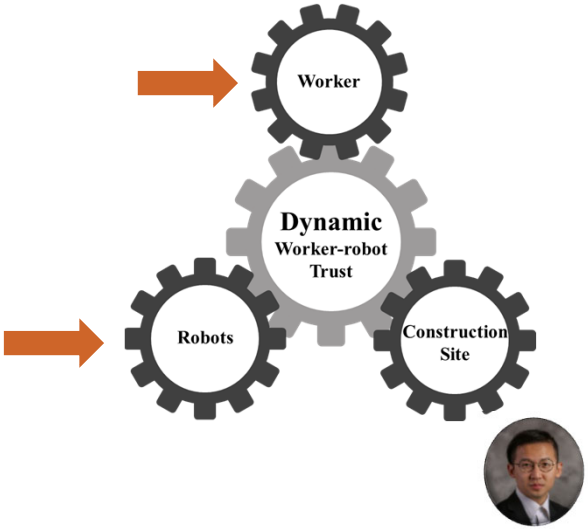
Worker-AI Teaming to Enable ADHD Workforce Participation



Worker-Autonomy Trust

- **Attributing Responsibility for Performance Failure on Worker-robot Trust in Collaborative Tasks**

Chang, W. C., Ryan, S. M., Hasanzadeh, S., & Esmaeili, B. (2023, July). Attributing responsibility for performance failure on worker-robot trust in construction collaborative tasks. In EC3 Conference 2023 (Vol. 4). European Council on Computing in Construction. ***(Best paper)***



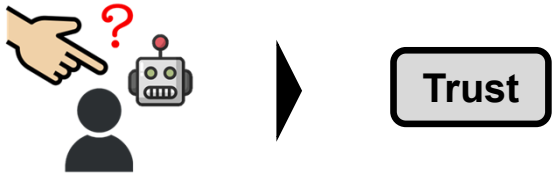
Attributing Responsibility for Performance Failure on Worker-robot Trust in Collaborative Tasks

- The **perfection** of autonomous agents still **cannot be guaranteed**, especially in such dynamic and unpredictable workplaces.
- Their unexpected performance (e.g., **failures**) will **decrease human trust** levels.
- In human-robot collaboration, **responsibility attribution for the failures** could be **humans** (*wishful thinking*) or **robots** (*self-serving bias*).
- Two types of **trust transfer** (i.e., **multi-tasks** and **multi-agents**) have been proposed by the literature.

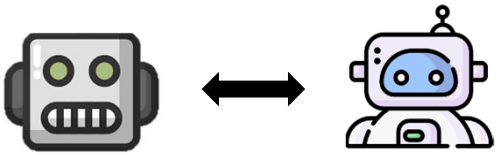
Attributing Responsibility for Performance Failure on Worker-robot Trust in Collaborative Tasks

Limitations of current literature:

1. *The impact of **responsibility attribution** for failures on **trust***



2. *Limited discussion on **multi-agent trust transfer***



This study aims to investigate the effect of **attributing responsibility for failure** and **trust transfer** on worker-robot trust in the future jobsite

Attributing Responsibility for Performance Failure on Worker-robot Trust in Collaborative Tasks

Autonomous Agents

Bricklaying Robot

(Lift/drop blocks)

Drones

(inspection, survey, delivery)

AI-assistant

(Provide drone info.)

Data Collection

1 HTC VIVE

(eye-tracking)

