Impact of hazard type on pre-attentive detection of safety hazards: Evidence from visual mismatch negativity

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Abstract. The failure to detect hazards is one of the most common human errors in construction accidents. Previous research mainly focused on later cognitive processes for hazard detection, such as workers' attention, distraction, and vigilance, ignoring cognitive impairment that may occur during elementary information processing. Using electroencephalography signals, this research investigated the impact of hazard type on construction workers' pre-attentive abilities for detecting hazards from the standpoint of a more early cognitive process. The pre-attention of construction workers to three types of hazards was compared using evidence from visual mismatch negativity, along with their behaviour performance, and self-perceived risks towards them. Results show that workers are more likely to turn a blind eye to slip and fall hazards that are on the same level than falls from height and be struck-by. Proactive and passive strategies for improving pre-attention were then suggested to improve construction workers' occupational safety in management practice.

1. Introduction

Construction has always been considered as a high-risk industry. Workers are frequently exposed to numerous types of hazards due to machinery or physical concerns. The first stage in preventing construction worker injuries or accidents is hazard detection, which is the act of detecting potential hazardous elements (Hasanzadeh et al. 2017). From a cognitive perspective, external information seen by eyesight need go through a two-step procedure when construction workers notice hazards, including early pre-attention and selective attention. Pre-attentive information processing is a primary filter during unintentional search for the perception and cognition of information from the outside world, which provides effective foundations for advanced cognitive function (Yang et al. 2020). Because pre-attention impairment can lead to problems with more complex cognitive processing, cognitive impairment, particularly pre-attention impairment, will arise when the filtering fails, posing safety risks to workers.

As a fundamental cognitive capacity, hazard pre-attention is needed on construction sites for almost all types of work, in addition to being a prerequisite for other cognitive processes during hazard detection. This is because except on-site inspectors, hazard detection is not a specific task that requires the attention of workers in other occupations. Construction workers under different occupational categories tend to have different tasks that they must focus on while at work, based on job obligations, such as pouring concrete, moving sands, and tying steel bars. However, construction tasks with fast paces, extended durations, and significant physical demands frequently, result in workers allocating insufficient attentional resources to hazards due to limited attention resources (Kim et al. 2021). In such cases, unconscious pre-attention can play a crucial role in hazard detection for safe behaviour makings. Therefore, focusing on how pre-attentive ability work in hazard detection is critical to ensuring construction workers' occupational safety in their daily tasks on dynamic and changing job sites.

2. Related Work

Over 80% of safety accidents in the construction sector may be the result of human error (Garrett and Teizer 2009). One of the most common errors at the individual level is the failure to detect hazards (Hinze and Teizer 2011). Traditional construction safety management relied heavily on self-reported questionnaires and safety checklists to assess hazard levels and safety performance, but such methods cannot objectively reflect construction workers' ability to detect hazardous conditions. This is due to the fact that the data obtained in this manner rely on feedback from construction workers recalling previous experiences, resulting in a relatively low ecological validity of information (Zhang et al. 2019). Scholars have recently attempted to understand the failure of hazard detection in construction workers by collecting objective physiological metrics (Ahn et al. 2019).

Electroencephalography (EEG) is a common physiological signal used to look into construction worker safety issues from a cognitive point of view. In these relevant EEG-based studies, some were for safety purposes by investigating mental status induced by the inherent features of construction works, including task workload and cognitive load, fatigue detection, stress recognition, emotional state and valence level (Saedi et al. 2022). Other research focuses have been on the impact of workers' attention, distraction, vigilance, and situational awareness on hazard detection and safety performance (Hasanzadeh et al. 2018, Ke et al. 2021, Wang et al. 2017). These studies were conducted in a view of individual cognitive abilities, but they mainly concerned about the phases of later information processing after hazardous information has passed the pre-attention filter. As a matter of fact, the impairment may happen at the level of elementary information processing, such as the possibility of compromised acuity of perceptual processes in vision (Gaál et al. 2017). However, there is still a lack of research on the failure of hazard detection from a more early and fundamental cognitive ability.

