Toward Ai-Informed Personalized Safety Training Using Multimodal Neuro-Psychophysiological Responses

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Statistics showed more than 1,000 fatal work injuries in construction—accounted for 25% of the total 4,061 fatal occupational injuries in the United States—in the private construction industry in 2020. Since a lack of situation awareness (SA) (e.g., failure to detect, perceive hazardous factors, and react properly) in construction can lead to various incidents, situation awareness has received significant attention within the construction safety domain as a vitally important human factor involved in accidents. As construction sites are dynamic and complex (e.g., face changes in physical structures, host various crews for different tasks, and include several simultaneous tasks), a worker's continuous attention is essential to maintaining situational awareness. Specifically, previous studies highlighted that workers' unsafe behaviors—caused by human error—are the primary reason for up to 80% of construction accidents. Especially, skill-based (e.g., attentional failure) and perceptual-based (flawed risk perception) errors highly connected to workers' situational awareness are known as the main causal factors for construction industry incidents. Many endeavors aimed to enhance workers' situational awareness abilities through new training strategies and mitigate safety risks by adopting psychophysiological metrics. However, the available trainings are not as effective as they supposed to be, highlighting the need to (a) investigate why the existing safety interventions failed to remarkably reduce skill-based and perceptual-based errors and (b) identify strategies to maximize the effectiveness of the safety training. Motivated by this critical need, this research aims to develop an AI-informed personalized safety training system that incorporates various advanced technologies (e.g., bio-sensors, 360-degree panoramas, and machine learning) to assess an individual's cognitive challenges and customize the training intervention based on the individual needs.

To accomplish this, a series of studies were conducted to examine the critical factors affecting workers' hazard identification capabilities and to develop a new assessment methodology. Regarding the effect of external factors on workers' hazard identification abilities, three aspects were primarily assessed: the impact of hazard delivery media, the effect of different hazard types (static vs. dynamic hazards), and the impact of the spatial-temporal characteristics of dynamic hazards. Additionally, to sophisticatedly examine workers' hazard recognition abilities with consideration of the unique nature of construction environments, several assessment methods were also designed. The findings from these investigations were then used as the foundation for developing the proposed personalized safety training.

Based on the results of prior steps, AI-informed personalized safety training incorporating a VR headset, eye-tracker, and medical band sensor was developed, and its effectiveness was validated. An innovative aspect of the proposed training is that the embedded AI system can classify key cognitive failures related to hazard recognition (e.g., attentional failure, inattentional blindness, and high-risk tolerance) by synchronizing a multimodal dataset and assigning intervention strategies based on individual needs. The validation results showed significant improvements in participants' hazard identification performance after receiving personalized training, with average increases of 28% and 30% for the two post-training evaluations, compared to the pre-training evaluation. Moreover, the training approach was successful in enhancing not only participants' safety knowledge but also their visual scanning strategies.

This dissertation contributes to the existing body of knowledge by providing actionable insights into the development and validation of personalized safety training strategies. By demonstrating the effectiveness of the proposed safety training, this interdisciplinary work highlights the importance and efficacy of integrating cognitive science, applied behavioral science, civil engineering, and advanced technologies to address critical safety issues in the construction industry. Furthermore, this dissertation addresses critical questions regarding (1) the limitations of current safety training methodologies, (2) the need for a more robust assessment of workers' hazard identification capabilities, and (3) the feasibility and sustainability of personalized safety training in minimizing human errors related to situational awareness.