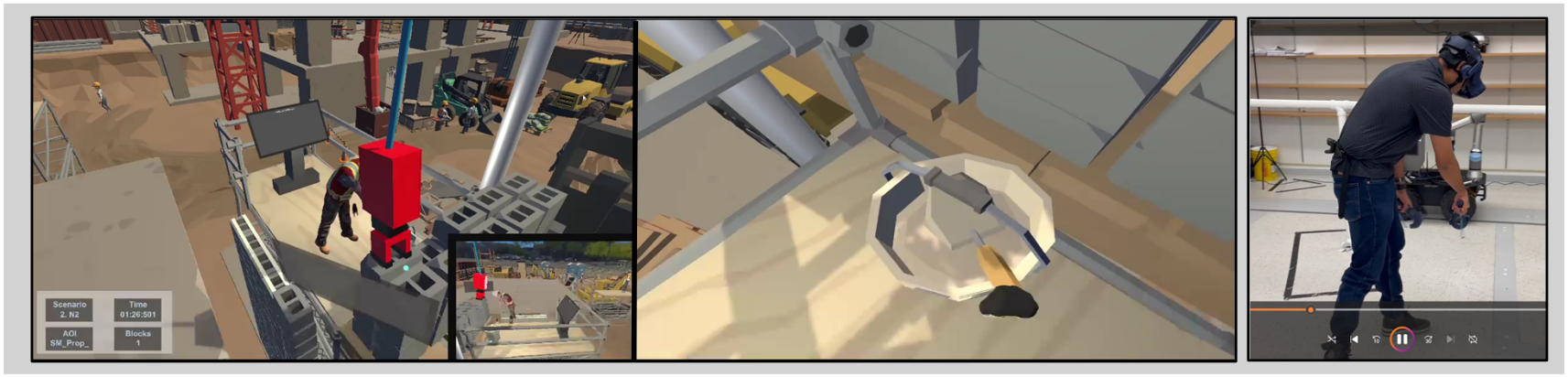
2 Trackers

(motion)

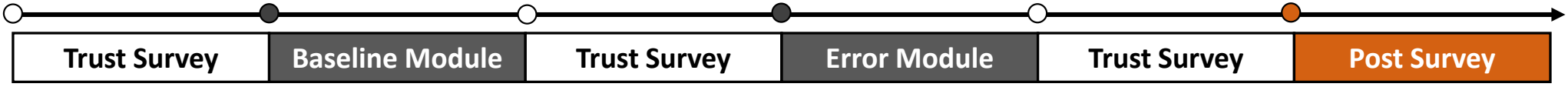
3 Sensors

(Psychophysiological)

Synchronization



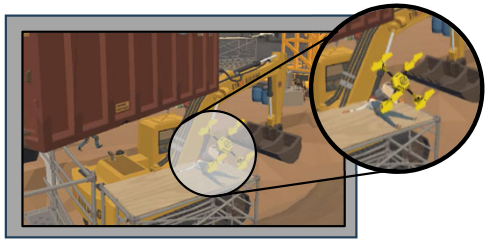
Attributing Responsibility for Performance Failure on Worker-robot Trust in Collaborative Tasks



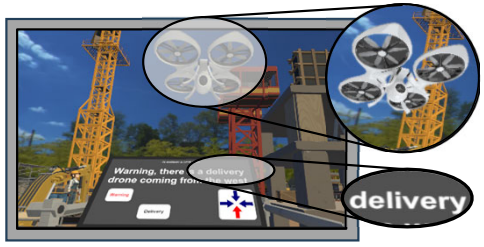
- To what extent the auto-agent's behavior can be **predicted**?
- To what extent can you **depend** on the auto-agent to do its job?
- What degree of **faith** do you have that the auto-agent will be able to cope with similar situations in the future?
- Overall, how much do you **trust** the auto-agent?

(1) ~ (5)

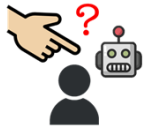
"Robot failure"



