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Influence of Safety Experience and Environmental Conditions on Site Hazard Identification Performance

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Abstract: Improving the hazard identification ability of workers is an important way to reduce safety accidents at construction sites. Although previous studies have succeeded in improving hazard identification performance, an important gap is that they consider only two factors, the worker's safety experience and objective environmental conditions, to analyze the impact on hazard identification performance. To fill the above gap, a visual cognitive model of hazard identification was established. Sixteen field scenes were selected to represent construction sites in each environmental condition. Eye-movement data were extracted through eye-tracking experiments, and the differences between experts' and novices' gazes during danger recognition in these scenes were analyzed. The results indicate the following: bright construction sites can significantly improve the correct recognition rate and information processing in hazard identification; tidy construction sites can improve the search efficiency and correct recognition rate of hazard identification; safety experience can improve workers' correct recognition rates and information processing; and reducing distractions can effectively improve the correct identification rate of hazards. Overall, optimal site brightness needs to be further studied to improve the efficiency of hazard search and reduce the distraction effect. This study provides recommendations for the direction of safety training and safety management on site.

Keywords: eye-tracking; hazard identification; construction safety; safety experience; environmental condition

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1. Introduction

Safety is one of the most important issues in the construction field [1]. In terms of construction safety, enterprises have done much to improve safety levels, such as improving the construction environment and strengthening safety management and training [2]. However, the safety level of the construction industry is still not sufficient due to the complex environmental conditions of construction sites, the large number of workers, and the complex spatial distribution of work surfaces [3,4]. According to statistics, the death rate in the construction industry is 4.24 times higher than that in all other industries, and more than 60,000 workers die on construction sites worldwide every year [5]. One of the major factors affecting employee safety performance in the construction industry is the failure to perceive the critical factors in a given environment to make the right predictions or decision [6]. Safety education is essential to promote a safe and healthy construction work environment [7]. A better understanding of the impact of hazard identification on construction safety performance can enhance existing safety education and further improve site safety performance.

To address this issue, researchers have worked to explore ways to identify the hazards that lead to construction accidents [8,9]. Hazard identification is emerging as one of the most effective ways to proactively prevent accidents, and unidentified hazards lead to a significant increase in the probability of accidents occurring [10–12]. Studies have shown that up to 57% of hazards at construction sites defy identification [13]. Poor construction site hazard identification has been identified as a major cause of poor building safety performance [14]. Therefore, improving hazard identification is of great significance to enhancing safety levels at construction sites.

Most studies have addressed the issue of poor construction site hazard identification by developing safety training models that attribute poor levels of hazard identification to a lack of knowledge and experience [11,15]. Although safety training can improve the safety knowledge base of novice workers, a lack of experience prevents the maximization of their hazard identification performanc [16]. Safety experience is gained through applying safety knowledge, and repeated practice with hazard identification tasks helps managers acquire identification expertise [17]. The difference in the level of hazard identification may be due to experienced workers having more opportunities for hazard identification. Experience facilitates subjects quickly identifying task-relevant areas, correctly identifying hazard [18,19], and reducing human error [20,21]. A lack of safety experience will result in the inability to identify potential hazar [22–24]. Therefore, understanding the differences in hazard identification between experienced and novice workers can help inform novice training and improve novice workers' hazard identification by learning from experienced workers. Proper identification of environment factors such as personnel, equipment, and materials that may lead to accidents requires a certain level of experience and a knowledge base among workers, but hazard identification as a visual search process is also highly susceptible to the complex environmental conditions on-sit [3,25]. Studies have shown that 49% of building construction accidents are closely related to the environmental conditions at the construction site [11]. Environmental conditions define the environment in which construction workers work on a daily basis. Due to the characteristics of construction projects themselves, in general, most of the workers' workplaces have bad lighting and dust, on-site materials and tools are often placed in a messy manner, and other phenomena that hinder the identification of hazards occur. In addition to poor lighting, site clutter is an important factor affecting the level of hazard identification [3]. Although previous studies have explored the differences in the performance of experienced and inexperienced construction workers in terms of hazard identification [26,27], there is a lack of methods to explore ways to enhance hazard identification from the perspective of combining safety experience and site environmental conditions; the interaction between safety experience and environmental conditions is unclear, and the differences in the performance of experienced and novice workers in hazard identification in various construction site environments have not been determined. In addition, exploring the differences in hazard identification performance allows for construction site-specific training for various environmental conditions and summarizes construction site management priorities.

In addition to the identification results, it is necessary to study the differences in the identification process to discover insights from training the inexperienced. The allocation of attention during hazard identification affects the level of hazard identification [28]. However, this tacit knowledge is difficult to obtain. Existing measures of hazard detection performance or other safety accountability for construction employees using a questionnaire survey approach [29] could be prone to subjectivity. The development and application of eye-tracking technology has given researchers the ability to obtain eye-movement data to analyze workers' cognitive processes during hazard identification. Eye-tracking techniques have been widely used in the cognitive process of building hazard recognition [30], including attention allocation and scanning path [4]. Therefore, the hazard identification process can be well analyzed by designing eye-tracking experiments to obtain eye-movement data during hazard identification.

To fill the above gap, this study intends to investigate how factors such as safety experience and environmental conditions interact with each other in the hazard identification process to influence hazard identification performance. To reasonably select performance indicators, the complete hazard identification cognitive process is analyzed based on cognitive psychology. Hazard identification is divided into specific cognitive stages. Corresponding performance evaluation indicators are selected according to the cognitive stages of hazard identification. A simulated eye-movement experiment was designed to evaluate the influence of work experience and two environmental factors, namely, brightness and site clutter, on hazard identification.

The rest of the study is structured as follows: Section 2 constructs a visual cognitive model of construction hazard identification and matches the corresponding hazard identification performance indicators to the various aspects of visual cognition. Section 3 designs an eye-movement experiment to simulate hazard identification to obtain eye-movement data of experienced participants performing hazard identification under various environmental conditions. Section 4 presents the analysis and discussion of the eye-movement experiment data. Finally, conclusions are drawn in Section 5.

2. Cognitive Model Construction and Index Selection

2.1. Visual Cognitive Model for Hazard Identification

In the perceptual domain of cognitive psychology, visual perception is the main way in which individuals perceive objective information about the external environment [4]. Visual search is a perceptual task that involves scanning the visual environment for specific objects (targets) and other irrelevant objects (distractors) [31]. In construction sites, workers scan the surrounding work environment to detect and identify the presence of hazards. Therefore, hazard identification can be essentially considered a multiobjective visual search process, where the hazard is the search target. A construction site is a complex and dynamic work environment in which large numbers of people, equipment, and materials are located, and the environmental factors are constantly changing. However, vision systems have a limited capacity to process information about the external environment and cannot perceive and process all objects or targets in the outside world at the same time. Therefore, workers may need sufficient knowledge and experience to accurately and quickly identify hazards in the environment that could lead to accidents, and appropriate environmental conditions (e.g., brightness, clutter, etc.) can help workers improve their hazard identification performance [3,27]. To better understand the visual cognitive process of hazard identification and analyze the factors influencing the identification, it is necessary to analyze the cognitive process of hazard identification and establish a cognitive process model.

To better understand the cognitive process of hazard identification at construction sites, further understanding of the cognitive process model is needed. Studies have been conducted to construct and optimize cognitive process models, and the cognitive process models familiar to scholars include the Wickens information processing model [32], the Rasmussen cognitive ladder model [33], the Drury visual search model [34], and the IDAC cognitive model [35]. The Wickens information processing model takes into account the influence of psychological factors on the cognitive subject and divides the individual cognitive process into four parts: receiving information, analyzing information, thinking and deciding, and executing responses. The Rasmussen cognitive ladder model further subdivides the four stages in Wickens's model into eight stages: activation, observation, recognition, interpretation, evaluation, defining the task, forming a protocol, and performing a response. The Drury visual search model considers the search processes for each target to be independent of each other. If the searcher does not find a target at certain locations, then subsequent searches will no longer focus on those areas. The IDAC cognitive model divides the cognitive process into four stages: external screening, information preprocessing, analytical decision-making, and executive response. Combining and analyzing these classical cognitive models reveals that they all hold that the cognitive process involves the processes of information collection, information analysis, and information decision-making, but the stages vary by problem and context. The construction workforce cognitive model in the construction environment needs to be considered together with the characteristics of the construction environment and the idiosyncrasies of the construction workforce itself. The construction operating environment is different from other operating environments in that it is characterized by many participants, site clutter, and crossed construction work surfaces [26]. Therefore, construction hazard cognition is different from general cognition, the cognitive process is more difficult, and the cognitive results are highly subjective, ambiguous, and easily influenced by the surrounding environment.

The visual search process can usually be divided into two parts: the search stage and the decision stage [36,37]. In the face of a dynamic construction site that is constantly changing, workers often do not enter the hazard search stage directly, and they conduct hazard target searches only when the stimulation of the surrounding environment makes them feel that there may be safety risks. Therefore, we divide the visual cognitive process of hazard identification into three links: the environment perception link, the hazard search link, and the analysis and decision link. The environment perception link occurs in the process of subconscious information collection through observing the environment of the construction scene, while the overall environment of the construction scene forms a stimulus for the operator. The sensitivity of the operator to various stimuli in the construction scene forms a subconscious screening of the hazard target, and if the stimulus level of the scene environment is lower than the sensitivity threshold of the operator, the hazards existing in the scene will be ignored. The hazard search link occurs in the process of collecting hazard information and extracting target hazard features through the visual search for scenes with incomplete information to initially determine the hazard targets with hazard information in the environment. The process is influenced by the personal experience of the worker in the hazard search stage, and experienced workers are usually able to identify hazard information more accurately. The analysis and decision link occurs in the process of analyzing and judging the target hazards in the construction scene, and the process requires the operator to have the corresponding safety knowledge.