Moreover, studies about pre-attention issues in other fields like psychology and neuroscience are still scarce, and the results are equivocal when stimuli are different. As for specific construction workers, what they need to perceive in version on sites is more complicated than in daily life, as construction workplaces are full of hazards, changes, and uncertainties. As a result, the current conclusions in non-construction areas could not explain whether workers had different pre-attentive abilities for hazard detection when confronted with different types of safety hazards. To fill in these knowledge gaps, this research aims to investigate the impact of hazard type on pre-attentive hazard detection ability in construction workers from an early cognitive standpoint. Then, safety management strategies will be suggested in order to improve the visual pre-attentive hazard detection skills of construction workers on job sites.

3. Methodology

3.1 Experiment Design

Participants. To avoid gender bias, only men were permitted to participate in this experiment. Five male front-line construction workers (aged 51.6±9.9) were recruited as self-motivated volunteers in exchange for monetary compensation. All of them have more than five years of working experience on construction sites. They were all right-handed, and their vision was normal or corrected-to-normal. They had no history of psychiatric or neurological disorders.

Stimuli presentation. This experiment focused on three types of hazards: falls from height, struck-by, and falls, slip, and trip on the same level, which were identified by the Occupational Safety and Health Administration as the leading cause of injuries and fatalities in the construction industry and were previously studied (Jeon and Cai 2021). Safe and unsafe scenes were both included as stimuli under each hazard type. These scenes were altered with photo-editing software (Photoshop version CC 2017) to emphasize whether they posed a hazard, as shown in Table 1.

Table 1: Stimuli presentation based on three hazard types.

Hazard type		Scene description		
Hazard1	Falls from height	Safe scene	Close to protected sides with no guardrails	
		Unsafe scene	Close to unprotected sides with no guardrails	
Hazard2	Struck-by	Safe scene	Close to a tower crane hanging no materials	
		Unsafe scene	Close to a tower crane hanging heavy materials	
Hazard3	Falls, slip and trip on the same level	Safe scene	Work in the area with no clutter and obstacles	
		Unsafe scene	Work in the area with clutter and obstacles	

Experiment procedure. A standard-deviant reversed oddball paradigm was used because it can elicit workers' pre-attentive abilities to detect hazards, which can be thought of as a type of automatic change detection response (Kimura et al. 2011). The whole experiment procedure is presented in Figure 1 in detail. Participants were instructed to pay attention to whether the fixation changed and to hit a button as soon as the fixation changed. E-Prime 3.0 was used to complete this visual attention control task. Participants were provided enough practice in advance, but the stimuli for practice were not the same as those used in the formal experiment.