Drone failure



AI-assistant failure



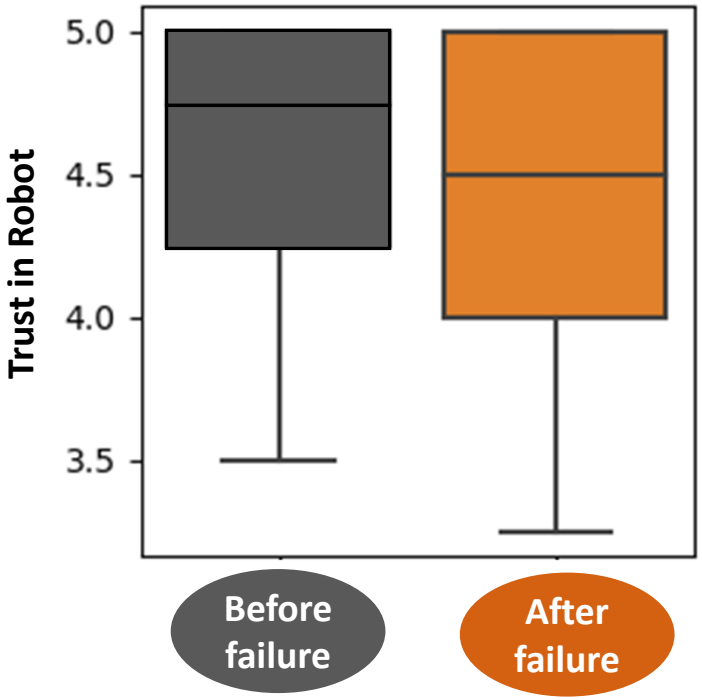
Responsibility Attribution

Human

Robot

Attributing Responsibility for Performance Failure on Worker-robot Trust in Collaborative Tasks

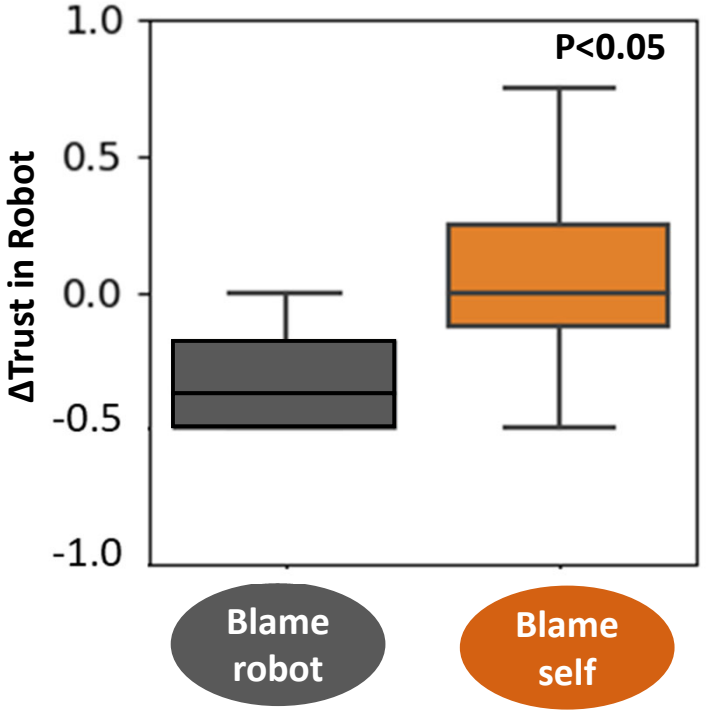
*The impact of **robot failures** on trust changes*



> ***Robot failure** did **not** significantly affect worker **trust***

Attributing Responsibility for Performance Failure on Worker-robot Trust in Collaborative Tasks