Accordingly, the construction site hazard identification visual cognitive process model can be divided into three links: the first link is the perception process of the construction site environment, the second link is the search process of the hazard target, and the third link is the process of analyzing and determining the hazard information of the locked hazard target. Based on the comprehensive analysis, the visual cognitive model of hazard identification is shown in Figure 1.

Based on the above visual cognitive model of hazard identification, this study selects the evaluation indices of hazard identification performance according to the three major links of environment perception, hazard search, and analysis and decision-making; selects evaluation indices to measure the performance of hazard identification according to the characteristics of the various cognitive links; and conducts variance analysis.

2.2. Hazard Identification Performance Evaluation Index

Since many inspection-oriented tasks, including hazard identification (e.g., airport security, construction inspection, and safety inspection), are mainly based on visual search, accordingly, this article proposes a visual cognitive model for hazard identification to understand the visual search mechanism and then provides a theoretical basis for the selection of performance evaluation indices for the recognition cognitive process.

Some studies have evaluated the performance level of hazard identification based on accuracy rate and recognition time, which are result-oriented and cannot effectively reflect the information processing (cognitive process) of hazard identification [4,26]. The development and application of eye-tracking technology have provided researchers with the ability to obtain eye-movement data to analyze cognitive processes. A series of eye-movement metrics, such as gaze count, gaze duration, first fixation time, pupil size, gaze heatmap, and scan path, have been introduced into the analysis process of hazard identification search performance, search load, and search pattern. Among them, metrics such as gaze duration, gaze number, and gaze duration ratio are often used to measure visual search performance [16,38,39]. To evaluate the hazard identification performance from the entire visual search cognition process, it is necessary to select among the many eye-movement indicators that match each cognitive link, and quantitative experimental studies from the cognitive perspective are needed to reduce the safety problems caused by cognitive failure.

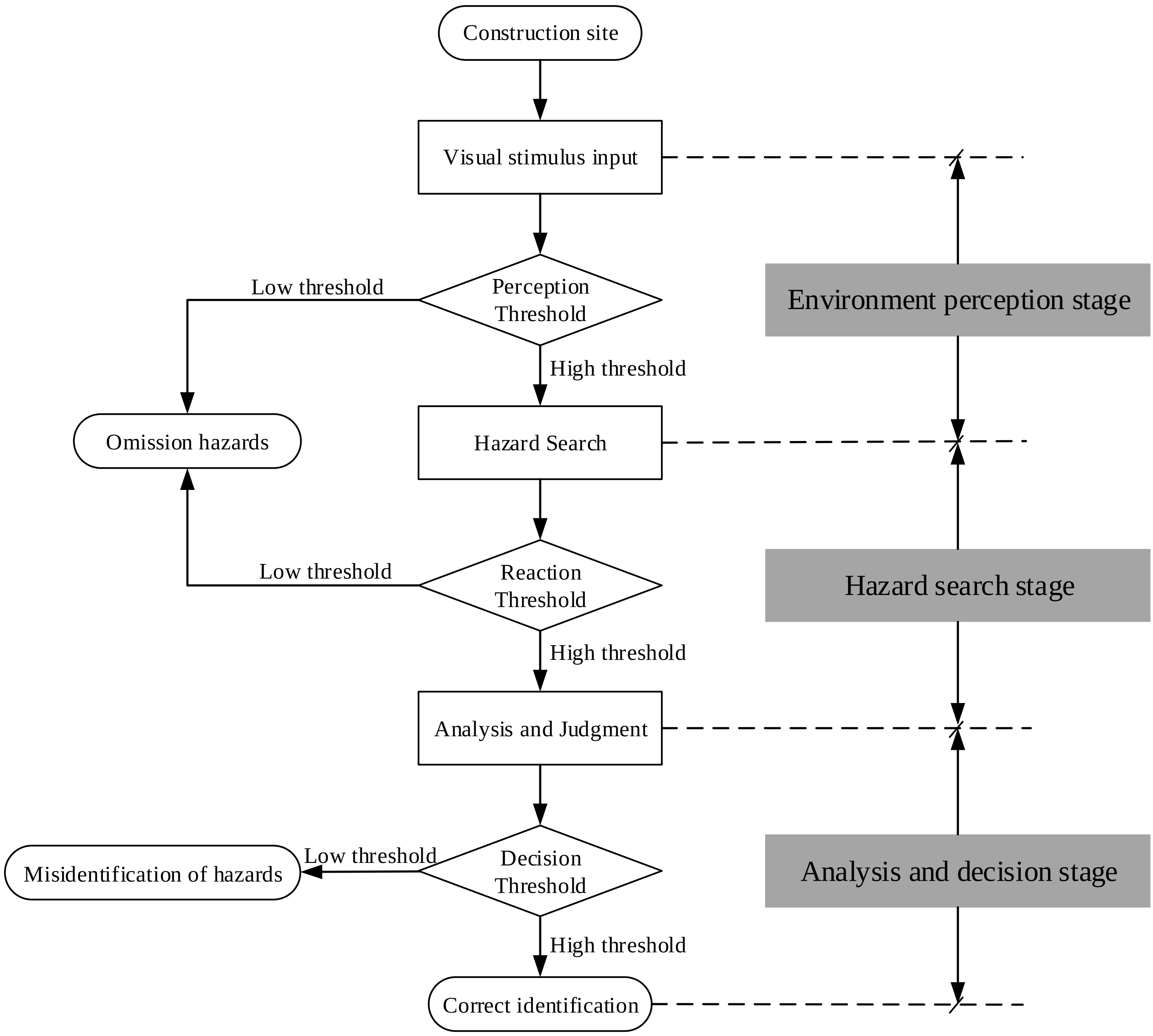

Figure 1. Visual cognitive model for identifying construction hazards.

In the constructed cognitive model of hazard identification, hazard identification is divided into three segments: environment perception, hazard search and analysis, and decision-making. When participants start to observe an unfamiliar scene, the environmental perception segment is usually completed subconsciously, and the demand time is relatively short. To enter the hazard search, the participant must first form a basic cognition of the scene through eye-sweeping and eliminate background distractions to find possible targets, which is the main task and cognitive process in the search phase. The fundamental purpose of the sweeping activity is the allocation and transfer of attentional resources. Therefore, the metrics related to attention allocation recorded by eye-tracking can better reflect the cognitive efficiency of the search phase. For example, many scholars have used total fixation time or total fixation number to measure attention allocation in the search and decision stage, and such metrics indicate search efficiency by calculating the total fixation time or total fixation number in the visual search process. In addition, the distraction effect is also an important metric for assessing the performance of hazard identification during the hazard search stage. Tipper argued that the successful selection of target information also requires the suppression of irrelevant information, which is an important mechanism of selective attention [40–42]. The less attention participants allocate to distracting information (irrelevant information), the smaller the distraction effect and the better the recognition of target hazards [43]. The ratio of the fixation time of the region of interest to the overall time is commonly used in psychological experiments to characterize the size of the distraction effect as well as the search accuracy. Therefore, in the present experiment, the values of fixation time and the number of times in the area of interest (AOI) as a proportion of the overall scene were used to characterize the size of the distraction effect and search precision. After the participants identified a target hazard, they entered the analysis and decision stage, which required analyzing the target information and matching the corresponding hazard information. For this stage, researchers often use the metric of AOI gaze to quantify decision-making efficiency, and the AOI mean fixation time has been used to indicate information complexity in previous eye-movement experiments. Therefore, in this experiment, the AOI mean fixation time was chosen to characterize the information processing level. In addition, for hazard identification as a visual search task, the success rate or the accuracy rate at which the participants search for a target is the main valid indicator of its performance [44], which is expressed as the correct recognition rate in this study. The statistical hazard identification performance evaluation metrics are shown in Table 1.

Table 1. Performance evaluation index for identification of hazards.

Indicators	Eye-Movement Indicators	Description	Stages of Cognition
Correct recognition rate	—	—	Hazard search stage; Analysis and decision stage
Search Efficiency	Total fixation time (TFT) Total fixation number (TFN)	The lower the TFT and the TFN, the faster the hazards search	Environment perception stage; Hazard search stage
Distraction effect	Ratio of fixation time of AOI (RFT(AOI)) Ratio of fixation number of AOI (RFN(AOI))	The higher the RFT(AOI) and (RFN(AOI)), the less distraction to nonhazardous areas and the higher the proportion of effective search	Hazard search stage
Information processing level	Average fixation time of AOI (AFT(AOI))	The lower the AFT(AOI), the higher the participant's information processing and cognitive ability	Hazard search stage

3. Methodology

A construction site is a complex working environment, and due to its dynamic nature and the interference of large numbers of people and materials, hazard identification requires sufficient experience and is susceptible to interference from environmental conditions. Therefore, in this study, two main environmental factors affecting hazard identification performance, namely, light brightness and site clutter, were selected as environmental characteristic variables, and experienced employees and novices were chosen to represent different experience levels to conduct simulated eye-movement experiments for hazard identification. To conduct the study, a large number of photographs of construction site scenes were taken, and 16 of them were selected after sorting and screening according to the environmental characteristics of the scenes. The participants were shown the photos in turn and asked to identify potential hazards. The hazards identified by the participants were recorded for further analysis. An eye-tracking device was used to record the participants' visual attention behaviors, including their gaze points and gaze durations. At the end of the experiment, the participants identified hazards, and their interpretation of the hazards was counted. The section begins with a detailed description of the experimental equipment setup and the background of the participants. Subsequently, photographs of the selected scenes are shown and illustrated. Finally, the experimental procedure is discussed.