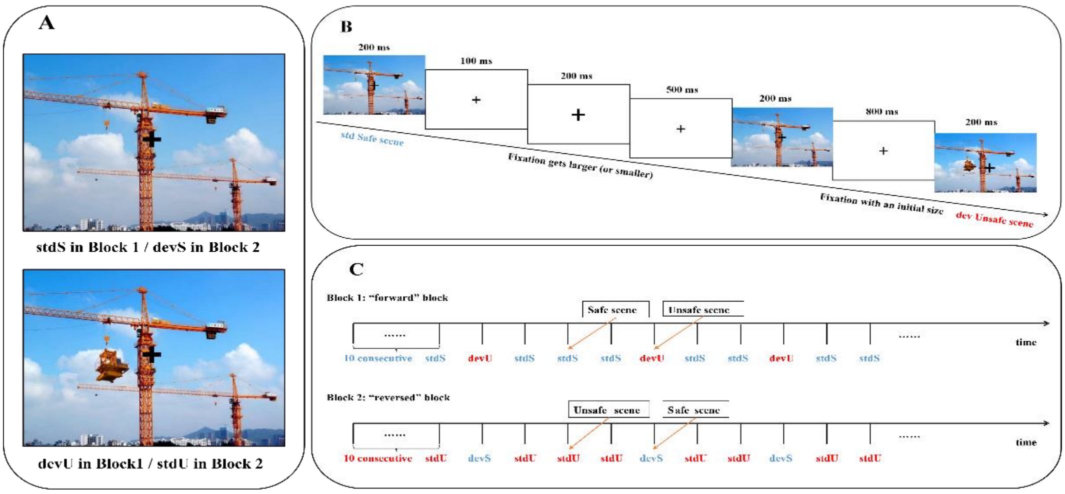

Figure 1: Experiment procedure (A) Stimulus examples (B) Schematic depiction (C) Stimuli settings (Abbreviations: stdS-standard safe, devU-deviant unsafe, stdU-standard unsafe, devS-deviant safe)

3.2 EEG collection and pre-processing

Equipment. A wireless EEG headset (Emotiv-EPOC Flex, 128 Hz) was used to collect EEG signals. It has 32 channels covering the prefrontal cortex, frontal lobe, temporal lobe, parietal lobe, and occipital lobe (Figure 2). The 10-20 international system was applied for placing electrodes. Saline solutions were used for the conduction. To guarantee data collection quality, EEG data was only collected when the recording quality was greater than 90%, which was automatically determined by the EmotivPro software.

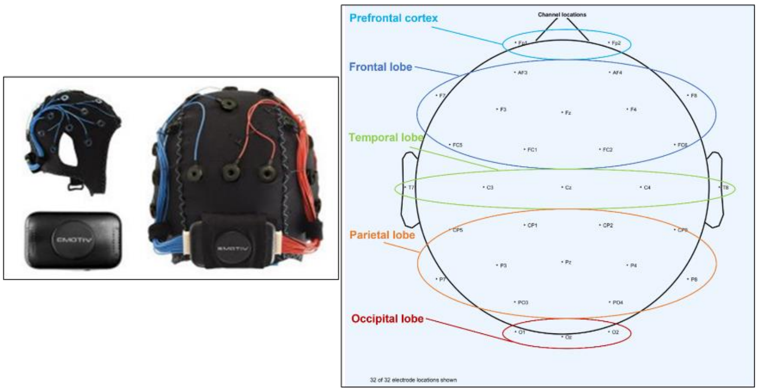

Figure 2: EEG headset for data collection and 32 channels in different brain regions

EEG pre-processing. MATLAB’s EEGLAB toolbox was applied to preprocess EEG data. They were corrected to the grand average. Offline filters with 0.1 Hz high cut-off frequencies and 30 Hz low cut-off frequencies were used. A 50 Hz notch filter was also used to eliminate wire noise caused by line interference. To find components for inherent artifacts, independent component analysis (ICA) was conducted. EEG data were segmented into 600 ms-long epochs, each of which began 100 ms before the commencement of the stimuli and ended 500 ms afterward. At epochs, voltage variations greater than 100 uV were disregarded. Problematic epochs were manually removed once more to make sure that only pure signals were kept.

3.3 Data Analysis

Measurement metrics. The visual mismatch negativity (vMMN) was selected to measure construction workers' pre-attentive ability for hazard detection because it is elicited without consuming attentional resources (Pazo-Alvarez et al. 2003). It tends to rise in the posterior part of the brain region between 100 ms and 500 ms after the start of stimuli (Kovarski et al. 2021). By subtracting the waveform representing the standard stimulus from the waveform representing the odd stimulus, the vMMN under each type of hazards was determined. Since the vMMN is theoretically a negative value, the smaller its value, the stronger the pre-attention it represents. Based on previous study on automatic information processing (Khvostov et al. 2021, Sulykos et al. 2017), channels from occipital lobes were selected to compute the vMMN, including O1, O2, and Oz. Furthermore, the automatic recording of accuracy rate and reaction time on E-Prime 3.0 was used to analyze participant behavior performance. Questionnaires were also used to measure self-reported risk magnitudes based on three hazard types.