*The impact of **responsibility** on trust changes*

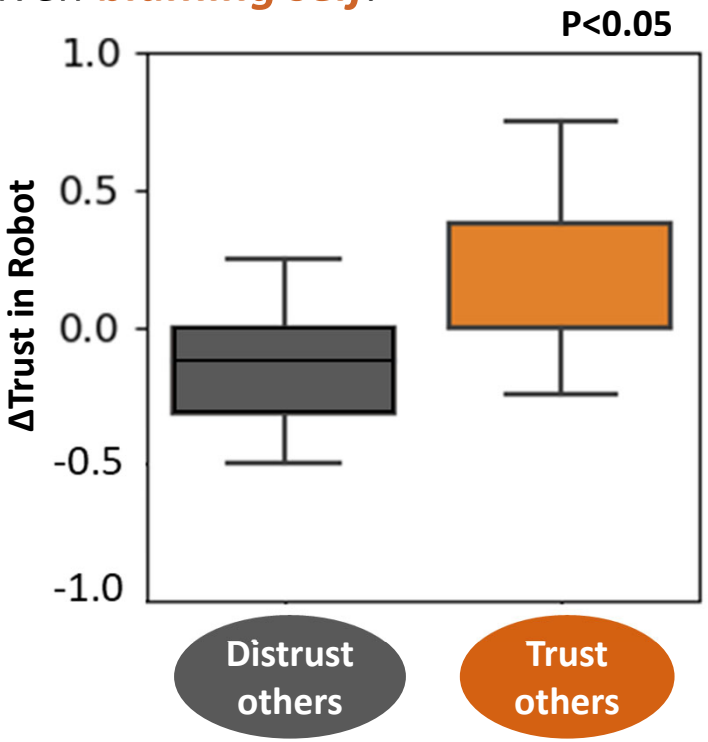


Robot failure** did **not** significantly affect worker **trust

Attributing responsibility** significantly affected workers' **trust changes

Attributing Responsibility for Performance Failure on Worker-robot Trust in Collaborative Tasks

*Given **blaming self**:*



Robot failure** did **not** significantly affect worker **trust

Attributing responsibility** significantly affected workers' **trust changes

Distrust in other agents** significantly affected workers' **trust change

Attributing Responsibility for Performance Failure on Worker-robot Trust in Collaborative Tasks

Robot failure *did* ***not*** *significantly affect worker* ***trust***

Attributing responsibility *significantly affected workers'* ***trust changes***

Distrust in other agents *significantly affected workers'* ***trust change***

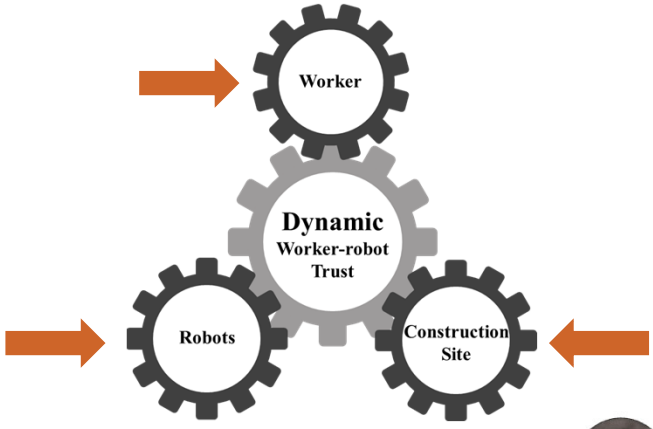
Those participants might ***overtrust*** *a faulty auto-agent*

Inappropriate *trust transfer might lead to* ***overtrust*** */* ***undertrust***

Safety issues

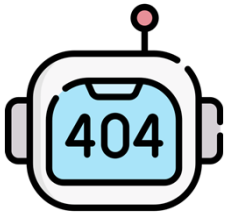
Situational Awareness

- **The Importance of Situational Awareness (SA) in Future Jobsite: Toward the Effects of Faulty Robot, Trust, and Time Pressure**



The Importance of Situational Awareness (SA) in Future Jobsite: Toward the Effects of Faulty Robot, Trust, and Time Pressure

- Workers must **allocate attention** to dynamic objects (e.g., robots) to maintain **situational awareness** (SA).
- The **decreasing trust**, caused by failures, makes workers **more attentive to robots**.
- **Time pressure** forces workers to focus on the designated tasks and to become **less attentive to robots**.



