

Effect of Time Pressure and Cognitive Demand on Line Workers' Risk-Taking Behaviors: Assessment of Neuro-Psychophysiological Responses in a Mixed-Reality Environment

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ABSTRACT

Recent research suggests construction workers fall prey to the cognitive biases of risk compensation, wherein workers offset safety improvements by taking more risks. Parallel previous literature indicates that time pressure and mental load may increase workers' arousal and stress. However, it is unclear whether time, productivity, and/or cognitive demands can worsen risk compensation behaviors by stimulating workers to make riskier decisions to complete tasks faster. Combining a multi-modal mixed-reality environment with wearable neuro-psychophysiological sensors, this study examines changes in safety and task performance for high-risk electrical-line tasks simulated under time/performance pressure and cognitive demand. The results show risk-compensation is in play as subjects over-rely on safety technologies and maintain their risk perception even while undertaking more risks to adapt to increased time pressure and/or cognitive demand. This paper contributes to body of knowledge by affecting safety-training approaches and the controls needed when providing workers with safety protection and new technological advances.

INTRODUCTION

Despite increasing safety interventions to curb the number of injuries occurring in the electrical construction industry, this sector still experiences one of the highest fatality rates. More than 50% of electrocution-related deaths took place on construction sites, and 166 fatal electrical injuries and 1,900 nonfatal injuries were reported in 2019 alone, a 3.75% increase over the previous year (ESFI 2019). Such statistics attest to the reality that workers (especially electrical line workers) require persistent attention and active situation awareness regarding their surrounding environment to identify and avoid potential risks.

In parallel, while safety is certainly a priority within the industry, the business of construction is highly competitive and drives conversations about increasing productivity in the construction industry (Park et al. 2005). Previous studies show that productivity demands (e.g., being pressed to work faster) negatively influence the safety performance of workers (Nahrgang et al. 2011). The literature also indicates that time pressure, productivity and cognitive demands increase worker arousal and stress (Mitropoulos et al. 2005). Workers under such time and productivity pressure tend to work out of sequence, generate work defects, and even cut corners with regard to safety in order to meet the schedule and production demands (Nepal et al. 2006). Similarly,

recent work shows that mental load plays a significant role in causing human errors (Hasanzadeh et al. 2017), many of which lead to safety concerns for workers. Such evidence raises questions as to whether time pressure and mental load cause workers to diverge from safety and sequence best practices to complete their tasks faster.

This study tests whether the efforts to improve safety and productivity through safety interventions are less effective than expected due to workers' risk compensation under time pressure and mental load. The authors hypothesize that safety interventions decrease in effectiveness under additional task stress since interventions stimulate workers to migrate their risk-taking behaviors closer to new, higher-risk behavior boundaries. Thus, here, we monitor and report risk-compensation behaviors when workers are under time, productivity, and mental strains.

BACKGROUND

Risk Compensation Under Time Pressure and Cognitive Demand

Risk compensation is a cognitive bias that posits people normally behave differently depending on their perceived levels of risk. In particular, risk compensation theory argues that individuals offset their behavioral responses to safety improvements by behaving in a riskier fashion (Wilde 1982). Accordingly, people are inclined to be more careful when they perceive a higher level of risk in a given situation and are prone toward riskier behaviors when they perceive their risk is reduced. Studies of risk compensation among construction workers showed increasing protective interventions lowers workers' perceived risk and creates a false sense of security that will ultimately stimulate protected workers to take more risks (Hasanzadeh et al. 2020, Hasanzadeh and de la Garza 2020). However, it is still not clear whether time pressure or excessive cognitive demand/mental load will worsen these negative behaviors.

Impacts of Time Pressure and Cognitive Load on Safety Behaviors

Excess stress, productivity demands, and/or mental loads may contribute to an increase in risk-taking behaviors. Stress-building time pressure and performance demands (i.e., being pushed to work faster) are factors that can adversely affect occupational safety (Nahrgang et al. 2011). Various studies have been conducted to observe the effects of time pressure and performance demands on safety behaviors in different disciplines, including road traffic and transportation (Cœugnet et al. 2013), and construction (Mitropoulos et al. 2005). In such situations, workers are encouraged to accomplish the work in a limited time without considering safety principles. Therefore, time and performance pressure can affect workers' safety behavior, leading to increases in accident rates (Nepal et al. 2006).