3.1. Apparatus

A portable wearable eye-tracking device was used to record the eye-tracking process, and the model of the eye-tracking device was Tobii Pro Glasses2, which is from Tobii (Sweden). The device is divided into a data acquisition unit and a data recording unit, as shown in Figure 2. The acquisition unit is shaped like a pair of glasses and collects the spatial 3D coordinates of the eye through six infrared cameras around the frame; the recording unit uses a built-in software algorithm to construct a 3D model based on the eye coordinates to calculate the location of the gaze point and obtain a video of the scene from the human eye perspective with a gaze sampling rate of 50 Hz. Wireless data transmission technology ensured unrestricted observation and movement of the participants. During the experiment, the LCD presented a photo of the construction site with the participants sitting 60 cm in front of the LCD; the scene camera above the eye-tracking device recorded the participant's view and eye-tracking and transmitted it to the tablet in real time.

Figure 2. Eye-tracking experimental setup consisting of (**a**) a data acquisition unit and (**b**) a data recording unit.

3.2. Participants

In studying the participant selection, it was found that construction workers' hazard identification abilities were generally more complex. Some construction workers remain more alert if they have been injured in similar scenarios or witnessed similar scenario accidents, while workers who are familiar with a particular scenario may experience a state of numbness during hazard perception, leading to a decrease in hazard sensitivity. To avoid the influence of background differences in cultural, psychological, and physical characteristics across personnel, experimental participants should be selected broadly. Meanwhile, participants' willingness to participate in the experiment, their understanding of the experimental protocol, and their cooperation with the experimental activities may have a large impact on the experimental results.

Considering the above factors, 30 subjects were recruited to participate in the experiment, 10 of whom were experienced college instructors in engineering at a university, and 20 of whom were graduate students in engineering management and other related majors with work or internship experience in construction units. In the following study, college instructors represent experienced workers, and graduate students represent novices. The age of the selected students was 23.4 $\pm$ 0.6 years. These students were novices on the job site. They had taken all the courses on construction safety but lacked experience in internships on construction sites. The age of the invited experts was 43.1 $\pm$ 4.0 years. In addition to being college instructors, they were all permanently responsible for job site safety inspections and had 12 $\pm$ 3.2 years of experience. The advantage of the selected subjects was that they had a certain base of professional knowledge and had not worked in a specific scenario for a long time, which prevented interference with the experimental results due to accident experience and work experience. At the same time, the selected subjects had higher overall quality, and their understanding of the experiment, cooperation level, and interest in participation was more in line with the experimental needs. All subjects had normal visual acuity or corrected-to-normal visual acuity, no color blindness or color weakness, and participated in the experiment voluntarily.

3.3. Experimental Material

Through the analysis of the hazard identification cognitive process, the two typical construction environment features of brightness and scene clutter were selected for the selection and classification of experimental construction scenes and combined with the characteristics of construction site scenes. The definitions of brightness and scene clutter were based on Han et al. [3], as shown in Table 2.

Table 2. Site scene selection and descriptions of each scene.

Scene Category	Environmental Conditions	Definition
Light brightness	Bright	Scenes with adequate lighting and little need for additional lighting devices
	Dark	Scenes with insufficient lighting needing additional lighting device (e.g., artificial lighting) to assist construction work
Scene clutter	Tidy	Scenes in which working zones are clearly defined with good housekeeping and with items well organized
	Messy	Scenes without clearly planned working zones and with materials or equipment disorganized

Initially, 142 site pictures were collected from construction sites for the selection and classification of experimental materials, while 26 publicly released, non-controversial site pictures were obtained on the internet as a supplement. The research team identified the hazards in all the pictures several times and screened out the site pictures with non-controversial hazard targets and consistent hazard explanations, and a total of 92 pictures were screened out from the 160 scene pictures. Then, the scene pictures were classified according to the scene features defined in the table, and 10 scene pictures of each type of scene feature were selected as the material for the pre-experiment.

To better select scenario pictures that fit the characteristics of the environmental conditions defined in Table 2, 30 undergraduate students who had taken courses related to construction project management participated in a pre-experiment. To avoid learning effects, all subjects who had participated in the pre-experiment did not participate in the formal experiment. The pre-experimental subjects first fully understood the scene characteristics defined in Table 2 and then judged the scene characteristics of the scene pictures screened by the research team. There was no time limit for the judgment, but subjects were asked not to think for too long. Then, the pre-experimental subjects and the research group were compared on the results of scene feature classification of the experimental material, and the scene pictures with consistent results were screened out. Finally, four construction site scenes were selected for each of the environmental characteristics of bright and tidy, bright and messy, dark and tidy, and dark and messy, and the order was disrupted before experimenting.

The AOI in eye-tracking experiments is the visual environment of interest [45]. In the study of construction site hazard identification, the AOI was the area in which the hazard was located [3,46]. The research team divided the AOI range for each experimental scene individually according to the overall spatial structure of the scene and the location of the hazards, and the experimental scene photos and AOIs are shown in Figure 3.

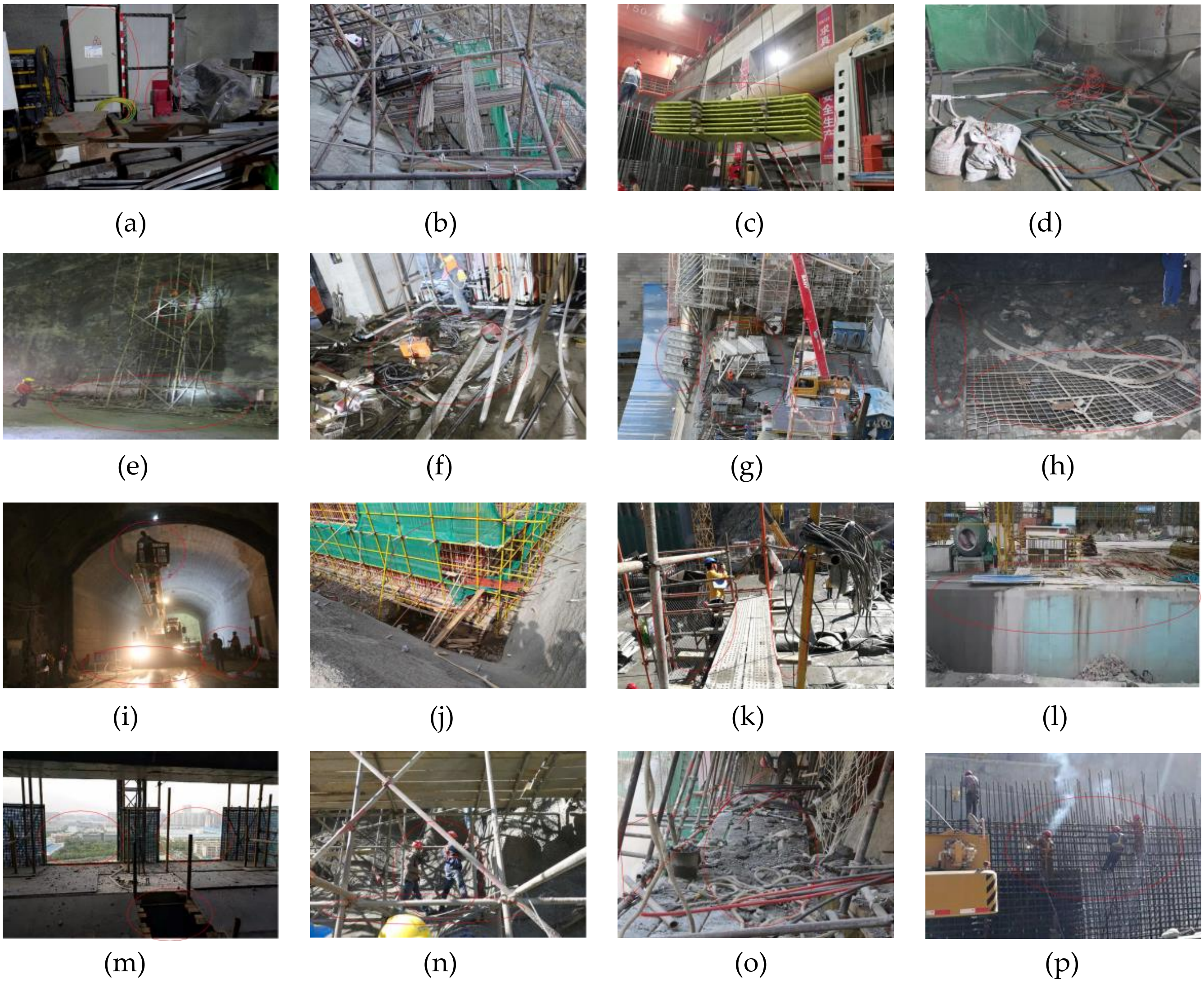

Figure 3. Photographs of the construction site used for the experiment: (**a**) dark, messy; (**b**) bright, messy; (**c**) dark, tidy; (**d**) dark, messy; (**e**) dark, tidy; (**f**) dark, messy; (**g**) bright, messy; (**h**) dark, messy; (**i**) dark, tidy; (**j**) dark, tidy; (**k**) bright, tidy; (**l**) bright, messy; (**m**) dark, tidy; (**n**) bright, tidy; (**o**) bright, messy; (**p**) bright, tidy.

3.4. Experimental Procedure

Each participant went through a consistent process under the guidance of the researcher, and the specific steps were as follows: (1) the researcher explained the purpose of the experiment and precautions to the participants; (2) the eye-tracking device was installed on-site and connected to the computer, and the device was debugged so that the eye-tracking recordings and the display met the experimental requirements; (3) the participants were identified in the order of scenarios 1 to 16, and the data were counted; and (4) Tobii Pro Lab software was used to organize the data recorded by the eye-tracking device, such as gaze point, fixation time, and gaze trajectory data.