The Importance of Situational Awareness (SA) in Future Jobsite: Toward the Effects of Faulty Robot, Trust, and Time Pressure

Limitations of current literature:

1

*Not considering the impacts of **robot-related** and **work-related** factors on **trust** simultaneously*

This study aims to examine which factor plays a **dominating role** in affecting workers' SA

The Importance of Situational Awareness (SA) in Future Jobsite: Toward the Effects of Faulty Robot, Trust, and Time Pressure

Autonomous Agents

Bricklaying Robot

Drones

AI-assistant

(Dynamic objects)

Data Collection

1 HTC VIVE

2 Trackers

3 fNIRS

(Eye-tracking)

Performance Metrics

Dwell Time

Run Count

Dynamic drones

(Situational Awareness) (Areas of Interest)

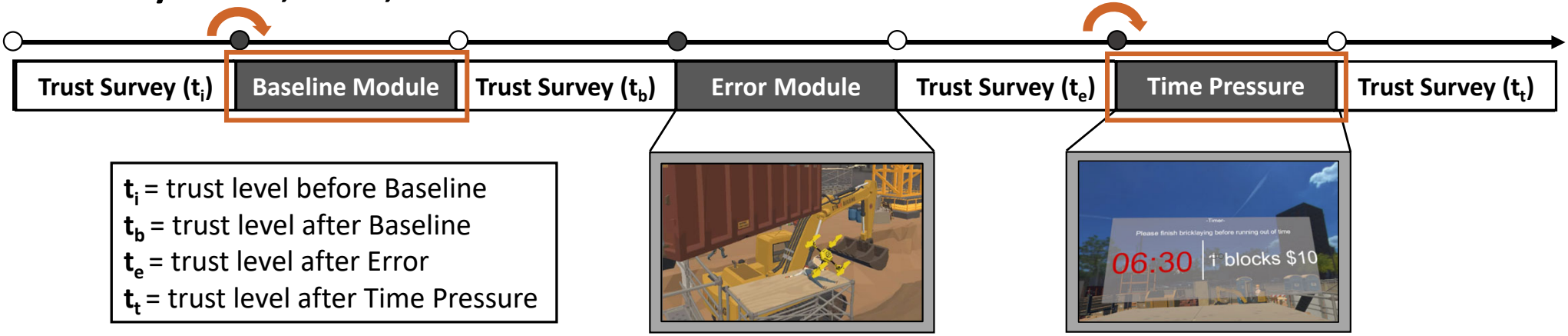
Dwell Time

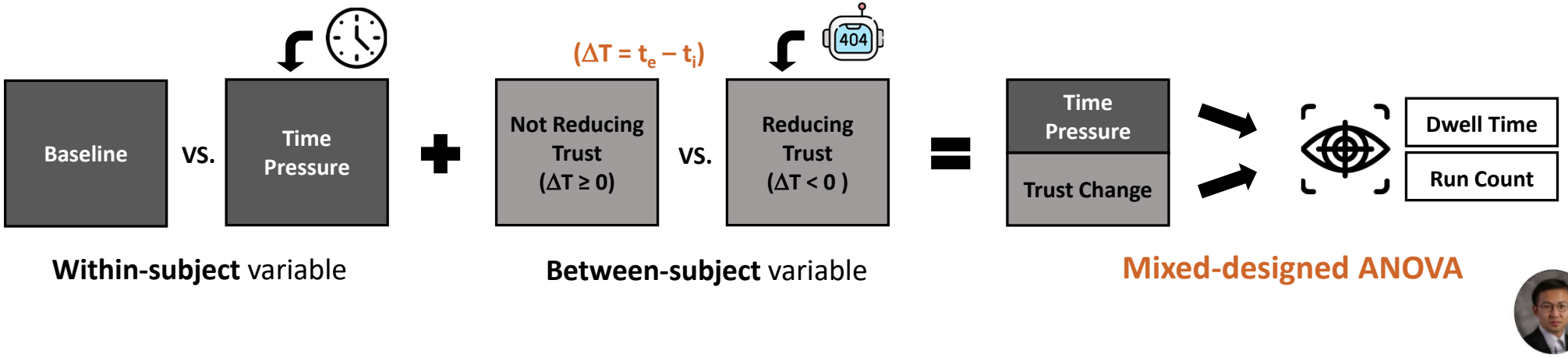
How much time did participants fixate on AOIs