Concurrently, cognitively demanding tasks require individuals to update and manipulate received sensory information from their surrounding environment, and such efforts have been linked to decision-making, perceived hazard, and attention (Rao et al. 2008). Within dynamic workplace environments—such as construction job sites—workers' must maintain high attention to remain conscious of potential hazards that can threaten safety (Hasanzadeh et al. 2017). However, considering workers' limited cognitive-processing capacity, performing additional and/or cognitively demanding tasks can lead to working memory failure and cognitive overload situations (Liko et al. 2020). In such situations, information processing collapses and may cause

workers to miss potential risks, leading to unsafe behaviors. Combined, these stress and cognitive pressures may influence worker safety behaviors, especially when risk-compensation may stimulate workers to misappropriate safety interventions as means by which to accelerate work.

RESEARCH METHODS

This study focuses on Transmission and distribution tasks performed when the lines are still energized, often with high voltage. Line maintenance is thereby classified as a high-risk occupation, and linemen are at high risk due to exposure to high voltage electricity while simultaneously often working at height. Thus, effective safety training methods are urged to be implemented for line workers to minimize electrical incidents (Santamaría-Bonfil et al. 2020). However, though many interventions (e.g., engineering controls, safety training/standards, and compulsory use of insulating/personal protective equipment) have been put into place to reduce the number of electrical injuries and fatalities among these workers, fatality and injury rates among line workers are still some of the highest in the construction sector (Gholizadeh and Esmaeili 2020). Therefore, understanding the reason behind the lower-than-expected safety benefit of electrical safety interventions remains an important question.

A mixed-reality environment was developed for an HTC VIVE Pro Eye system to simulate replacing and relocating live distribution lines within a U.S. suburban area (Figure 1). The 3D model was created in Maya, and passive-haptics (i.e., bucket, hot-stick, fall-arrest system, and insulating gloves) were added to develop a mixed-reality environment in Unity. Five V.R. trackers were used to collect the physical pose of each individual, to adjust the V.R. accordingly, and to register interactive behaviors (simulated virtual arc flash including visual and audio representations). To increase realism and subjects' sense of presence, wind and suburban sounds were included in the environment. Furthermore, real-time head/body trackers, eye-tracking sensors, psychophysiological sensors (heartrate, H.R.; and electrodermal activity, EDA), and a cognitive brain-monitor sensor (functional near-infrared spectroscopy, fNIRS) were all synchronized with the V.R. system to monitor subject's motion and behaviors during the experiment.