There was no time limit for the identification process, and the total number of target occultations was not known. During the experiment, the identification of a target occlusion was considered successful only when the participant pointed out the target occlusion and correctly explained why the target occlusion constituted a hazard. For example, the target hazard was considered correctly identified only when the participant pointed out the empty fire extinguisher box and explained that a fire extinguisher should be in the box for it to be in a functional state when identifying construction site 1.

4. Results

Experimental eye-movement data were preprocessed by Tobii Pro Lab software, and experimental data with a gaze sampling rate lower than 80% were excluded [47]. If the participants' binocular data were lost, the monocular data were used for oculomotor data analysis; if both eyes were validly collected, the average value was taken for oculomotor data analysis. Since the total fixation time and total gaze number corresponding to the search efficiency varied in the same direction, the percentage of AOI fixation time and the percentage of AOI gaze number corresponding to the distraction effect also varied in the same direction. Therefore, the total fixation time was selected for search efficiency, and the AOI fixation time ratio was selected to measure the distraction effect as a representative index for analysis. According to the index analysis requirements, eye-movement parameters such as total fixation time, AOI fixation time ratio, and AOI average fixation time were extracted and counted.

4.1. Hazard Identification Performance

Table 3 shows the correct recognition rate, total fixation time, AOI fixation time percentage, and AOI average fixation time of experts and novices in the working scenes of various environments. The correct recognition rate and AOI fixation time of the experts were on average higher than those of the novices, and their total fixation times and AOI average fixation times were on average smaller than those of the novices; the correct recognition rates and AOI average fixation times of the participants varied greatly with brightness, and the correct recognition rates and total fixation times of the participants varied greatly with scene clutter. The descriptive statistics showed that the experienced workers could identify hazards more accurately than the novice workers, their levels of all performance indicators in the hazard search segment were better than those of the novice workers, and poor environmental conditions such as darkness and clutter reduced the hazard identification performance of the participants, including the experts. To investigate how each factor affects hazard identification performance, the data of each performance indicator were further analyzed.

Table 3. Correct recognition rate, total fixation time, AOI fixation time ratio, and average AOI fixation time for experts and novices in scenes of various environmental conditions.

Indicators	**Participants**	**Mean(SD)**			
		Bright	**Dark**	**Tidy**	**Messy**
CRR (%)	Experienced workers	74.57 (6.56)	54.44 (12.62)	72.35 (12.69)	56.67 (6.94)
	Novice workers	50.39 (15.25)	40.52 (5.62)	50.31 (9.72)	43.61 (9.34)
TFT (ms)	Experienced workers	5848.48 (2789.43)	5133.58 (1692.36)	4544.05 (1206.11)	6738.68 (1780.17)
	Novice workers	6982.79 (2509.18)	6954.97 (1861.82)	5984.01 (2420.07)	8558.75 (1795.76)
RFT(AOI) (%)	Experienced workers	54.79 (10.99)	50.58 (11.87)	56.07 (10.97)	50.68 (8.05)
	Novice workers	42.62 (6.22)	49.27 (7.70)	50.60 (8.71)	39.28 (6.48)
AFT(AOI) (ms)	Experienced workers	190.55 (21.30)	208.14 (40.31)	196.19 (17.84)	193.97 (21.05)
	Novice workers	227.02 (41.15)	250.76 (27.23)	230.89 (49.85)	224.90 (42.99)

4.1.1. Correct Recognition Rate

According to the target hazard information, the correct recognition rate of participants' hazards under each environmental scene was counted, and an independent sample t test [48] was conducted for the correct recognition rate of the experts and novices in the same environment. The test results showed that for four environmental construction scenes of brightness, dimness, neatness, and clutter, the correct recognition rates of the experts and novices varied significantly (significance $p < 0.001$). The Shapiro–Wilk test showed that the differences in the correct recognition rates of the participants in the two groups were normally distributed across the environments with different brightnesses and the control scenes with different levels of clutter ($p > 0.05$), which satisfied the parametric test hypothesis, and the paired sample *t* test was used to test the significance of the differences in the correct recognition rates under various brightness and clutter levels. The test results showed that the correct recognition rate was significantly higher in bright and neat scenes than in dim and cluttered scenes ($p < 0.001$). The statistics and test results of the correct recognition rates of the participants across environmental scenes are shown in Figure 4, where the significance levels were all 95%.

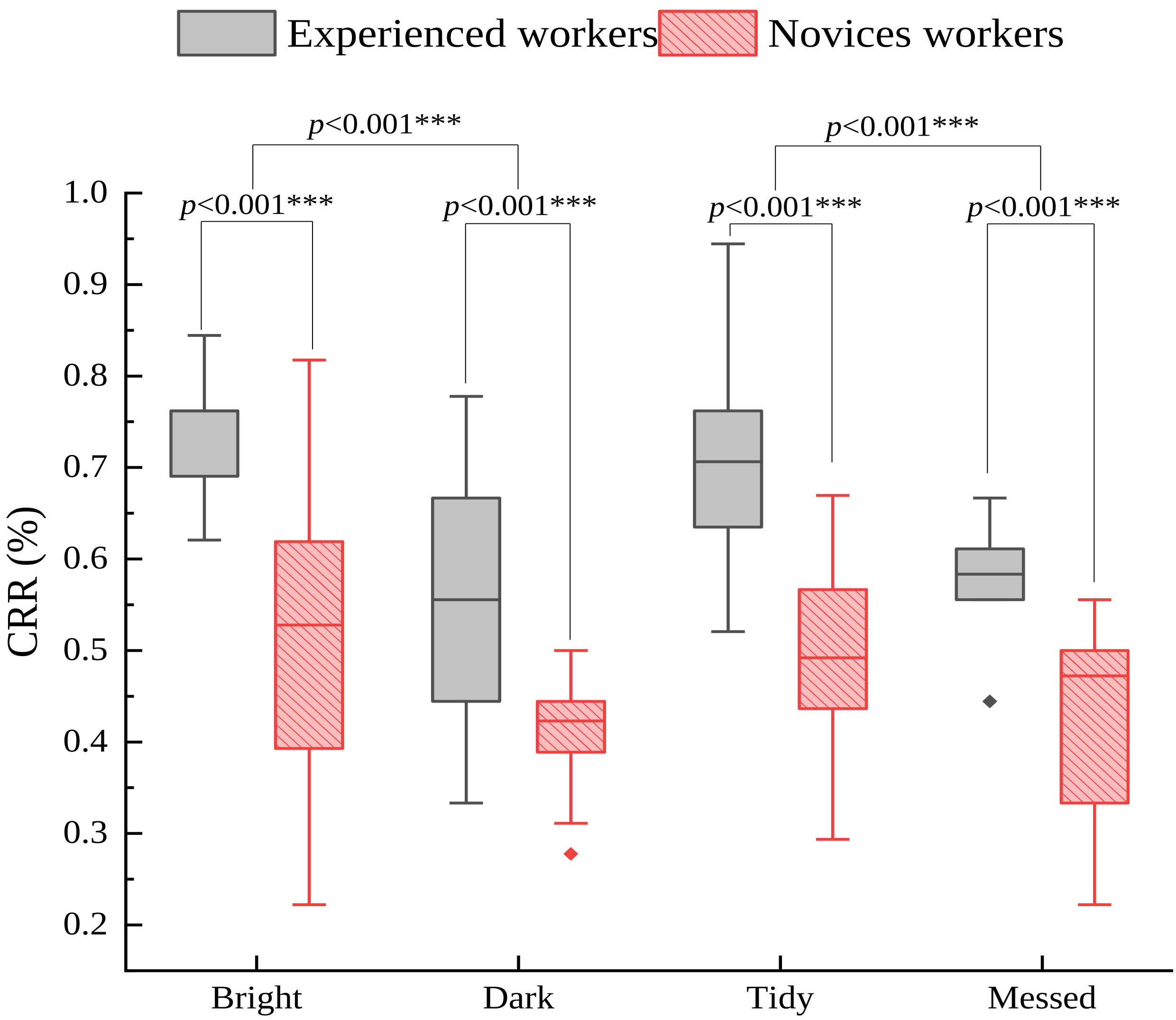

Figure 4. CRR for experts and novices in construction sites with various environmental conditions. (*** indicate significant differences at the 0.001 level.)

4.1.2. Search Efficiency

The total fixation time (ms) of the participants during hazard identification in each scene was counted, and independent sample *t* tests were conducted on the total fixation time of the experts and novices in the same environment. The test results showed that there was no significant difference in the total fixation times of the experts and novices in the bright and neat environment scenes ($t = -1.086$, $p = 0.287$; $t = -1.714$, $p = 0.097$); in the dim, cluttered scenes, the total fixation time of the experts was significantly lower than that of the novices ($t = -2.514$, $p = 0.018$; $t = -2.536$, $p = 0.017$). The Shapiro–Wilk test showed that the difference in total fixation times were normally distributed across the two groups of environments with different brightnesses and the control scene with two groups of environments with different clutter levels ($p > 0.05$), which satisfied the parametric test hypothesis; the paired samples *t* test was used to test the significance of the difference in total fixation time across brightness and clutter levels. The test results showed that there was no significant difference in the total fixation times for hazard identification between participants in the bright and dim environment scenes (t = 0.628, p = 0.535), while the total fixation time was significantly shorter in the cluttered environment scenes than in the neat scenes (t = −5.857, p < 0.001). The total fixation time statistics and test results of the participants across environmental scenes are shown in Figure 5.

Figure 5. TFT for experts and novices in construction sites with different environmental conditions. (* and *** indicate significant differences at the 0.05 and 0.001 levels, respectively.)

