

The Neural Basis of Risk Attitude in Decision-Making Under Risk: fNIRS Investigation of the Simulated Electrical Construction Task

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Abstract –

Risk propensity, or individuals' attitude toward risk, can highly impact individuals' decision-making in high-risk environments since those who merely focus on positive consequences associated with high-risk acts are more likely to engage in risk-taking behaviors. Previous studies identified activation in the prefrontal cortex during decision-making under risk to be a sign of an individual's attitude toward risks. To investigate whether such past work—prevalent in behavioral research domains—translates into construction safety, this study conducted an experiment in a mixed-reality environment using functional near-infrared spectroscopy (fNIRS) technology to examine whether positive risk attitudes cause individuals to adopt risky construction behaviors and whether the activation of the prefrontal cortex of the brain can represent such risk attitudes. The results show that participants with a higher risk propensity had a higher brain activation during the risky electrical tasks; these individuals merely focused on gains, which motivated them to increase their risk-taking behavior and consequently experience more electrical accidents. Understanding workers' attitudes toward risk will thus influence future understandings of decision behavior under risk.

Keywords –

Risk attitude; Construction safety; Decision-making; Risk-taking behavior; fNIRS neuroimaging; Mixed-reality (MR)

1 Introduction

Despite various efforts to reduce the number of incidents occurring within the electrical construction industry, this area still experiences a high rate of fatalities, representing a 3.75% increase over recent years [1]. In part, these fatalities may be sourced in construction workers' behaviors, which can be easily influenced by their individual characteristics. Consequently, investigating the individual characteristics that can affect workers' unsafe behaviors may help avoid future accidents.

Risk propensity, or one's attitude toward risks, is one influential characteristic that can affect jobsite safety as high-risk propensity causes individuals to adopt risky behaviors [2]. Previous research highlighted the direct connection between risk attitude and risk decision-making [2,3], the latter of which ties into cost-benefit analysis weighing the costs (risks) against the benefits (gains) delivered by the behavior. Thus, the extent to which one engages in risky behaviors is a function of individuals' positive attitudes (i.e., focused on gains) and/or negative attitudes (i.e., focused on losses) related to risk consequences [4]. Individuals with positive attitudes mostly consider positive consequences over negative ones, which stimulates them to take more risks.

The impacts of risk propensity conceivably manifest profoundly within such competitive and dynamic workplaces as construction jobsites, since the business nature of construction is highly competitive and may turn stakeholders' focus toward gains (e.g., earning more money) [5]. In such situations, managers stimulate workers by offering extra compensation as an incentive to speed up or perform simultaneous tasks in order to

offset delays or increase the company's profits. As a result, risk propensity in terms of expecting pleasurable outcomes and benefits may guide individuals to engage in more risky actions.

While the impacts of risk propensity in gain-loss decision-making under risk have been widely discussed in behavioral research domains, there is a paucity of research within the construction sector despite the fact this industry's high-risk work environment may be considerably impacted by the concept of risk attitude. Therefore, this study examined whether perceiving greater benefits during risky activities causes workers to engage more in risky behaviors on jobsites. To achieve this objective, this study asked subjects to perform a simulated high-risk electrical activity under conditions with varying benefits. The research team then used traditional (questionnaires) and emerging neuroimaging (functional near-infrared spectroscopy) techniques to document subjects' risk propensity; the latter method monitored subjects' cortical hemodynamic responses (i.e., brain activation) during the high-risk situations to quantify cognitive appraisals associated with risky decisions. Combined, this methodology enabled the team to both better understand subjects' attitudes towards risk and discern whether functional near-infrared spectroscopy (fNIRS) signals could be considered a useful method for studying individual risk attitudes in dynamic risky decision-making. The outcomes of this research, therefore, deliver both an innovative methodology for monitoring construction workers' real-time risk propensity and a deeper understanding of workers' attitudes towards risk to enhance evaluations of decision-making behaviors under risk.

2 Background

2.1 Risk Propensity and Expected Consequences

Generally, risk propensity is defined as individuals' attitudes toward risk and reflects their orientation toward taking or avoiding risks [2]. Therefore, risk attitude includes both risk-seeking and risk-aversion and signifies "the degree to which a person has a favorable or unfavorable evaluation or appraisal of a behavior" [6, p. 188].

Risk attitude can be quite influential in explaining individuals' risk-taking behaviors and risk decision-making. As with the cost-benefit analysis discussed above, one's behavior evaluation will include gains or losses, depending squarely on individuals' attitude toward the risk (i.e., risk-seeking or risk-aversion). Workers who are risk-takers primarily look forward to gaining potential benefits from the risky activity, which they perceive as worth any associated potential negative consequences [2].