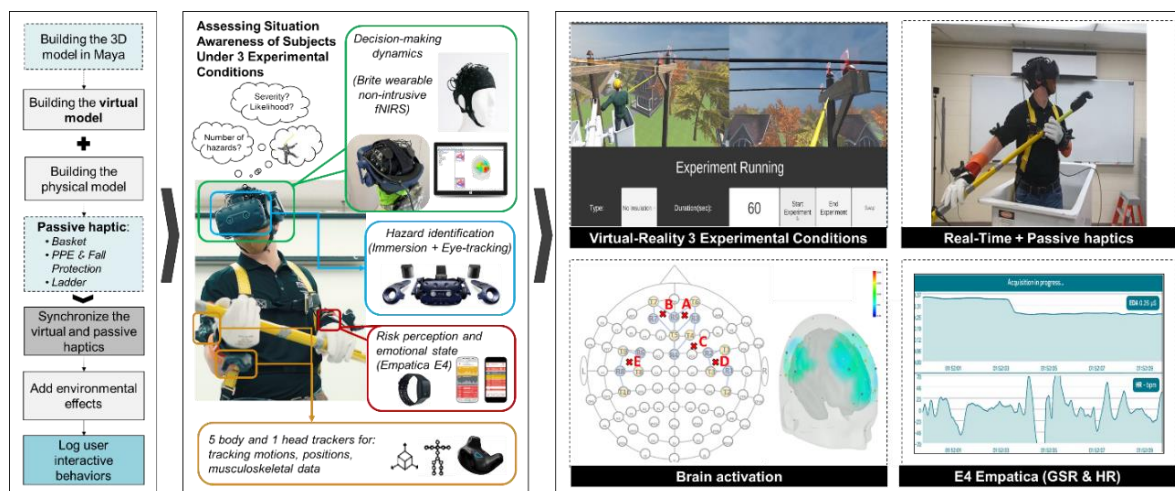


Figure 1. Research framework for multi-sensor mixed-reality environment

Thirty-three healthy civil engineering and construction management students (22 males and 11 females; aged 21.3 ± 2 years; ~ 1.5 years of work experience on average) participated in the study. All procedures were approved by Purdue's Institutional Review Board (IRB). Before starting the experiment, all participants signed a consent form, and an explanation of the experiment was provided. After a 20-minute comprehensive training on the electrical tasks and potential hazards, each participant filled out several surveys. The neuro-psychophysiological responses were monitored for two minutes as a baseline. Then, subjects were asked to perform two tasks under three conditions: one, to move *completely* insulated energized power lines from old poles to new poles, and two, to remove conductor hoods; the three experimental conditions involved (I) normal condition; (II) time pressure condition, wherein the subject was given 10 seconds less than the time it took for them to complete the task under normal condition; and (III) time pressure and cognitive demand condition, wherein, the subject was asked to complete the task while completing 2-back working memory task simultaneously. If the subjects can complete the tasks under conditions II and III, they receive the incentive (additional compensation). At the end of the experiment, a semi-structured interview was conducted to evaluate changes in each participant's perceived risk under each condition as well as their overall mixed-reality experience.

The HTC VIVE Pro Eye (110° field of view) with millisecond synchronization and a seamless and complete eye-tracking integration at 90Hz was used to monitor the hazard identification of subjects. Affective risk perception refers to the arousal (high-low) of feelings associated with the risk: stress, fear, and anxiety. Perception of risk is a core component of physiological "stressors," so analyzing cardiovascular psychophysiological metrics (e.g., stress level and emotional state) can signify a worker's sense of risk. The autonomic nervous system plays a crucial role in individual's regulatory response toward immediate stress (Ulrich-Lai and Herman 2009). This system consists of two subsystems: (1) the sympathetic nervous system (SNS) that facilitates behavioral responses to perceived risk, and (2) a parasympathetic nervous system (PNS) that facilitates homeostasis of the body. Here, an Empatica E4 wristband tracked subject's real-time H.R. and EDA psychophysiological responses. The H.R. data (SNS and PNS) contained average heartrate in spans of 10 seconds, with a sampling rate of 1 Hz, and was derived from interbeat interval (IBI) data; the EDA (PNS, microSiemens μS sampled at 4 Hz) was measured from electrical conductance of skin after sweating due to emotional activation or stress.

Experiential risk perception is the output of experiential processing accompanied by the heuristic, rule-governed, risky decision-making that guides risk-taking behavior. This study examined brain activation in both cognitive and motor regions via three designed manipulations. Brain activation manifests with increases in both cerebral oxyhemoglobin and blood flow throughout brain regions (Rao et al. 2008). The subjects wore a wireless fNIRS (*Brite* 20 channels) to capture the brain activations associated with their recognized risk under each condition. Figure 1 demonstrates the arrangement of the optodes' locations along with the defined region of interest (ROIs): *A* and *B* are Prefrontal Cortex (PFC), particularly the Dorsolateral Prefrontal Cortex (DLPFC), which is considered the cognition region in neuroscience and is mainly involved in cognitive behavior (e.g., decision-making). *C*, *D*, and *E* are the premotor cortex and supplementary motor cortex, respectively, which are mostly involved in the execution of movements (Figure 1). The neural activity from the hemodynamic response function (HRF) that characterizes the blood-oxygen-level-dependent (BOLD) signal overtime was used for the analysis.

RESULTS AND FINDINGS

Taking into account individual differences, this study applied within-subject analysis to closely investigate the changes in individuals' performance—via hazard identification, risk perception, decision-making, and task performance—under various conditions.