Statistical analyses. To determine the time window of the vMMN, a data-driven method based on a set of point-by-point two-sample t-tests between two stimulus types (safe and unsafe scenes) under each hazard type was used. Three statistically significant discontinuous time intervals were identified as workers' response periods for further analysis. They were classified as early period (210ms-230ms), middle period (320ms-340ms), and later period (470ms-490ms) after the start of stimuli based on earlier research (Czigler et al. 2006, Kovarski et al. 2021). As the data was generally distributed normally, paired t-tests were performed in each response period to test whether construction workers have different pre-attentive abilities for hazard detection when faced with different types of safety hazards. Using a two-way analysis of variance (ANOVA), the interactive effects of hazard type and response period on construction workers' pre-attention to unsafe stimuli were also considered in the current research.

4. Results

4.1 The vMMN under three hazard types.

As is shown in the spatial distribution of Figure 3, the unsafe scene-evoked vMMN appeared on the O1 and O2 channels when construction workers faced the hazards of falls from height and falls, slip and trip on the same level, while it appeared on the Oz channel when workers faced the hazard of struck-by. Given that hazards in real construction workplaces always occur unexpectedly or suddenly, the unsafe scene-evoked vMMN was taken as a channel benchmark. Therefore, the average vMMN of the O1 and O2 channels was used to assess workers' pre-attention performance in the face of falls from height as well as falls, slip, and trip on the same level. The Oz channel's vMMN was used to measure workers' pre-attention performance while they were at risk of being struck (Figure 3). In general, the vMMN values evoked by unsafe scenes are more negative than those evoked by safe scenes. This indicates that construction workers gave more pre-attention to hazardous elements than to safe ones, regardless of the type of hazards they encountered. Nonetheless, construction workers were not sensitive to the hazard of falls from height in the early response period after stimuli onset, with safe scene-evoked vMMN significantly lower than unsafe scene-evoked vMMN.

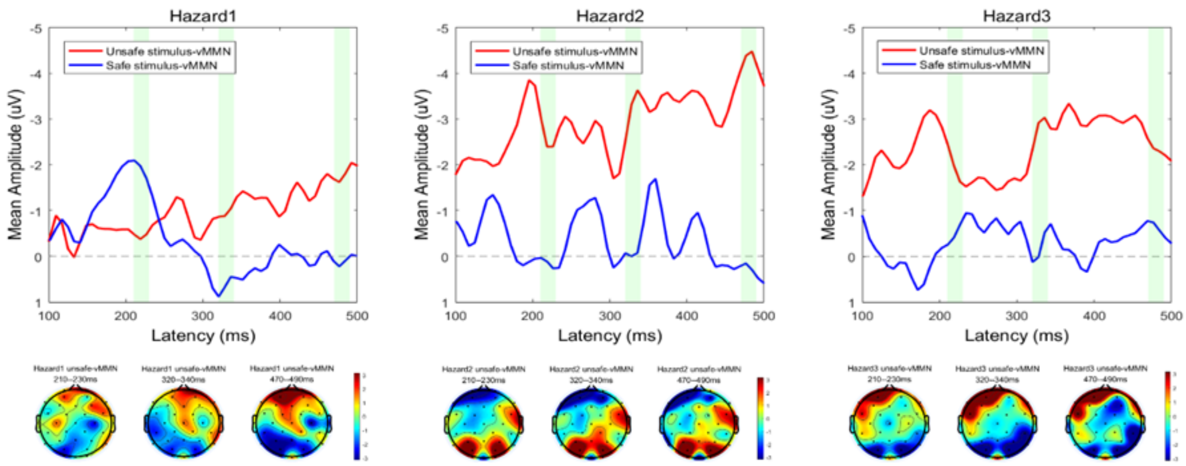

Figure 3: The vMMN showing the pre-attentive ability for hazard detection (Hazard1: Falls from height, Hazard2: Struck-by, Hazard3: Falls, slip and trip on the same level)