Previous literature showed that individuals may adopt risky behaviors when the balance between the perceived losses of a situation and the perceived gains of that situation is considered favorable [4]. In a related study, Slovic and his colleagues observed that individuals who were more engaged in risky activities perceived greater associated benefits and also greater control over potential losses than those who did not engage in risky activities [4]. In one of the recent studies, Hasanzadeh and her colleagues examined risk propensity as a factor of individuals' risk-taking behavior in a simulated mixed-reality environment. They observed that risk propensity moderated the relationship between safety protection and risk-taking behaviors since individuals with higher risk propensity took more risks when protections were in place [2,7]. Therefore, it is crucial to investigate the substantial differences at play in individuals' risk attitude and how these gain expectancies in non-targeted risky events are linked to individuals' at-risk decisions on construction jobsites.

2.2 Cortical Brain Activation and Decision-making Correlates

Previous studies showed that neuroimaging provides an excellent understanding of the underlying cognitive processes involved in considering trade-offs between costs (loss) and benefits (gains) under risky conditions [8,9]. The prefrontal cortex (PFC) plays a substantial role in these decision-making processes [10]. Particularly, the increase of cerebral oxyhemoglobin and blood flow within the PFC reflects processing variances, uncertainties, risks, expected values, and probabilities [9]. Furthermore, previous studies showed that increased expected benefits of risky actions (greater gain) will increase the prefrontal area's brain activation, specifically among risk-seeking individuals (i.e., those with higher risk propensity) [11,12]. As such, cortical brain activity can functionally reveal the correlation between risk and associated benefits and can signify how individuals perceive the consequences of risky decisions (i.e., whether they focus on gains or losses). Several neuroimaging and human behavior studies have investigated risk attitude and decision-making under risk using cortical brain activation (e.g., [13,14,15]), but there is limited research in this field within the construction safety domain.

3 Methodology

This study examined risk perception and risk decision-making during a risky construction activity to identify the correlation between risk-taking behaviors, expected benefits, and brain cortical responses. To accomplish this objective, this study used the

transmission and distribution of energized powerlines as a high-risk task since linemen are required to work in close proximity to high-voltage powerlines while they are also at the height [16,17]. We hypothesize that risk attitude (i.e., concentrating on expected gains or expected losses) serves as a key contributor to stimulating risk-taking behaviors and exacerbates the likelihood of incidents (e.g., experiencing arc flash, which is an electrical discharge that includes burns, blasts, and electrocution hazards) within high-risk tasks among those with high-risk propensity.

3.1 Experimental Design

A mixed-reality environment consisting of virtual and physical models was developed to simulate an electrical task in a U.S. suburban area (Figure 1). The physical model included passive haptics (i.e., bucket, hot-stick, fall-arrest system, and insulating gloves). The virtual model entailed the simulated setting as well as five virtual reality trackers attached to the subject's body to capture individuals' postures and adjust the virtual avatar accordingly; these trackers also registered interactive behaviors—e.g., simulated electrical arc flash—and the virtual reality system included any corresponding visual and audio representations to enhance participants' sense of presence within the mixed-reality simulation. Environmental modalities, including wind and sound effects, were also added to increase realism and subjects' sense of presence. Most of the participants reported a high presence score (Mean = 4, SD = 0.5), given a 5-point Likert scale post-trial presence questionnaire (with 1 = low and 5 = high). This conveys that the developed MR environment offered a valid and appropriate framework to trigger the naturalistic behaviors of line workers. All subjects wore a wireless functional near-infrared spectroscopy (fNIRS, Brite) neuroimaging cap so the research team could monitor subjects' decision-making and risk attitude while the subjects completed the electrical tasks.

3.2 Data Collection

Thirty-three healthy subjects—11 females and 22 males aged 21.3 ± 2 years, with at least 1.5 years of work experience in the construction industry—were recruited to participate in this study. All procedures were approved by Purdue University's Institutional Review Board (IRB).

After a 30-minute comprehensive training regarding the experimental process and electrical tasks, each participant filled out several questionnaires, including the cognitive appraisal of risky events (CARE) questionnaire. The CARE questionnaire, developed by Fromme et al. (1997), evaluates individuals' expectations of gains (i.e., positive outcomes known as PCARE) and losses (i.e., negative outcomes known as NCARE) as consequences of risky behaviors [18]. Subjects responded to this questionnaire based on a 7-point Likert-scale that ranged from 1 (not at all likely) to 7 (extremely likely). Their responses evaluated the expected positive and negative outcomes of six various types of risky behaviors, including (I) Illicit drug use, (II) Aggressive and illegal behaviors, (III) Risky sexual activities, (IV) Heavy drinking, (V) High-risk sports, and (VI) Academic/work behaviors. This study considered the positive outcome expectancies of subjects (i.e., PCARE) for further analysis.