Effect of Time Pressure and Cognitive Demand:

(1) *Visual Search and Hazard Identification:* Within this experimental design, the cables participants moved from the old electricity pole to the new pole are the source of risk. Therefore, to study hazard identification and changes in participants' attention toward sources of electrical risk versus non-hazardous stimuli in the environment, we examined the changes in participants' visual attention (i.e., fixation durations) using the Wilcoxon Signed Ranks test. The results show that under stressful conditions (time pressure and cognitive demands), they had limited attentional resources and usually used them to focus more on sources of potential electrical hazards than the surrounding environment [$Z_{II}=-4.809$, $p=0.000$, and $Z_{III}=-4.245$, $p=0.000$] (Table 1).

Table 1. Differences in fixation duration of 33 participants across hazard-relevant and hazard-irrelevant AOIs under two stressful conditions (II and III)

	Areas of Interest (AOIs)	Mean	STD	Test Statistics	<i>p</i> -value
II	Sources of electrical risks	16.455	5.734	-4.809	0.000*
	Surrounding environment	9.530	2.910		
III	Sources of electrical risks	18.470	7.723	-4.245	0.000*
	Surrounding environment	11.546	5.004		

* p -value < 0.05

(2) *Affective Risk Perception:* Changes in subjects' cardiovascular psychophysiological metrics (H.R. and EDA) were monitored as a measure of the affective risk perception under the experimental conditions. A repeated-measures ANOVA revealed that measured heart rate mean (H.R. mean) values are statistically significantly different between the baseline, the normal condition (I), and the stressful conditions (II and III) [$F(2.351, 72.888)=18.976$, $p=0.000$] (Table 2). The post hoc test with a Bonferroni correction applied demonstrates that the H.R. mean is significantly higher under all conditions (I, II, and III) compared to the baseline (all $p<0.005$), whereas no significant differences manifest between the normal condition (I) and the stressful conditions (II and III).

Furthermore, Friedman's tests indicate that there is a statistically significant difference in the EDA (emotional) responses across the various experimental conditions [$\chi^2(2) = 47.212$, $p=0.000$] (Table 2). Therefore, the test results show that all the EDA measures from all three conditions are significantly higher than the baseline EDA measure. Post hoc analysis with a Bonferroni correction shows that differences in participants' EDA responses are observed between the baseline and all other conditions [$Z_{b&I}=-3.515$, $p=0.000$; $Z_{b&II}=-3.964$, $p=0.000$; and $Z_{b&III}=-4.563$, $p=0.000$], between condition I and II [$Z_{I&II}=-4.207$, $p=0.000$], and between condition I and III [$Z_{I&III}=-4.394$, $p=0.000$], with no significant difference only between the two stressful conditions (II, III).

Table 2. Differences in the affective risk perception of 33 participants under baseline, normal (I), and two stressful conditions (II and III)

Metrics	Exp. Conditions	Mean	STD	Test Statistics	<i>p</i> -value
HR mean	baseline	76.485	12.582	18.976 ^a	0.000*
	I	90.209	13.442		
	II	94.548	17.777		
	III	95.721	17.413		
EDA	baseline	2.154	2.813	47.212 ^b	0.000*
	I	7.436	9.030		
	II	9.275	10.095		
	III	9.824	10.214		

a: *F* value from repeated measures ANOVA test

b: Chi-Square value from Friedman Test

* *p*-value < 0.05

(3) *Experiential Risk Perception and Decision-Making*: This study monitored the hemodynamic brain activation across several ROIs—as measured by the fNIRS and depicted by increasing oxy-Hb and total-Hb as well as decreasing deoxy-Hb—to assess risk perception and decision-making. We particularly consider the oxy-Hb concentration results due to their lower vulnerability to cross-talk in comparison with deoxy-Hb (Strangman et al. 2003), and due to the fact, oxy-Hb is mainly considered a substantial indicator of hemodynamic changes (Zhou et al. 2021).