Figure 5 shows that under the dim and cluttered environmental conditions, the experts' hazard search efficiency was significantly higher than that of the novices, while under the bright and neat environmental conditions, the difference was not significant; under the neat environmental conditions, the participants' search efficiency was significantly higher than under the cluttered environment conditions, while there was no significant difference across environmental brightness levels. This is because novice operators in bright, neat, and other visual conditions work in a better environment, so the hazard identification process psychological load is smaller, they are more confident in the search process, and the total fixation time and the expert difference are not significant; however, the effect of the dim, cluttered special environment on the novices' search key information was greater than that on the experts, resulting in the total fixation time of the novices being significantly higher than that of the experts, indicating that the search efficiency of experts is less affected by the environment during the hazard identification process than that of novices.

4.1.3. Distraction Effect

The results of the independent samples *t* test on the percentage of total AOI fixation time between the experts and novices in the same environment showed that there was no significant difference in the percentage of total AOI fixation time between the experts and novices in the dim and neat environmental scenes (t = 0.367, $p = 0.716$; t = 1.486, $p = 0.148$); in the bright, cluttered scenes, the percentage of total AOI fixation time was significantly higher for the experts than for the novices (t = 3.899, $p < 0.01$; t = 4.190, $p < 0.001$). The Shapiro–Wilk test showed that the difference in the percentage of total AOI fixation time was normally distributed across the two groups of environments with different brightness levels and the control scenes with different clutter levels ($p > 0.05$), which satisfied the parametric test hypothesis, and the paired sample *t* test was used to test the significance of the difference in the percentage of total AOI fixation time of the two groups of environments across brightness and clutter levels. The test results showed that there was no significant difference in the proportion of total AOI fixation time between the participants in the bright and dimly lit scenes (t = −1.144, $p = 0.262$), while the proportion of total AOI fixation time was significantly shorter for the participants in the cluttered scenes than for those in the neat scenes (t = 4.544, $p < 0.001$). The statistics and test results of the percentage of total AOI fixation time of the participants in the various environmental scenes are shown in Figure 6.

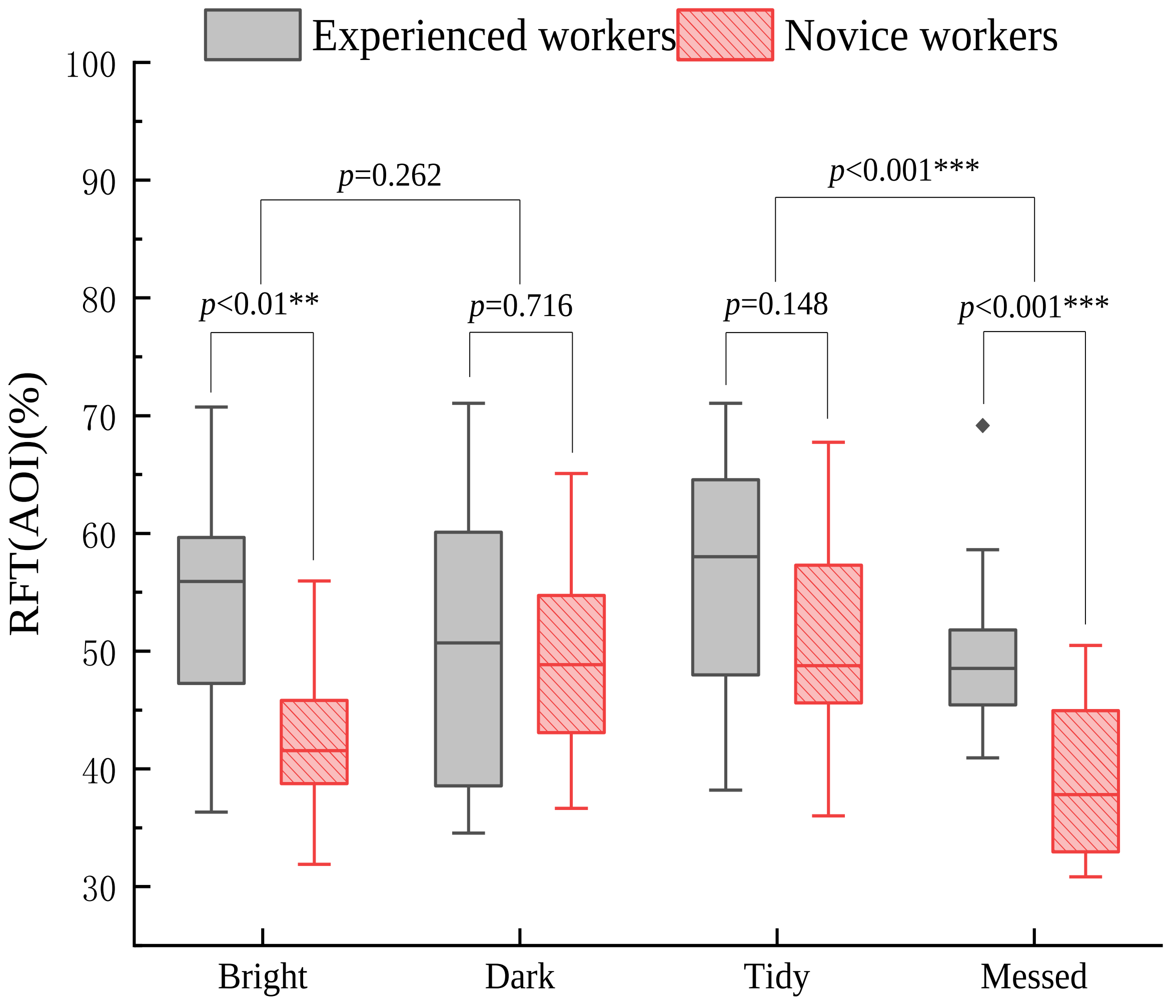

Figure 6. RFT(AOI) for experts and novices in construction sites with various environmental conditions. (** and *** indicate significant differences at the 0.01 and 0.001 levels, respectively.)

Figure 6 and the test results show that the ratio of AOI fixation time to total fixation time for the participants when identifying hazards in the cluttered environments was significantly smaller than that in the tidy environments, and there was no significant difference in the ratio of AOI fixation time in the environments with different brightnesses. This indicates that cluttered environments bring inconvenience to the operator's search for key hazard information, undermining an effective search. In the bright and cluttered environments, the percentage of AOI fixation time of the novices was significantly lower than that of the experts, and there was no significant difference in the dim and tidy environments. Combined with the analysis of the test results of total fixation time in the bright and dim environments in 4.2, it is usually difficult for participants to collect color information in dim environments, and at the same time, participants' search for some information in the scene is hindered, resulting in an increase in participants' total fixation time and a decrease in the percentage of AOI fixation time. However, the test results showed that there was no significant difference in the two indicators for the participants in the bright and dim environments. In addition, this may be due to the brighter scenes having better visual conditions and the increase in the number of irrelevant objects in the scene, resulting in a nonsignificant difference in search efficiency and effective search ratio between the dimmer and brighter scenes, while the experts were able to grasp key information better than the novices, resulting in the percentage of AOI fixation time being significantly higher for the experts than for the novices.

4.1.4. Information Processing Level

The average AOI fixation time for the participants during hazard identification in each scenario was counted, and independent sample *t* tests were conducted for the average AOI fixation times of the experts and novices in the same environment. The test results showed that the average AOI fixation time of the experts was significantly shorter than that of the novices in all four environments: bright, dim, neat, and cluttered ($t = -2.435$, $p = 0.022$; $t = -3.093$, $p = 0.004$; $t = -2.327$, $p = 0.027$; $t = -3.103$, $p = 0.002$). The Shapiro–Wilk test showed that the difference in the percentage of total AOI fixation time was normally distributed across two groups of environments with different brightnesses and the control scene with two groups of environments with different clutter levels ($p > 0.05$), satisfying the parametric test hypothesis, and the paired-sample *t* test was used to test the significance of the difference in the average AOI fixation times across brightness and clutter levels. The test results showed that the participants' average AOI fixation time was significantly shorter in the bright environment than in the dim environment ($t = -3.101$, $p = 0.004$); there was no significant difference in the average AOI fixation time across the cluttered environments ($t = -1.269$, $p = 0.214$). The statistics and test results of the participants' AOI mean fixation time across environmental scenes are shown in Figure 7.

Combined with Figure 7, it can be seen that the information processing level of the experts was significantly higher than that of the novices across environments; the information processing level of the participants in the bright environment was significantly higher than that in the dim environment, and there is no significant difference between the neat and cluttered environments. This indicates that bright environments increase the visibility of the search object, which helps the operators analyze the search target to better obtain hazard information and improve the information processing level.

4.2. Correlation Analysis between Recognition Rate and the Rest of the Indicators

In the data processing stage, four indicators, including the correct recognition rate (CRR), total fixation time (TFT), ratio of AOI fixation time (RFT(AOI)), and average AOI fixation time (AFT(AOI)), were counted for each expert and novice worker in identifying hazards in various environmental construction scenarios. To better present and analyze the association between the data of each indicator and the variation pattern of the data of the same indicator across participants, the data of each indicator obtained from the experiment were squared and normalized (SSN), and the processing method is shown in Equation (1):

$$x_i' = \frac{x_i}{\sqrt{\sum_{i=1}^{n} x_i^2}} \tag{1}$$

where x_i represents the value of the original data of each indicator, and x_i' represents the corresponding standardized value of each indicator data. The processed indicator data were transformed into standardized data between [0–1].