After completing the questionnaires, participants were equipped with the fNIRS cap, and their brain cortical responses were captured for 120 seconds as the baseline. Thereafter, they were required to complete the line replacing task, which included two sub-tasks: (1) move the energized powerlines from an old pole to a new pole, (2) remove conductor hoods from energized lines. The participants were equipped with complete safety interventions and performed the task under two experimental conditions: (A) normal condition, and (B) high-risk with incentive. For this latter, high-risk with incentive, condition B, the research team added productivity demand, time pressure, and cognitive demand to the expectations: subjects were given 10 fewer

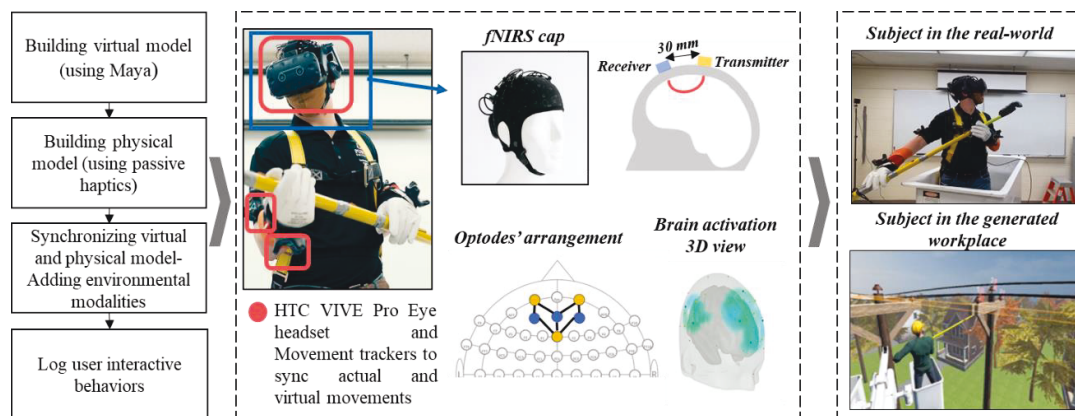


Figure 1. Research framework for real-time mixed-reality environment synchronized with fNIRS

seconds than they needed to complete the task under the normal condition, and they were asked to complete a 2-back working memory task simultaneously while they performed the main task. Critically, under Condition B, participants were told that if they could complete the task in a timely manner while completing the secondary task accurately, they would receive \$10 additional compensation. At the end of the experiment, the research team conducted a semi-structured interview to assess participants' risk perception within each condition.

As explained, brain activation manifests as increases in both cerebral oxyhemoglobin and blood flow throughout the brain, which appears to serve as a proxy for risk-seekers concentrating on gains during risky decision-making [10]. The arrangement of the fNIRS optodes' locations along with the PFC is demonstrated in Figure 1, which covers both right and left hemispheres. Specifically, a trajectory of 7 optode channels was implemented, which covered mostly the dorsolateral prefrontal cortex (DLPFC). The neural activity from the hemodynamic response function (HRF) that specifies BOLD signals overtime was used for the analysis.

4 Results and Findings

This study investigated subjects' behavioral responses and safety-related decisions under risk when gains and losses were in place. To do so, the research team began by differentiating the 33 participants' responses to the CARE questionnaire across the six categories of risk activities, discussed above. Then, correlations between the PCARE six categories and the PFC activations under Condition B, as well as the correlations between the PCARE categories and the subjects' Δ brain activation (i.e., changes in brain

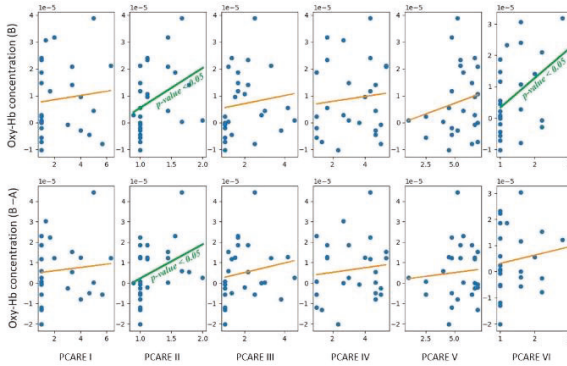


Figure 2. Correlation among brain activation and different categories of PCARE

activation from the normal Condition A to the risky Condition B), were identified (Figure 2).