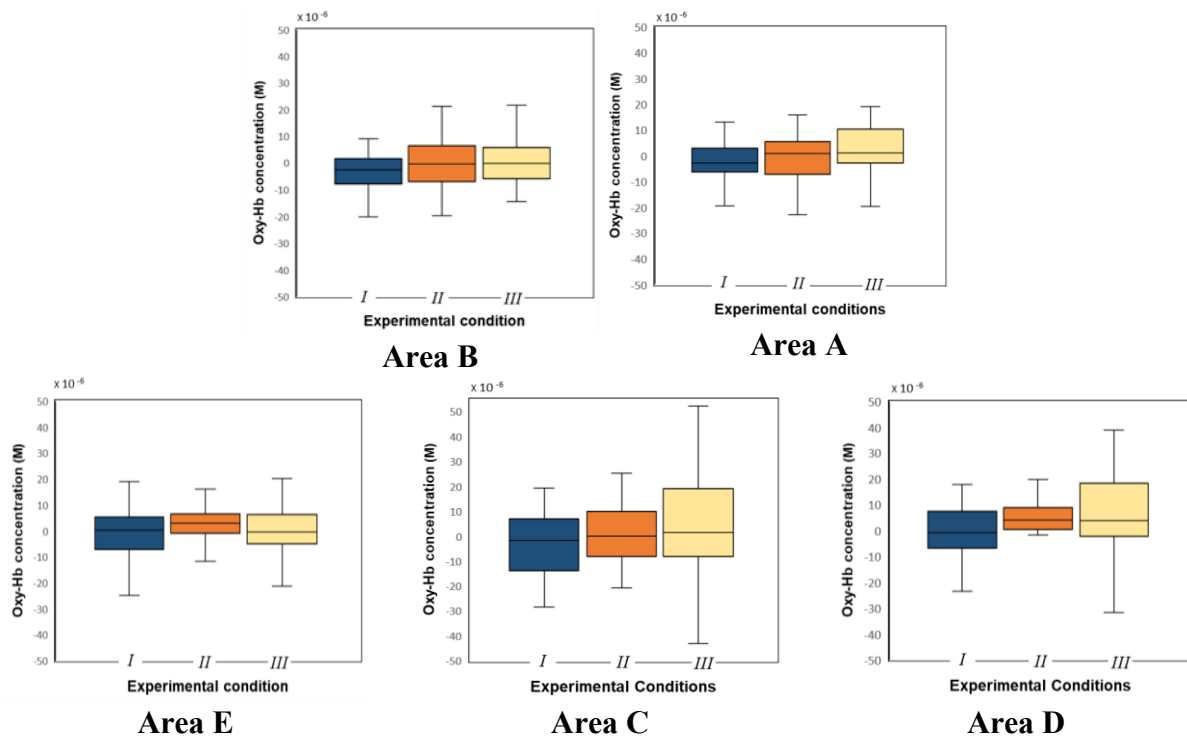


Figure 2. Changes in brain activities (Oxy-Hb concentration for five ROIs_ represented Figure 1) across three conditions

Figure 2 presents the average brain activation changes in concentration of oxy-Hb throughout the five defined ROIs across three experimental conditions (i.e., I, II, and III). The values shown in this figure were obtained through block average, and HRF processing with band-pass filtering of 0.01–0.5Hz to remove physiological noises, and the values show the average concentration of oxy-Hb across all associated channels of each ROI for subjects; three participants' activation results were excluded due to issues with calibration. As shown, considerable increase in oxy-Hb are identified within the right hemisphere between the normal condition (I)—where the powerlines were fully protected—and the stressful conditions (i.e., starting with only time pressure in II and advancing to time pressure and cognitive demand in III), especially in the PFC (Figure 2). However, it must be noted that the oxygenated hemoglobin concentrations vary regarding both ROI's (brain regions) functionality and experimental conditions.

(4) *Task Performance and Risk-Compensatory Behavior*: The total performance was evaluated based on participants' safety performance (finish task without experiencing arc flash), task completion in the time-pressure experiment, and accuracy assessment in the (2-back working memory) mental load task. The results indicate that, on average, participants' total performances declined under stressful time pressure and cognitive demand conditions (reduced by 13% in condition II, and 42% in condition III).

DISCUSSION

These findings underscore the notion that decision-making behaviors and situation awareness are considerably affected both by dynamic and complex construction environments as well as by many task and environmental factors. The results in Table 2 show that, as expected, in comparison to participants' resting condition (i.e., baseline), participants experienced higher stress and arousal under all conditions (I, II, III). During the normal condition (manipulation I), participants conducted the pole replacement task with no time pressure or cognitive demand, and the live power lines were completely insulated. Yet, affective risk perception (seen in subjects' H.R.) increased compared to the baseline, showing that completely insulating live lines reduced the risk of electrical hazards associated with the task but did not completely eliminate the risk. However, the increased heartrate was not that significant. Moreover, under stressful conditions—when external factors were added to the experimental environment—the physical risk associated with the electrical task did not change, so risk perception (i.e., increased heartrate) did not differ significantly. The authors expect the main reason for the partial changes in H.R. under stressful conditions is that the parasympathetic systems of heartrate act within milliseconds, while the sympathetic effects act in seconds. These findings indicate that H.R. must be used with caution as a measure of stress or perceived risk.