4.2 Pre-attention differences for hazard detection based on hazard types.

There exists a significant difference in construction workers' vMMN-based pre-attentive ability to detect the hazard of falls from height, seen in Table 2. Although safe scenes occupied more pre-attention than unsafe scenes in the early period after the stimuli were exposed to workers (p=0.014<0.05), their pre-attention to hazardous information increased and became more than safe information over time, especially in the middle period after the stimuli onset (p=0.011<0.05). Additionally, the positive or negative vMMN values indicate that, in contrast to the unprotected scenes, the protected working scenes at height did not appear to evoke workers' pre-attention.

Table 2: Paired t-test results of two stimuli-evoked vMMN for falls from height.

Response period	**Stimulus type (Mean±SD)**		**t-value**	**p-value**
	Unsafe stimulus	**Safe stimulus**		
Early period (210ms-230ms)	-0.44±0.51	-1.93±1.18	4.173	**0.014***
Middle period (320ms-340ms)	-0.93±0.84	0.67±1.09	-4.48	**0.011***
Later period (470ms-490ms)	-1.72±2.44	0.16±1.95	-1.417	0.229

* p<0.05 ** p<0.01.

Different from the pre-attention response to falls from height, construction workers showed a significantly greater pre-attentive ability to detect the hazard of being struck-by in the later period after the start of stimuli (p=0.027<0.05). Similarly, the increasing negative vMMN values over time, with a peak in the later response period, show that workers' pre-attention rose after seeing the hazardous information related to struck-by risks, as presented in Table 3.

Table 3: Paired t-test results of two stimuli-evoked vMMN for being struck-by.

Response period	**Stimulus type (Mean±SD)**		**t-value**	**p-value**
	Unsafe stimulus	**Safe stimulus**		
Early period (210ms-230ms)	-2.60±2.73	0.14±5.51	-0.807	0.465
Middle period (320ms-340ms)	-3.16±3.48	-0.05±5.36	-0.96	0.392
Later period (470ms-490ms)	-4.43±3.83	0.23±5.60	-3.404	**0.027***

Note: * p<0.05 ** p<0.01.

Contrarily, regardless of whether construction workers are exposed to safe or unsafe stimuli, the vMMN-based pre-attentive ability to detect the potential hazard of falls, slip, and trip on the same level does not demonstrate any significant difference during the entire response period (Table 4). However, workers still paid more pre-attention to the uneven ground with clutter and obstacles than to the same area without them.

Table 4: Paired t-test results of two stimuli-evoked vMMN for falls, slip and trip on the same level.

Response period	**Stimulus type (Mean±SD)**		**t-value**	**p-value**
	Unsafe stimulus	**Safe stimulus**		
Early period (210ms-230ms)	-2.01±1.83	-0.46±1.49	-1.121	0.325
Middle period (320-340ms)	-2.76±2.54	-0.13±1.48	-1.519	0.203
Later period (470ms-490ms)	-2.33±1.69	-0.66±1.14	-1.47	0.216

Note: * p<0.05 ** p<0.01.

4.3 Interaction of hazard type and response period on pre-attention to unsafe stimuli.

The vMMN results were compared between the hazards of falls from height and falls, slip, and trip on the same level, as both appear in the same channels and additionally, these two hazards tend to be homogeneous according to previous research (Jeon and Cai 2022). Statistically significant periods between 130ms-150ms and 340ms-360ms were identified for analysis using a millisecond-by-millisecond data-driven approach for time window selection (Figure 4). In the early stages of automatic visual processing, construction workers were found to be more sensitive to hazardous information related to falls on the same level than falls from height.