While only the correlation between subjects' PCARE score and brain activation under Condition B in

categories II and VI, and their PCARE score and changes in brain activation (B - A) in category II are significant, all scatterplots demonstrate positive correlations between these two factors. Such insight reveals that as participants perceived more benefits than harm from being involved in irrelevant risky events, they perceived more gains in a risky construction task when there is an incentive in place.

For further analysis, participants were divided into two groups based on their average score in each category of the PCARE: (1) those more likely to focus on gains (high PCARE) versus (2) those less likely to focus on gains and more likely to focus on losses (low PCARE). Then, the changes in hemodynamic responses (oxy-Hb) in Condition B compared to Condition A (i.e., B-A) were compared between high-PCARE and low-PCARE groups across the six categories. Figure 3 demonstrates that, on average, there is more brain activation (changes in oxy-Hb) among participants in the high-PCARE groups than those in the low-PCARE groups in all six risky-activities categories. Moreover, there is a significant difference between the average brain activation among the high-PCARE group compared to the low-PCARE group within category II (i.e., aggressive and illegal behaviors).

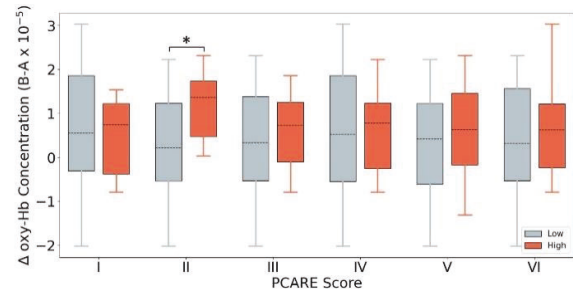


Figure 3. Box plot representing the distribution of brain activation (oxy-Hb concentration) in high-PCARE and low-PCARE groups

To examine whether there are significant differences in decision dynamics and associated PFC brain activation among individuals with positive risk attitudes (high-risk propensity group) when they need to complete a risky electrical task with (Condition B) and without incentive (Condition A), the Oxy-Hb changes were compared between the two conditions across all six risky event categories. As Table 1 shows, there are statistically significant differences in oxy-Hb concentrations in PCARE categories II, III, IV, V, VI between the normal condition (A) and the risky condition (B) (p -value II = 0.016, p -value III = 0.048, p -value IV = 0.040, p -value V = 0.025, p -value VI = 0.048). Partially significant changes in oxy-Hb were identified in PCARE category I (p -value I = 0.070). Further investigation of their safety performance indicated that those with higher risk

propensity took additional risks under situations with heightened risk-benefit dynamics and ended up experiencing more electrical arc flashes during the experiment.

Table 1. Statistical results comparing changes in brain activation of high-risk propensity group between Conditions A and B across six PCARE categories

Cond.	P CARE	MEAN	STD	Test Statistics (t)	p-value
A	I	0.471	0.712	-1.579	0.070**
B		1.128	1.473		
A	II	0.257	0.875	-2.672	0.016*
B		1.622	1.421		
A	III	0.173	0.562	-1.725	0.048*
B		1.000	1.423		
A	IV	0.280	0.674	-1.899	0.040*
B		0.995	1.311		
A	V	0.329	0.560	-2.154	0.025*
B		0.959	1.120		
A	VI	0.687	0.640	-1.832	0.048*
B		1.314	1.380		

**p-value < 0.1, *p-value < 0.05

Further, while the mean brain activation values across all categories were higher in Condition B than A for individuals with lower risk propensity (low-PCARE groups), there was no significant difference in oxy-Hb between Conditions A and B (p -value > 0.05) (Table 2), suggesting those with lower risk propensity will likely not take additional risks under situations with heightened risk-benefit dynamics.

Table 2. Statistical results comparing brain activation of low-PCARE groups within conditions A and B across six categories

Cond.	P CARE	MEAN	STD	Test Statistics (t)	p-value
A	I	0.144	0.634	-1.428 ^a	0.088
B		0.694	1.266		
A	II	0.180	0.609	0.003 ^a	0.499
B		0.192	0.886		
A	III	0.240	0.747	-1.598 ^a	0.089
B		0.790	1.349		
A	IV	0.226	0.732	-1.337 ^a	0.102
B		0.755	1.385		
A	V	0.164	0.915	-0.343 ^a	0.370
B		0.301	1.179		
A	VI	0.058	0.583	-1.151 ^a	0.134
B		0.386	0.954		

**p-value < 0.1, *p-value < 0.05

5 Discussion

Construction activities are known as high-risk activities, so proper perception of risks inherent to the surrounding environment is crucial for worker safety [19]. However, there are substantial differences among individuals in how risk is perceived. Such differences especially manifest in how individuals exhibit different sensitivities to losses and gains when making decisions under risk, a factor rooted in individuals' various risk attitudes.