In contrast, observed EDA under stressed conditions (II and III) varied significantly compared to the normal condition (I). One reason for such a powerful difference may be explained by the fact that EDA is only influenced by the sympathetic nervous system's activity in response to the stressor. As in previous studies, our study showed that EDA is also very sensitive to changes in cognitive demand. The H.R. and EDA results combined suggest subjects did not perceive any additional risk with the stressed conditions, and the false sense of security about the situation appears to have indirectly signaled them that they could speed up or increase their risk-taking behavior to meet expectations regarding time and mental load task. The findings of this study are well aligned with previous studies indicating time pressure and cognitive load by themselves could be considered risk factors for injuries and incidents (e.g., Nepal et al. 2006,

Mitropoulos et al. 2005). Some subjects who experienced simulated arch flash incidents or had lower task performance under the stressful conditions often reported the time pressure and cognitive demand played a significant role in their reduced perceived risk associated with the electrical task, their overreliance on safety interventions, and their choice to take risks by speeding up when completing the task.

Figure 3 demonstrates changes in the affective risk perception (heartrate and emotional states) of one subject. As can be seen, the stress of the subject increased considerably when the experimental tasks (conditions I and II) exceeded the adaptive resources. In the context of this paper, the subject's primary cognitive appraisal would estimate the time needed to complete the task based on the previous task (condition I), and the second appraisal would be made with respect to the time constraints, the possible gains, and the expected consequences of encountering the electrical hazards. The difficulties in coping raise negative emotions and stress, which can mainly be seen in the EDA signals.

This study joins several other studies in using fNIRS data to examine the association between risk decision-making behaviors, risk-taking behaviors, and brain activation (Pleskac 2008). Previous findings indicated that the PFC is the often dominantly activated cortex during risk-taking behaviors, whereas the functionality and activation of the right part are different from the left one; an increasing level of activation has been observed in the PFC throughout the risk decision-making process, specifically in the right PFC (Rao et al. 2008). In our study, under experimental condition II, the participants needed to complete the task under time pressure, which directly affects the task difficulty. Based upon previous research, increasing task difficulty is accompanied by increases in the PFC activation, which is a significant proxy for efforts undertaken in decision-making and planning (Fairclough et al. 2018). As such, the current study results demonstrate a higher activation in the PFC, namely areas A and B, and higher hemodynamic response within areas C, D, and E.

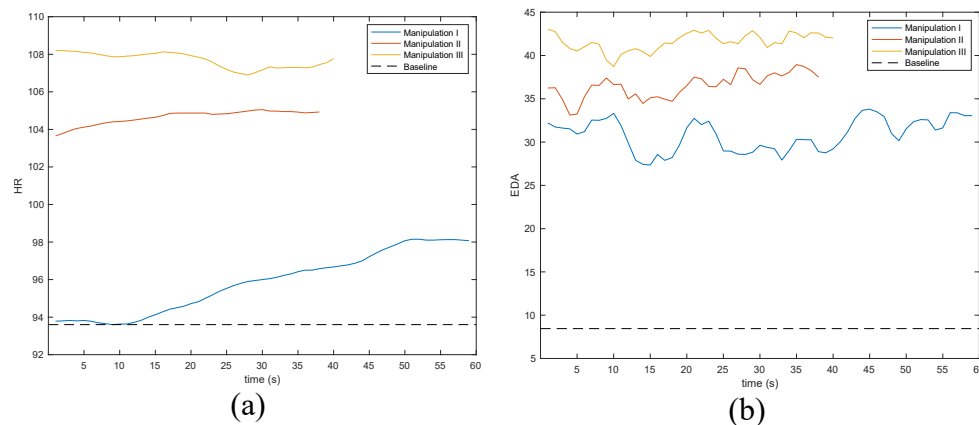


Figure 3. Changes in affective risk perception (EDA and H.R.) of one subject across conditions