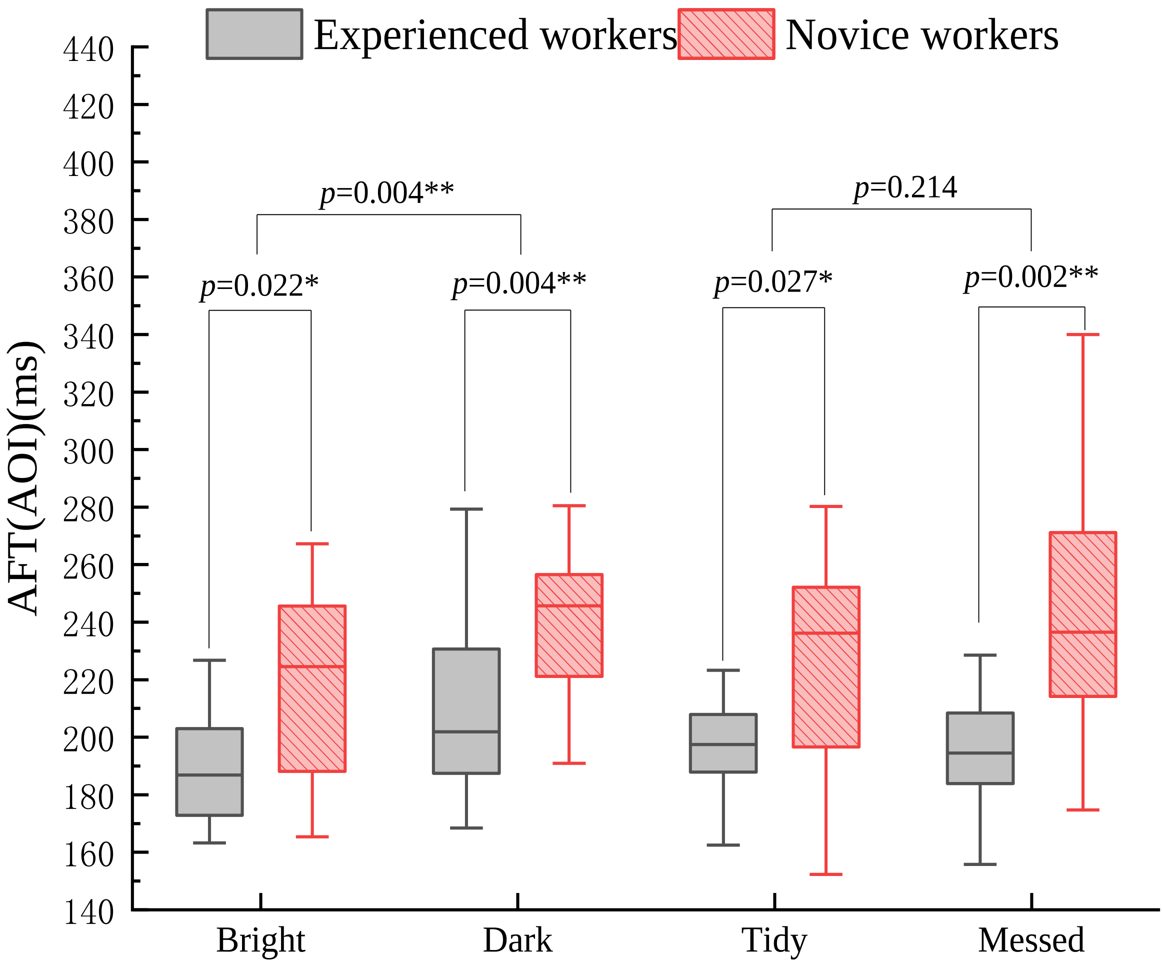

Figure 7. AFT(AOI) for experts and novices in construction sites with different environmental conditions. (* and ** indicate significant differences at the 0.05 and 0.01 levels, respectively.)

Figure 8 shows the statistics of each index datum after normalization. As seen from the figure, the differences in the CRR, RFT(AOI), and AFT(AOI) between experts or novices are small, and the TFT fluctuates more, which indicates that the search efficiency varies more among subjects with the same experience. Observing the gaze points and gaze hotspots of different subjects revealed that the subjects with higher total gaze time examined all objects in the construction site more comprehensively. However, the increase in total gaze time did not have a positive effect on the correct identification of hazards, as shown in Figure 8, and it decreased search efficiency. When the subjects focused mainly on the target objects that attracted more attention or interest, the search efficiency could be improved, hazards could be found in a more timely and effective manner, and safety accidents could be avoided. Therefore, strengthening workers' attention to areas with a high number of hazards through safety training and attracting workers' attention through safety signs can effectively improve their search efficiency.

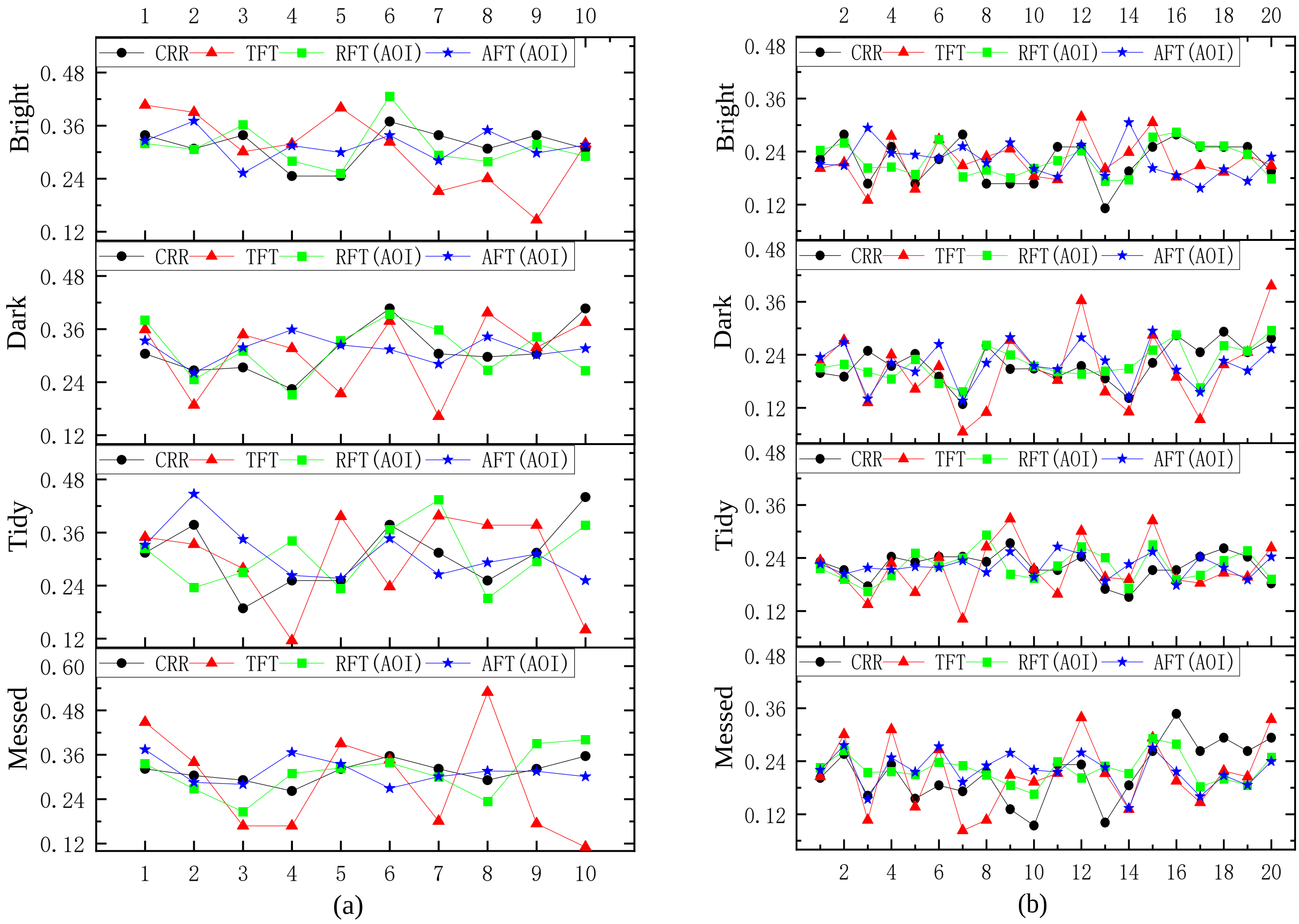

Figure 8. Standardized data of each indicator of the subjects: (**a**) experienced workers; (**b**) novice workers.

To further explore the correlation between the indicators in the identification process and the identification results, Pearson correlation tests were conducted on the indicators of CRR and TFT, RFT(AOI), and AFT(AOI), and the results are shown in Table 4. The test results show a significant positive correlation between the CRR of the experts during hazard identification in the bright and messy construction sites and the RFT(AOI), and there was a significant positive correlation between the CRR of the novices during hazard identification in the bright, tidy, or messy construction sites and the RFT(AOI); no significant correlation between the CRR and other indicators was found.

A larger RFT(AOI) indicates that the participants allocated more attention to the AOI and that the participants were less distracted by the distraction effect of irrelevant targets, increasing the chance that the participants correctly identified the target hazards. However, Table 3 shows that this correlation was not present in the dark construction site, indicating that a larger RFT(AOI) did not enhance the correct identification rate of the hazards. This may be because the participants entered the analysis and judgment stage after the hazard search to lock the hazard area, the dark conditions prevented the participants from analyzing the target, and the participants were unable to obtain further relevant hazard information, resulting in missed hazard detection.

Table 4. Pearson correlation test between CRR and TFT, RFT (AOI), and AFT (AOI).