Run Count

How many times did participants return their attention to AOIs

The Importance of Situational Awareness (SA) in Future Jobsite: Toward the Effects of Faulty Robot, Trust, and Time Pressure



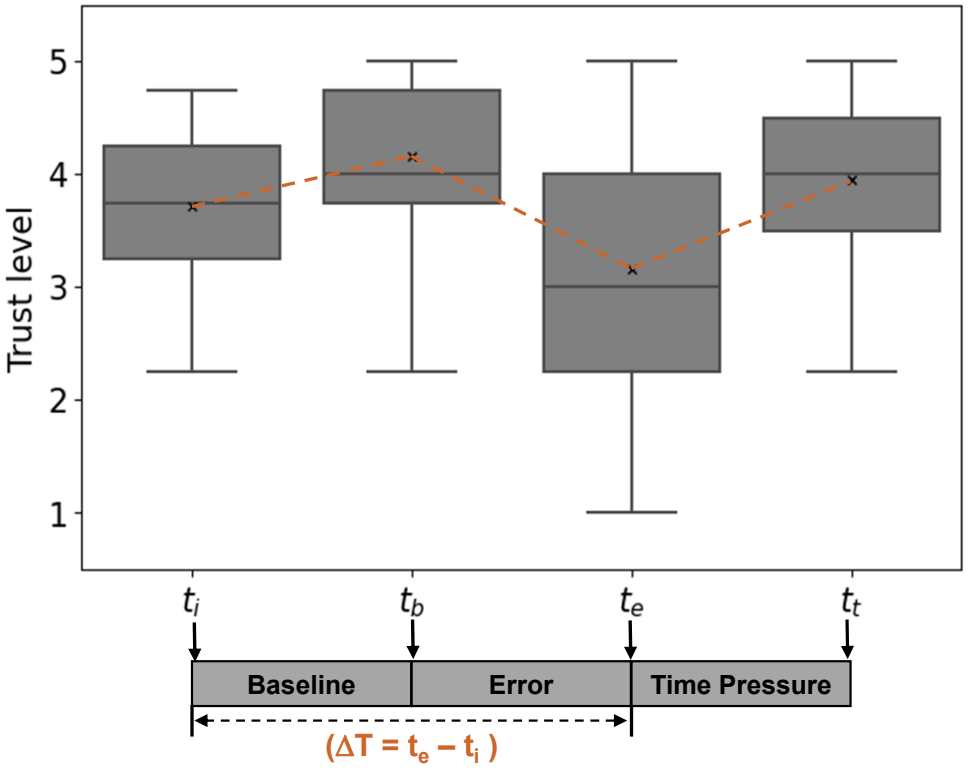


Within-subject variable

Between-subject variable

Mixed-designed ANOVA

The Importance of Situational Awareness (SA) in Future Jobsite: Toward the Effects of Faulty Robot, Trust, and Time Pressure



72%

Reducing Trust

($\Delta T < 0$)