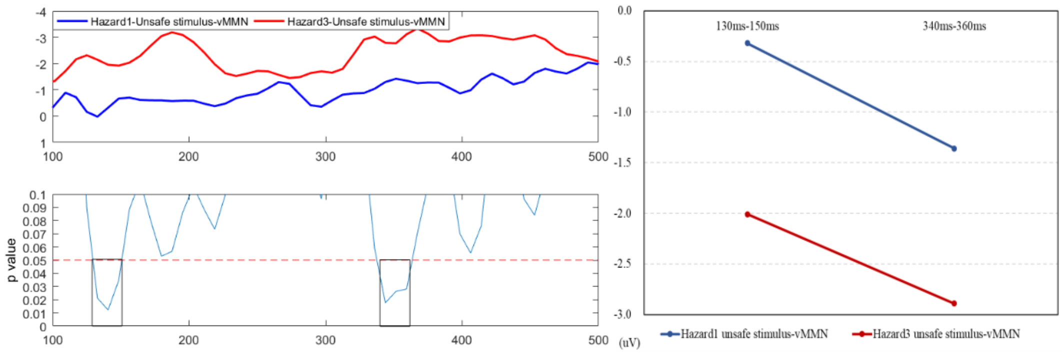

Figure 4: Differences in the unsafe stimuli-evoked vMMN between hazard types (Hazard1: Falls from height, Hazard3: Falls, slip and trip on the same level)

Table 5 shows the main effects and interactive effects of hazard type and response period on vMMN-based pre-attention of construction workers. The type of hazard was found to have a significant main effect on vMMN values (p=0.032<0.05), but the response period did not. Moreover, there was no significant interactive effect of both on unsafe stimuli-evoked vMMN components. This further indicates that workers' pre-attentive ability to detect dangerous elements are quite influenced by different hazard types on construction sites.

Table 5: Two-way ANOVA results of unsafe stimuli-evoked vMMN between hazard types.

	Response period (Mean±SD)		**F-value**	**p-value**
	130ms-150ms	**340ms-360ms**		
Hazard1: Falls from height	-0.32±0.55	-1.36±2.01	-	-
Hazard3: Falls, slip and trip on the same level	-2.01±1.14	-2.89±1.94		
Hazard type	-	-	5.538	**0.032***
Response period	-	-	1.966	0.18
Hazard type * Response period	-	-	0.012	0.916

Note: * p<0.05 ** p<0.01.

4.4 Behaviour performance and self-reported risk perception.

Table 6 shows that construction workers acted more correctly but quickly in the face of unsafe scenes of falls from height and being struck-by than falls, slips, and trips on the same level. Based on their experience, they perceived higher risks for the first two hazards than the latter.

Table 6: Behavior performance and self-reported risks of participants.

Hazard type	Accuracy rate (%) [a]	Reaction time (ms) [a]	Perceived risk magnitude [b]
Hazard1: Falls from height	36.67	459.92	7.60
Hazard2: Struck-by	36.67	458.82	7.60
Hazard3: Falls, slip and trip on the same level	28.89	487.10	4.60

Note: [a] Accuracy rate and reaction time refer to the behaviour performance in the forward block where unsafe scenes functioned as deviant stimuli. [b] estimated by the likelihood of incident occurrence and the recovery period after it using self-reported questionnaires.

5. Discussion

5.1 Pre-attentive hazard detection mechanisms of construction workers

The present research provides evidence of an automatic pre-attentive hazard detection mechanism sensitive to unsafe scenes in the visual system of construction workers under three hazard types. Concerning the vMMN cortex source, it demonstrates that vMMN-based workers' pre-attention to hazards on construction sites exists in the occipital lobe. Nonetheless, unsafe scenes involving the hazard of being struck-by evoked the vMMN-based pre-attention from the central Oz channel, whereas unsafe scenes involving the hazards of falls from height and falls, slip and trip on the same level evoked the vMMN-based pre-attention from both sides of the cortex (the O1 channel on the left and the O2 channel on the right). According to the vMMN results, construction workers have more sensitive pre-attentive detection abilities when confronted with unsafe scenes than when confronted with safe scenes, because the vMMN evoked by unsafe stimuli has more negative values than that evoked by safe stimuli during their entire response period. This can be explained by the threat-superiority effect (Marcos and Redondo 2005), which gives threats priority in automatically grabbing attention and gaining access to awareness. Depending on the type of hazard, differences in workers' pre-attention to hazards evolved in different ways when it comes to the impact of hazards. They appear to be more likely to turn a blind eye to the hazard of falls, slip and trip on the same level than the other two, as there is no statistically significance in vMMN differences between unsafe and safe stimuli under this hazard type. This is primarily due to the fact that such hazards are always the most prevalent in construction workplaces and frequently cause non-fatal accidents (Chang et al. 2016), which makes workers less aware of them. Workers' unconscious pre-attention to them may decrease if they are not paying attention, because personal perception is positively affected by attending to something (De Brigard 2012).