This study examined the neural correlates and safety performance measures (i.e., number of arc flashes they have experienced while completing the task) among individuals with different attitudes toward gain and loss to assess risk-taking behaviors under varying risk-benefit conditions. The findings indicate that there is a positive correlation between each category of PCARE and brain activation during risky-with incentives tasks; thereby, risk attitude modulated brain activation in the prefrontal cortices more in participants who perceived greater positive consequences from risky actions than in participants who perceived more losses from risky actions. This finding is well-aligned with other neuroimaging studies that reported the involvement of PFC in risk decision-making behaviors [20,21]. As an example, a related study empirically showed a higher brain activity for subjects with more consideration of gains than losses [20]. In addition, previous studies observed decreased and increased hemodynamic responses in individuals who were focused on losses (i.e., having negative attitudes toward risks) versus those who mostly considered gains (i.e., having positive attitudes toward risks), respectively [9]. Therefore, activation of the PFC can serve as a proxy of individuals' risk attitude: Those more focused on gains (i.e., incentives in Condition B) will have higher brain activation.

These correlation results also indicate that subjects who are often highly focused on positive outcomes in other risky activities (e.g., the thrill of driving while intoxicated outweighs the perceived risk of arrest) are those who are highly concentrated on gains rather than losses in the simulated electrical construction task. Here, response generalization theory may come into play, as this theory explains that individuals who tend to be involved in a targeted risky behavior can also be involved in non-targeted risky behaviors [22].

Problematically, underestimating the risk of a hazardous situation increases the likelihood of taking more risks [2,7], especially as individuals who have positive attitudes toward risks tend to adopt risky behaviors by assigning higher expected values to the outcome. In contrast, people with negative attitudes perceive lower benefits and higher negative outcomes when involved in risky actions [2,7]. Well-aligned with this discussion is our observed changes in brain activation—i.e., the

differences in oxy-Hb concentration from the normal condition (A) to the risky condition (B, with incentives). These values showed higher average values for the high-PCARE groups versus low-PCARE groups within each category.

Although the risk level was higher in Condition B due to the time pressure and productivity demand—which may increase the risk of potential losses (experiencing arc flash)—the presence of incentives (i.e., gains) caused subjects to concentrate merely on achieving the gains and correspondingly increase their risk-taking behavior by speeding up to complete the defined task faster to obtain the incentive. These participants, who were also grouped high in various CARE categories, experienced more arc flashes in Condition B. So, the associated gains (i.e., additional compensation as an incentive) increased their perceived benefits and caused them to overlook losses as they found more value in taking risks. Collectively, these findings regarding subjects' assessment of expected value (i.e., gain) and harm (i.e., electrical accident) provided empirical evidence regarding the contributing role of risk attitude in workers' unsafe behaviors and at-risk decisions.

6 Conclusion

By employing a mixed-reality environment and neuroimaging technology, this study empirically investigated participants' risk propensity in a simulated high-risk construction scenario when gains and losses were in place. Results indicate that oxy-Hb concentration captured by fNIRS sensors may serve as a proxy of participants' risk attitudes since this value positively correlates with the evaluated PCARE scores. The present study also shows that expected value signals (gain) in the prefrontal cortex are considerably increased among risk-seeking individuals, which indicates that the more participants focus on gains during a risky situation, the greater their brain activation will be. Further, as subjects perceived more benefits associated with a situation, they valued positive consequences (i.e., gains) over negative ones (i.e., losses), which stimulated them to engage in greater risk-taking behaviors.

Together, the findings argue that fNIRS signals are reliable to provide behavioral information regarding individuals' risk propensity, decision-making, and risk-taking behaviors. This study provides insights into identifying at-risk workers whose positive attitudes toward risky situations may put them at high risk of engaging in potentially dangerous activities on jobsites. Future studies may incorporate different physiological sensors (e.g., Electrodermal activity (EDA)) to see the correlation between physiological responses and fNIRS signals, in investigating individuals' risk attitude and risk-taking behaviors. Using such knowledge can help in

suggesting behavioral interventions that incorporate educational information regarding risk perception, as a modifiable construct, to counteract excessive risk-taking.

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