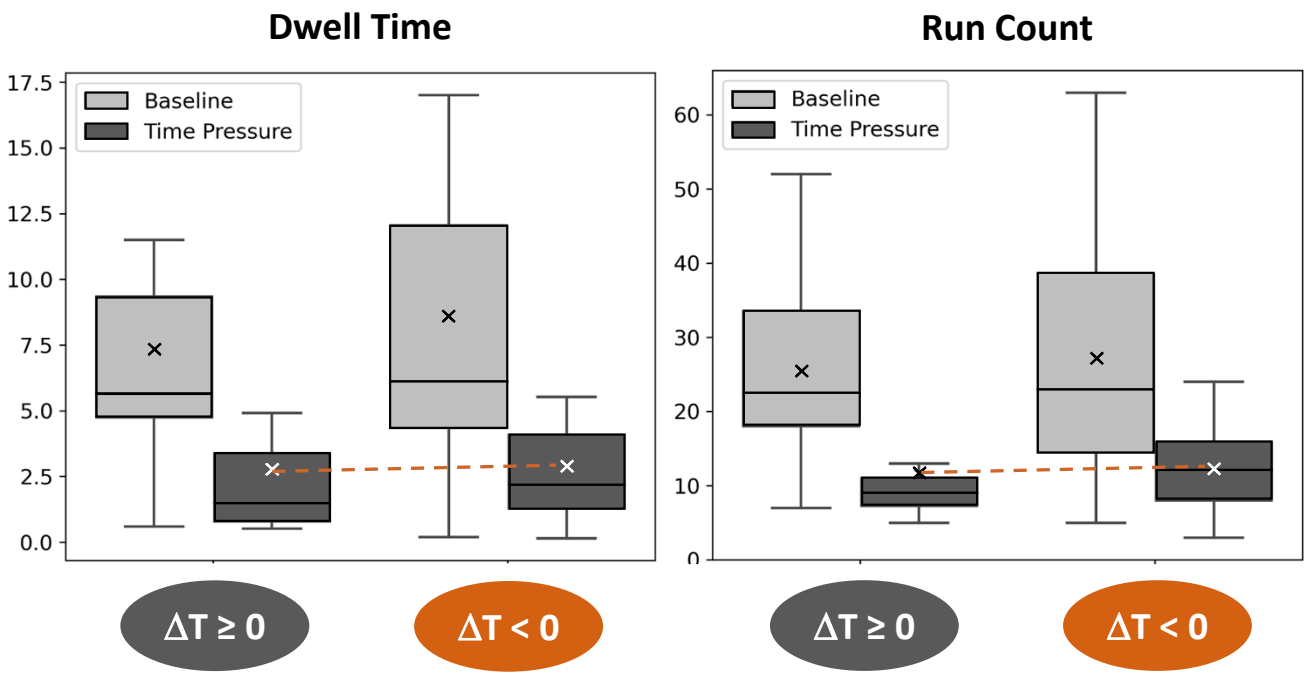
VS.

28%

Not Reducing Trust

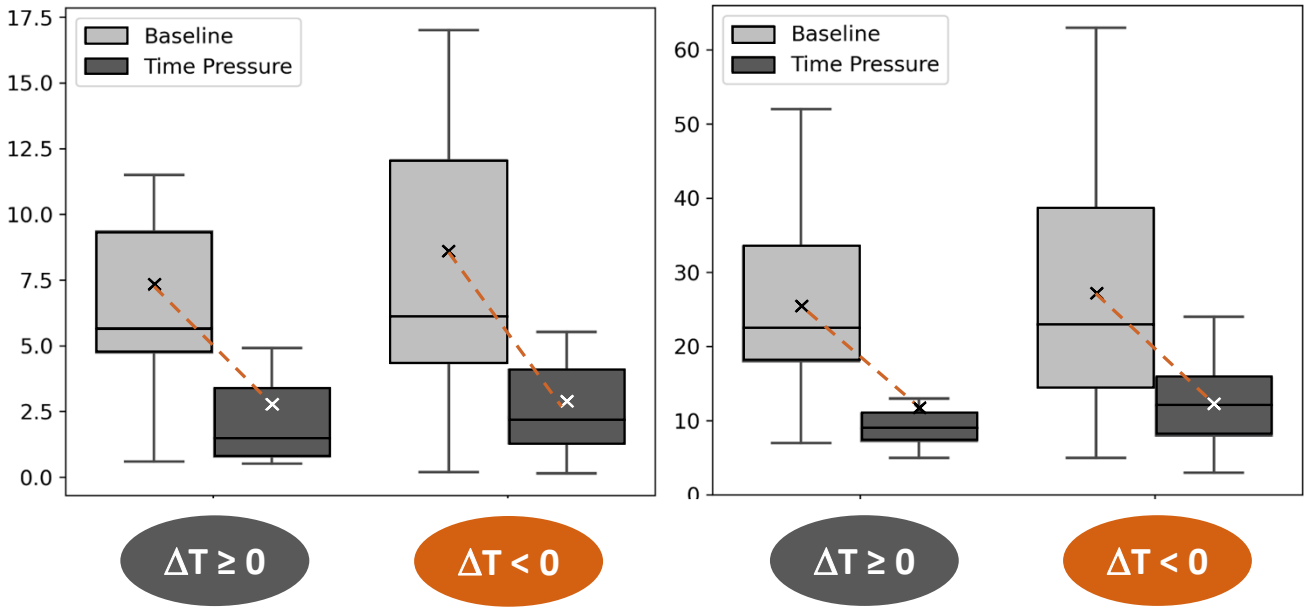
($\Delta T \geq 0$)