CRR		Experienced Workers		Novice Workers	
		Pearson Correlation	Sig. (2-Tailed)	Pearson Correlation	Sig. (2-Tailed)
Bright	TFT	−0.046	0.899	0.356	0.124
	RFT(AOI)	0.638 *	0.047	0.463 *	0.040
	AFT(AOI)	−0.394	0.260	0.069	0.772
Dark	TFT	−0.261	0.466	0.260	0.269
	RFT(AOI)	0.432	0.213	0.403	0.078
	AFT(AOI)	0.165	0.648	0.192	0.418
Tidy	TFT	0.317	0.373	0.284	0.225
	RFT(AOI)	0.481	0.160	0.689 **	0.001
	AFT(AOI)	−0.104	0.774	0.170	0.473
Messy	TFT	−0.334	0.346	0.285	0.224
	RFT(AOI)	0.771 **	0.009	0.671 **	0.001
	AFT(AOI)	−0.059	0.872	−0.249	0.291

** Correlation is significant at the 0.01 level (2-tailed); * correlation is significant at the 0.05 level (2-tailed).

According to the results of the study, reducing the distraction effect can improve the correct identification rate of hazards. It can also, on the one hand, reduce irrelevant distractions on site, i.e., ensure that the construction site is as tidy as possible, and on the other hand, enhance the prominence of hazardous areas, such as the use of eye-catching safety signs to indicate hazardous locations or areas in the construction site safety management process.

5. Discussion

This study investigated the effects of safety experience and environmental conditions (light brightness and scene clutter) on the performance of the hazard identification process and outcomes, and eye-movement data were obtained from subjects during the hazard identification process through an eye-movement experiment. This study may have implications for the safety training of novice workers and safety management at construction sites.

5.1. How Does Safety Experience Affect Hazard Identification?

Experimental data analysis revealed that experienced workers were able to identify construction hazards more accurately (Figure 4), which is similar to the results of previous studies [16]. In addition, we found that the experienced workers identified hazards faster than the novices and were less likely to have their attention allocation affected by extraneous distractions. Previous studies on construction workers also reported that safety experience helped subjects identify hazards faster [26]. The results suggest that safety experience can influence hazard detection skills [49].

Practice is one factor that distinguishes novices from experts in a discipline [50]. The difference in correct identification rates may be due to experienced workers having more experience in applying safety knowledge. They have more experience in identifying safety problems at the job site. Repeated hazard identification practice helps workers acquire expertise in identification. Practice greatly increases the likelihood that students permanently remember new information; likewise, this practice helps managers permanently remember the safety information they apply. Conversely, novices have difficulty remembering safety knowledge learned in the classroom if they have not had the opportunity to practice. A lack of experience in hazard identification may make it difficult for novices to identify hazards that require significant knowledge; for example, in our study, the novices' performance identifying unsafe scaffolding hazards indicated their poor safety experience. The determination of scaffold safety status involves a large number of safety regulations [51], and it is difficult for novices to identify unsafe scaffolds in a scenario (picture 10). In addition, novices report that they put themselves in scenarios or check the safety of people on the job site because of their limited safety experience. This hazard detection method can help them identify some obvious hazards. For example, in our study, the novices had relatively high accuracy in collision hazards (i.e., the probability of being struck by a falling object or the distance between the worker and the machine). However, the method may not identify hazards that appear to be safe, making it difficult for subjects to perceive hazards. Similarly, this is the main reason experienced workers identify hazards faster than novices and are less affected by extraneous distractions.

In summary, novices do not apply safety knowledge on construction sites as well as experienced workers due to an inability to put into experience what they have learned in the classroom. Identifying the hazards associated with safety knowledge can be difficult for novices. Therefore, it is recommended that safety training should start with more simulation exercises for hazard identification rather than just learning the relevant safety knowledge to give novice workers the opportunity to apply their safety knowledge and gain safety experience to improve their hazard identification performance.

5.2. How Does Light Brightness Affect Hazard Identification?

Humans are unable to discriminate colors in the dark. In general, dark environments reduce or even prevent the detection of objects and affect the processing of environmental information. The present study found that the dark scenes reduced accurate hazard recognition but did not reduce the subjects' search efficiency or distraction effects. This is because the bright scenes exposed the subjects to more objects and increased their gaze time on more irrelevant objects that were visible due to the increased light. As a result, the subjects spent more of their attentional resources staring at these additional objects. When working at night or in a dark environment, it is recommended that contractors allocate lighting resources wisely and distribute lighting primarily in the work area. Adding easily spotted safety signs to supplement the lighting conditions allowed the subjects to allocate more of their attentional resources to the work area. According to Table 4, these reasonable lighting conditions will reduce the distraction effect on subjects and thus enhance the rate of correctly identifying hidden hazards.

5.3. How Does Scene Clutter Affect Hazard Identification?

The messy construction site environments had a great effect on the subjects' safety hazard detection, and the subjects in the tidy construction sites were able to focus their attention more accurately on the hazard area and identify hazards more correctly and quickly. A tidy and organized site can reduce the cognitive load of subjects by reducing the amount of energy spent on other nonrelevant objects or on saccadic movements. According to Chun [52], subjects had to spend more attentional resources to recognize more complex site layouts or irregular spatial conditions. According to Table 4, when subjects allocate more attention to irrelevant distractions, it corresponds to an increase in the distraction effect ground, which increases difficulty for subjects to identify hazards. Therefore, it is recommended that construction sites be planned rationally and laid out clearly. Materials, equipment, and other construction resources should be placed regularly so that employees can find them easily. In addition, site managers should make hazard areas as attractive as possible by adding hazard signage or using different-colored safety signs to indicate locations and areas with safety hazards.

6. Conclusions

This research investigated the effects of safety experience and construction site environment (i.e., bright/dark, tidy/messy) on workers' hazard identification performance. First, a visual cognitive model of hazard identification was established through the study of cognitive processes, and performance indicators were selected and matched with corresponding eye-movement indicators according to the model. Then, 16 field scenes were selected to represent construction sites in each environmental condition, and the eye-movement characteristics of experienced and novice workers performing faint hazard identification in these scenes were recorded and extracted through eye-tracking experiments. Finally, the recorded data were analyzed. The conclusions are as follows:

(1) Safety experience allows subjects to identify hazards more accurately and quickly. Novice workers are less likely to identify hazards that require a higher level of safety knowledge because they have not had sufficient time to acquire safety knowledge. Therefore, safety training should start with more simulation exercises for hazard identification rather than just learning the relevant safety knowledge.
(2) Brighter environmental conditions can help subjects identify hazards more accurately but can reduce identification speed because brighter light exposes more extraneous distractions while increasing visibility. Therefore, contractors should allocate lighting resources wisely and distribute lighting primarily in the work area.
(3) Subjects can focus their attention more accurately on the hazard area and identify the hazard more correctly and quickly at tidy construction sites. Therefore, construction sites should be planned rationally and laid out clearly. In addition, site managers should make the hazard areas as attractive as possible by adding hazard signs or using different-colored safety signs to indicate the location and areas with safety hazards.

This study analyzed the effects of three factors (i.e., safety experience, light brightness, and scene clutter) that may affect hazard identification performance and provided recommendations for the direction of safety training and safety management on site. However, the study also has some limitations. The experiments used static pictures for hazard identification and could not take into account other distracting factors on the construction site, such as noise and inter-worker effects. A follow-up study will use VR technology to simulate dynamic construction site scenes for the experiments. In addition, this study is limited to comparing inexperienced and experienced subjects. While this helps train novices, more construction safety personnel would benefit from this study if the differences between experienced subjects with different safety experience were compared. Future studies should include fairly large samples to obtain such differences.

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References

1. Liu, J.; Wang, X.; Nie, X.; Lu, R. Incentive Mechanism of Construction Safety from the Perspective of Mutual Benefit. *Buildings* **2022**, *12*, 536. [CrossRef]
2. Carter, G.; Smith, S.D. Safety Hazard Identification on Construction Projects. *J. Constr. Eng. Manag.* **2006**, *132*, 197–205. [CrossRef]
3. Han, Y.; Yin, Z.; Zhang, J.; Jin, R.; Yang, T. Eye-Tracking Experimental Study Investigating the Influence Factors of Construction Safety Hazard Recognition. *J. Constr. Eng. Manag.* **2020**, *146*, 4020091. [CrossRef]
4. Xu, Q.; Chong, H.-Y.; Liao, P.-C. Exploring eye-tracking searching strategies for construction hazard recognition in a laboratory scene. *Saf. Sci.* **2019**, *120*, 824–832. [CrossRef]
5. Lingard, H. Occupational health and safety in the construction industry. *Constr. Manag. Econ.* **2013**, *31*, 505–514. [CrossRef]
6. Endsley, M.R. Toward a Theory of Situation Awareness in Dynamic Systems. *Hum. Factors J. Hum. Factors Ergon. Soc.* **2016**, *37*, 32–64. [CrossRef]
7. Pedro, A.; Le Quang, T.; Park Chan, S. Framework for Integrating Safety into Construction Methods Education through Interactive Virtual Reality. *J. Prof. Issues Eng. Educ. Pract.* **2016**, *142*, 4015011. [CrossRef]
8. Abdelhamid, T.S.; Everett, J.G. Identifying Root Causes of Construction Accidents. *J. Constr. Eng. Manag.* **2000**, *126*, 52–60. [CrossRef]