Furthermore, experimental condition III was executed under both time pressure and a designed 2-back test, which highly demands working memory. Working memory is a cognitive system that integrates, updates, and maintains received information temporarily and thus is chiefly concerned with short-term memory (Liko et al. 2020). This system is capacity limited, and increases in working-memory load result in increasing cognitive response along with the

PFC, specifically in the DLPFC (Fairclough et al. 2018). Although this concept is new in the construction industry, several valuable studies have been conducted in this area by investigating drivers' cognitive behavior in simulated environments while conducting n-back tests and undergoing induced changes in working memory load (Unni et al. 2016). These studies indicate that working memory load mostly activates the right DLPFC. The results of this research also illustrate a higher oxy-Hb concentration rate in area A (i.e., right DLPFC) in comparison to area B (i.e., left DLPFC).

With regards to our hypothesis that workers migrate their risk-taking behaviors closer to new, higher-risk behavior boundaries when under additional time and mental stress, we observe risk-compensatory behaviors in workers' changes in response to the different experimental conditions. In this study, subjects had to deal with uncertainty, so trade-offs had to be made between the benefit of action (gain)—for example, receive the incentive (additional compensation)—versus the risks involved in over-relying on safety interventions and technologies in place. Previous studies have demonstrated and discussed the diminished value of added safety interventions when users over-relying on the safety interventions and technological advances (e.g., Hasanzadeh et al. 2020). Here, it is interesting to note that imposing time pressure and cognitive demands significantly changed how participants made decisions and performed actions, since the added risk factor of stress did not impact subjects' perceived risk while the same safety protections remained in place. This change in behavior demonstrates a risk compensation effect: adding stress—a risk factor—without changing safety interventions impacted how subjects over-relied on safety interventions.

Interestingly, the subjects reported they were only stressed under time pressure and mental load task due to the potential of losing compensation but were not stressed by the possibility of a fatal consequence resulting from not paying attention to potential hazards and/or taking risky actions. Thus, overestimating the benefits of safety protections, underestimating the risk associated with a situation, and focusing on a goal (gain) may lead workers to discount the dangers of taking risks, leading to overreliance on safety interventions (i.e., risk compensation bias).

CONCLUSION

By taking advantage of a mixed-reality environment and wearable neuro-psychophysiological sensors, this study empirically investigated the role of time pressure and cognitive demand on subjects' situation awareness and risk-compensatory behavior when completing an electrical task. The findings show no significant increase in perceived risk (H.R. changes) but do demonstrate higher stress (EDA signals) and higher hemodynamic responses in both the prefrontal and motor cortex (fNIRS signals) during stressful and challenging conditions (II and III). Thus, when workers perceive the situation as safe (lower than an individual's risk tolerance), time pressure and cognitive demand deleteriously disrupt attention and require a greater amount of cognitive resources, leading risk-taking behaviors to migrate closer to a new, higher boundary, where the safety interventions become counterproductive—indicating risk compensation comes into play. The findings also indicate that fNIRS and EDA signals are reliable for studying individual affective and experiential risk perception in risky and stressful construction jobsites. While future research may recruit a larger sample size and replicate the findings with actual linemen to overcome this study's limitations, these results advance current

understandings about how time pressure and cognitive demand affect construction workers' safety performance.