The Importance of Situational Awareness (SA) in Future Jobsite: Toward the Effects of Faulty Robot, Trust, and Time Pressure



Decreasing trust** did **not** significantly affect the **SA

The Importance of Situational Awareness (SA) in Future Jobsite: Toward the Effects of Faulty Robot, Trust, and Time Pressure



Decreasing trust** did **not** significantly affect the **SA

Time pressure** significantly affected the **SA

The Importance of Situational Awareness (SA) in Future Jobsite: Toward the Effects of Faulty Robot, Trust, and Time Pressure

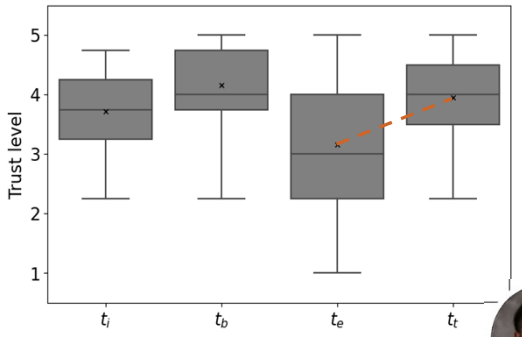
Decreasing trust *did* ***not*** *significantly affect the* ***SA***

Time pressure *significantly affected the* ***SA***

Time pressure *plays a* ***dominating*** *role in affecting worker SA than trust*

Time pressure provokes ***attentional tunneling*** *and* ***overtrust*** *for workers*

Safety issues

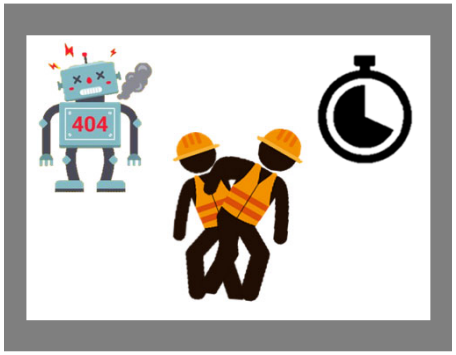


Conclusions

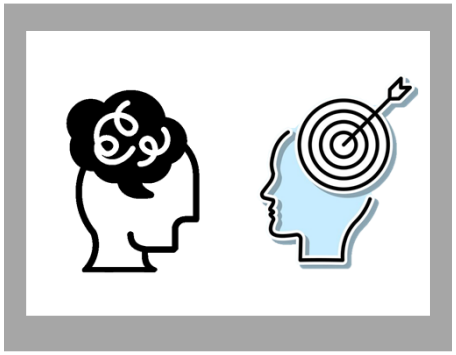
What are the next steps after identifying the following uncertainties?

Trust-building

Situational Awareness



Inclusivity



Human-centric, **sustainable**, and **resilient** **worker-autonomy teaming**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ANY QUESTIONS?
Thanks for your Time and Attention!