9. Rajendran, S.; Gambatese, J.A.; Behm, M.G. Impact of Green Building Design and Construction on Worker Safety and Health. *J. Constr. Eng. Manag.* **2009**, *135*, 1058–1066. [CrossRef]
10. Rasmussen, J. Risk management in a dynamic society: A modelling problem. *Saf. Sci.* **1997**, *27*, 183–213. [CrossRef]
11. Haslam, R.A.; Hide, S.A.; Gibb, A.G.; Gyi, D.E.; Pavitt, T.; Atkinson, S.; Duff, A.R. Contributing factors in construction accidents. *Appl. Erg.* **2005**, *36*, 401–415. [CrossRef] [PubMed]
12. Liao, P.-C.; Sun, X.; Zhang, D. A multimodal study to measure the cognitive demands of hazard recognition in construction workplaces. *Saf. Sci.* **2021**, *133*, 105010. [CrossRef]
13. Bahn, S. Workplace hazard identification and management: The case of an underground mining operation. *Saf. Sci.* **2013**, *57*, 129–137. [CrossRef]
14. Albert, A.; Hallowell, M.R.; Kleiner, B.M. Enhancing Construction Hazard Recognition and Communication with Energy-Based Cognitive Mnemonics and Safety Meeting Maturity Model: Multiple Baseline Study. *J. Constr. Eng. Manag.* **2014**, *140*, 4013042. [CrossRef]
15. Jeelani, I.; Albert, A.; Azevedo, R.; Jaselskis, E.J. Development and Testing of a Personalized Hazard-Recognition Training Intervention. *J. Constr. Eng. Manag.* **2017**, *143*, 4016120. [CrossRef]
16. Ouyang, Y.; Luo, X. Differences between inexperienced and experienced safety supervisors in identifying construction hazards: Seeking insights for training the inexperienced. *Adv. Eng. Inform.* **2022**, *52*, 101602. [CrossRef]
17. Coleman, W.L. Learning and Memory. *J. Dev. Behav. Pediatr.* **1996**, *17*, 229–239. [CrossRef]
18. Kellman, P.J.; Garrigan, P. Perceptual learning and human expertise. *Phys. Life Rev.* **2009**, *6*, 53–84. [CrossRef]
19. Gegenfurtner, A.; Lehtinen, E.; Säljö, R. Expertise Differences in the Comprehension of Visualizations: A Meta-Analysis of Eye-Tracking Research in Professional Domains. *Educ. Psychol. Rev.* **2011**, *23*, 523–552. [CrossRef]
20. Zhang, L.; He, J. Critical Factors Affecting Tacit-Knowledge Sharing within the Integrated Project Team. *J. Manag. Eng.* **2016**, *32*, 4015045. [CrossRef]
21. Fang, D.; Zhao, C.; Zhang, M. A Cognitive Model of Construction Workers' Unsafe Behaviors. *J. Constr. Eng. Manag.* **2016**, *142*, 4016039. [CrossRef]
22. Goh, Y.M.; Chua, D.K.H. Case-Based Reasoning Approach to Construction Safety Hazard Identification: Adaptation and Utilization. *J. Constr. Eng. Manag.* **2010**, *136*, 170–178. [CrossRef]
23. Gadd, S.A.; Keeley, D.M.; Balmforth, H.F. Pitfalls in risk assessment: Examples from the UK. *Saf. Sci.* **2004**, *42*, 841–857. [CrossRef]
24. Brewer, N.T.; Chapman, G.B.; Gibbons, F.X.; Gerrard, M.; McCaul, K.D.; Weinstein, N.D. Meta-analysis of the relationship between risk perception and health behavior: The example of vaccination. *Health Psychol.* **2007**, *26*, 136–145. [CrossRef]
25. Sun, X.; Liao, P.-C. Re-assessing hazard recognition ability in occupational environment with microvascular function in the brain. *Saf. Sci.* **2019**, *120*, 67–78. [CrossRef]
26. Dzeng, R.-J.; Lin, C.-T.; Fang, Y.-C. Using eye-tracker to compare search patterns between experienced and novice workers for site hazard identification. *Saf. Sci.* **2016**, *82*, 56–67. [CrossRef]
27. Hasanzadeh, S.; Esmaeili, B.; Dodd, M.D. Measuring the Impacts of Safety Knowledge on Construction Workers' Attentional Allocation and Hazard Detection Using Remote Eye-Tracking Technology. *J. Manag. Eng.* **2017**, *33*, 4017024. [CrossRef]
28. Jeelani, I.; Albert, A.; Han, K.; Azevedo, R. Are Visual Search Patterns Predictive of Hazard Recognition Performance? Empirical Investigation Using Eye-Tracking Technology. *J. Constr. Eng. Manag.* **2019**, *145*, 4018115. [CrossRef]
29. Han, Y.; Jin, R.Y.; Wood, H.; Yang, T. Investigation of Demographic Factors in Construction Employees' Safety Perceptions. *KSCE J. Civ. Eng.* **2019**, *23*, 2815–2828. [CrossRef]
30. Wang, J.M.; Cheng, R.; Liu, M.; Liao, P.C. Research Trends of Human-Computer Interaction Studies in Construction Hazard Recognition: A Bibliometric Review. *Sensors* **2021**, *21*, 6172. [CrossRef]
31. Rahim Abdul Hamid, A.; Azhari, R.; Zakaria, R.; Aminudin, E.; Putra Jaya, R.; Nagarajan, L.; Yahya, K.; Haron, Z.; Yunus, R. Causes of crane accidents at construction sites in Malaysia. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *220*, 12028. [CrossRef]
32. Wickens, C.D.; Helton, W.S.; Hollands, J.G.; Banbury, S. *Engineering Psychology and Human Performance*; Routledge: Oxfordshire, UK, 2021.
33. Rasmussen, J. *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineer*; North-Holland: New York, NY, USA, 1987.
34. Drury, C.G.; Hong, S.-K. Generalizing from single target search to multiple target search. *Theor. Issues Ergon. Sci.* **2000**, *1*, 303–314. [CrossRef]
35. Chang, Y.H.J.; Mosleh, A. Cognitive modeling and dynamic probabilistic simulation of operating crew response to complex system accidents. Part 4: IDAC causal model of operator problem-solving response. *Reliab. Eng. Syst. Saf.* **2007**, *92*, 1061–1075. [CrossRef]
36. Liao, P.C.; Sun, X.; Liu, M.; Shih, Y.N. Influence of visual clutter on the effect of navigated safety inspection: A case study on elevator installation. *Int. J. Occup. Saf. Ergon.* **2019**, *25*, 495–509. [CrossRef]
37. Spitz, G.; Drury, C.G. Inspection of sheet materials—Test of model predictions. *Hum. Factors* **1978**, *20*, 521–528. [CrossRef]
38. Fang, Y.; Cho, Y.K. Effectiveness Analysis from a Cognitive Perspective for a Real-Time Safety Assistance System for Mobile Crane Lifting Operations. *J. Constr. Eng. Manag.* **2017**, *143*, 5016025. [CrossRef]
39. Li, S.; Jiang, Y.; Sun, C.; Guo, K.; Wang, X. An Investigation on the Influence of Operation Experience on Virtual Hazard Perception Using Wearable Eye Tracking Technology. *Sensors* **2022**, *22*, 5115. [CrossRef]

40. Tipper, S.P. The negative priming effect: Inhibitory priming by ignored objects. *Q. J. Exp. Psychol. Sect. A* **1985**, *37*, 571–590. [CrossRef]
41. Tipper, S.P.; Driver, J. Negative priming between pictures and words in a selective attention task: Evidence for semantic processing of ignored stimuli. *Mem. Cogn.* **1988**, *16*, 64–70. [CrossRef]
42. Tipper, S.P.; Weaver, B.; Cameron, S.; Brehaut, J.C.; Bastedo, J. Inhibitory mechanisms of attention in identification and localization tasks: Time course and disruption. *J. Exp. Psychol. Learn. Mem. Cogn.* **1991**, *17*, 681–692. [CrossRef]
43. Cosman, J.D.; Vecera, S.P. Object-based attention overrides perceptual load to modulate visual distraction. *J. Exp. Psychol. Hum. Percept. Perform.* **2012**, *38*, 576–579. [CrossRef]
44. Greening, C.P. Mathematical Modeling of Air-to-Ground Target Acquisition. *Hum. Factors J. Hum. Factors Ergon. Soc.* **1976**, *18*, 111–148. [CrossRef]
45. Jeelani, I.; Albert, A.; Gambatese, J.A. Why Do Construction Hazards Remain Unrecognized at the Work Interface? *J. Constr. Eng. Manag.* **2017**, *143*, 4016128. [CrossRef]
46. Jeelani, I.; Han, K.; Albert, A. Automating and scaling personalized safety training using eye-tracking data. *Autom. Constr.* **2018**, *93*, 63–77. [CrossRef]
47. Varzgani, F.; Norouzi Nia, J.; Alrefaei, D.; Shojaeizadeh, M.; Djamasbi, S. Effects of Text Simplification on Reading Behavior of Older and Younger Users. In Proceedings of the Human Aspects of IT for the Aged Population: 7th International Conference, ITAP 2021, Online, 24–29 July 2021; pp. 240–252.
48. Yao, S.-N.; Lin, C.-T.; King, J.-T.; Liu, Y.-C.; Liang, C. Learning in the visual association of novice and expert designers. *Cogn. Syst. Res.* **2017**, *43*, 76–88. [CrossRef]
49. Hadikusumo, B.H.W.; Rowlinson, S. Capturing Safety Knowledge Using Design-for-Safety-Process Tool. *J. Constr. Eng. Manag.* **2004**, *130*, 281–289. [CrossRef]
50. Ericsson, K.A.; Krampe, R.T.; Tesch-Römer, C. The role of deliberate practice in the acquisition of expert performance. *Psychol. Rev.* **1993**, *100*, 363–406. [CrossRef]
51. Halperin, K.M.; McCann, M. An evaluation of scaffold safety at construction sites. *J. Saf. Res.* **2004**, *35*, 141–150. [CrossRef]
52. Chun, M.M. Scene Perception and Memory. In *Psychology of Learning and Motivation*; Academic Press: Cambridge, MA, USA, 2003; Volume 42, pp. 79–108. [CrossRef]