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REFERENCES

- Cœugnet, S., Naveteur, J., Antoine, P., and Anceaux, F. (2013). "Time pressure and driving: Work, emotions and risks." *Transportation Research Part F: Traffic Psychology and Behaviour*, Elsevier Ltd, 20, 39–51.
- ESFI. (2019). "Workplace Safety Workplace Injury & Fatality Statistics 2003-2019" <https://www.esfi.org/workplace-injury-and-fatality-statistics> (Accessed June 8, 2020).
- Fairclough, S. H., Burns, C., and Kreplin, U. (2018). "FNIRS activity in the prefrontal cortex and motivational intensity: impact of working memory load, financial reward, and correlation-based signal improvement." *Neurophotonics*, SPIE-Intl Soc Optical Eng, 5(03), 1.
- Gholizadeh, P., and Esmaili, B. (2020). Cost of Occupational Incidents for Electrical Contractors: Comparison Using Robust-Factorial Analysis of Variance. *Journal of Construction Engineering and Management*, 146(7), 04020073.
- Hasanzadeh, S., Dao, B., Esmaili, B., and Dodd, M. D. (2017). "Measuring the Impact of Working Memory Load on the Safety Performance of Construction Workers." *American Society of Civil Engineers (ASCE)*, 158–166.
- Hasanzadeh, S., and de la Garza, J. M. (2020). "Productivity-Safety Model: Debunking the Myth of the Productivity-Safety Divide through a Mixed-Reality Residential Roofing Task." *Journal of Construction Engineering and Management*, American Society of Civil Engineers (ASCE), 146(11), 04020124.
- Hasanzadeh, S., de la Garza, J. M., and Geller, E. S. (2020). "Latent Effect of Safety Interventions." *Journal of Construction Engineering and Management*, American Society of Civil Engineers (ASCE), 146(5), 04020033.
- Liko, G., Esmaili, B., Hasanzadeh, S., Dodd, M. D., and Brock, R. (2020). "Working-memory load as a factor determining the safety performance of construction workers." *Construction Research Congress 2020*, American Society of Civil Engineers (ASCE), 499–508.
- Mitropoulos, P., Abdelhamid, T. S., and Howell, G. A. (2005). "Systems Model of Construction Accident Causation." *Journal of Construction Engineering and Management*, American Society of Civil Engineers (ASCE), 131(7), 816–825.
- Nahrgang, J. D., Morgeson, F. P., and Hofmann, D. A. (2011). "Safety at Work: A Meta-Analytic Investigation of the Link Between Job Demands, Job Resources, Burnout, Engagement, and Safety Outcomes." *Journal of Applied Psychology*, J Appl Psychol, 96(1), 71–94.
- Nepal, M. P., Park, M., and Son, B. (2006). "Effects of Schedule Pressure on Construction Performance." *Journal of Construction Engineering and Management*, American Society of Civil Engineers (ASCE), 132(2), 182–188.

- Park, H.-S., Thomas, S. R., and Tucker, R. L. (2005). "Benchmarking of Construction Productivity." *Journal of Construction Engineering and Management*, American Society of Civil Engineers (ASCE), 131(7), 772–778.
- Pleskac, T. J. (2008). "Decision Making and Learning While Taking Sequential Risks." *Journal of Experimental Psychology: Learning Memory and Cognition*, 34(1), 167–185.
- Rao, H., Korczykowski, M., Pluta, J., Hoang, A., and Detre, J. A. (2008). "Neural correlates of voluntary and involuntary risk taking in the human brain: An fMRI Study of the Balloon Analog Risk Task (BART)." *NeuroImage*, Neuroimage, 42(2), 902–910.
- Santamaria-Bonfil, G., Ibáñez, M. B., Pérez-Ramírez, M., Arroyo-Figueroa, G., and Martínez-Álvarez, F. (2020). "Learning analytics for student modeling in virtual reality training systems: Lineworkers case." *Computers and Education*, Elsevier Ltd, 151.
- Strangman, G., Franceschini, M. A., and Boas, D. A. (2003). "Factors affecting the accuracy of near-infrared spectroscopy concentration calculations for focal changes in oxygenation parameters." *NeuroImage*, Academic Press Inc., 18(4), 865–879.
- Ulrich-Lai, Y. M., and Herman, J. P. (2009). "Neural regulation of endocrine and autonomic stress responses." *Nature Reviews Neuroscience*, Nat Rev Neurosci.
- Unni, A., Ihme, K., Surm, H., Weber, L., Ludtke, A., Nicklas, D., Jipp, M., and Rieger, J. W. (2016). "Brain activity measured with fNIRS for the prediction of cognitive workload." *6th IEEE Conference on Cognitive Infocommunications*, 349–354.
- Wilde, G. J. S. (1982). "The Theory of Risk Homeostasis: Implications for Safety and Health." *Risk Analysis*, John Wiley & Sons, Ltd, 2(4), 209–225.
- Zhou, X., Hu, Y., Liao, P. C., and Zhang, D. (2021). "Hazard differentiation embedded in the brain: A near-infrared spectroscopy-based study." *Automation in Construction*, 122, 103473.