5.2 Strategies for workers' pre-attention improvement

From an early cognitive standpoint, this research can shed light on providing safety management strategies to improve occupational safety of construction workers. Two kinds of strategies, proactive and passive, are suggested in safety practice. Pre-attention trainings on hazard detection could be carried out for construction workers in a proactive manner, particularly in terms of the hazard of falls, slip, and trip on the same level. Bottom-up processing based on object saliency (such as unsafe safe scenes) should be emphasized in these visual trainings, rather than top-down visual searches driven by tasks like material handling on the same level, in order to assist workers in developing unconscious situational awareness of the unsafe stimuli that they may regard as safe based on their personal cognition and subjective experience (Chraca 2018). For example, safety managers can create an attention-training-control condition in which stimuli are individual unsafe scenes (such as unprotected openings, poor site housekeeping, lifting overload, and workers at height without personal protective equipment) and the matching safe scenes. Construction workers are required to mouse-click on the presented unsafe scenes amongst safe scenes as quickly and accurately as possible to train their pre-attention improvement. Furthermore, visual aids for improving construction workers' pre-attention while on the job related to on-foot construction tasks could be designed. In a passive perspective, the assessment on pre-attentive abilities for detecting different kinds of hazards could be included as a metric of pre-employment screening for various occupations in construction, which could aid in the development of a high-quality worker team comprised of workers with acute pre-attention to safety hazards.

6. Conclusion

Hazard detection is the first step in preventing construction injuries or accidents. Early pre-attention, as a prerequisite of cognition process, work first and foremost to ensure that perceived risks are involved in advanced visual information processing during workers' attention stages. Previous studies, however, were primarily concerned with the phases of later cognitive processes for hazard detection, such as workers' attention, distraction, and vigilance after hazardous information passed the pre-attention visual filter, ignoring cognitive impairment that may occur at the level of elementary information processing. Therefore, this research investigated the impact of hazard type on workers' pre-attentive abilities for detecting hazards from the standpoint of a more early cognitive process based on EEG signals. Three typical types of visibility-related hazards, including falls from height, struck-by, and falls, slip and trip on the same level, were compared in this research. Five construction workers were recruited to participate in the experiment, which used a standard-deviant reversed oddball paradigm to elicit vMMN-based pre-attention. Results show that workers pay more sensitive pre-attention to unsafe scenes than safe scenes. There is no significant interactive effect between hazard type and response period on the onset of unsafe stimuli on pre-attention. Nonetheless, hazard types significantly affect workers' pre-attentive abilities for hazard detection. They are more susceptible to falls from height and being struck-by than falls, slip and trip on the same level in the early cognitive process according to the vMMN results. Findings from behaviour performance and self-perceived risks show that they reacted less correctly and slowly to the third hazard type and perceived less risks as a result. Overall, it appears that construction workers are more likely to turn a blind eye to slip and fall hazards that are on the same level than another two hazards. This research helps expand the cognitive model of construction workers' failure to hazard detection by exploring an automatic pre-attentive hazard detection mechanism sensitive to unsafe scenes in the visual system. It also sheds light on providing safety management strategies for pre-attention improvement in order to facilitate the occupational safety of construction workers. Because the current study's sample size is limited, more workers could be recruited for experiment participation to verify these evidence.

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