Extracting Knowledge for Searching for and Identifying Hazards on Construction Site

Ren-Jye Dzeng and Yi-Cho Fang
Department of Civil Engineering, National Chiao Tung University, 1001 Ta-Hsueh Road, Hsinchu, Taiwan

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Abstract: The construction industry accounts for a high number of accidents. Although identifying hazards before construction starts or during construction is widely employed to prevent accidents, it typically fails because of insufficient safety experience. The experience helps in training novice inspectors, although extracting and describing tacit knowledge explicitly is difficult. This study created a 3-D virtual construction site, and designed a hazard-identification experiment involving 14 hazards (e.g., falls, collapses, and electric shocks), and an eye-tracker was used to compare the search patterns of the experienced and novice workers. The results indicated that experience assisted the experienced workers in assessing hazards significantly faster than the novice workers could; however, it did not improve the accuracy with which they identified hazards, indicating that general work experience is not equivalent to safety-specific experience, and may not necessarily improve workers' accuracy in identifying hazards. Nevertheless, the experienced workers were more confident in identifying hazards, they exhibited fewer fixations.

1 INTRODUCTION

The construction industry is one of the most hazardous industries, and it accounts for an extremely high number of accidents and fatalities. Hazard identification is the most frequently employed approach to preventing and reducing accidents on construction sites. However, it is difficult to extract hazard-identification knowledge from experienced workers and describe explicitly in text due to the dynamic work nature on job sites. Understanding how experienced workers search for and identify hazard may help formulating guidelines and strategies that can be used in training materials of related courses.

Some studies have successfully used eye-tracking devices to evaluate the difference between the approaches used by experienced and novice drivers for identifying road hazards, and have shown that visual strategies differ between these two groups. Their valuable contributions have elucidated approaches for comparing the inspection strategies and search patterns employed by experienced and novice workers in the construction industry. Thus, this study attempts to use an eye-tracking device to study differences between the experienced and novice workers in identifying hazards in the snapshots of virtual construction site that containing hazards.

Hazard identification is important to construction safety management. Nevertheless, Carter and Smith (2006) reported that current hazard-identification levels need considerable improvement. Furthermore, the Ministry of Labour of Taiwan (MOL, 2013) reported that the 33,332 construction site inspections conducted in Taiwan have resulted in 2,412 suspensions, with 2,436 financial penalties valued at US$3.73 million because of inappropriate or insufficient safety management. However, the corresponding fatalities in the construction industry accounted for 45.8% (148 of 323) of all fatalities among all industries in 2012. Poor safety awareness among workers and managers is the primary reason for the high incidence of accidents in the construction industry (Cheng et al., 2010). Thus, poor hazard-identification levels or insufficient inspection quality is a crucial safety management problem in the construction industry. Moreover, providing effective hazard-identification training for workers, managers, and inspectors is essential.

Hazard identification requires sufficient knowledge and experience to identify potential sources of physical, chemical, or physiological harm, as well as for identifying situations related to labour,

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equipment, material, and environmental factors that could cause accidents, which may affect productivity and profitability as well as injuries. It is also a complex task that requires knowledge of both regulations and experience because of the dynamic nature of construction environments. Goh and Chua (2009) indicated that safety experience may assist workers in improving their safety performance and preventing recurring mistakes, and those poor hazard-identification processes are the result of a lack of experience.

Several studies have successfully employed eye-tracking devices to evaluate the difference between the visual search patterns that experienced and novice drivers employ to identify road hazards (Hosking et al., 2010). They showed that novice drivers employ visual strategies that differ from those used by experienced drivers (Falkmer and Gregersen, 2005). Furthermore, under risky driving conditions, the scanning behaviour of novice drivers is narrower than that of experienced drivers; moreover, novice drivers typically look directly ahead, and they fail to perceive and assess hazard information (Pradhan et al., 2005). Konstantopoulos et al., (2010) reported that because experienced drivers are more familiar with hazardous events than novice drivers are, their fixations are shorter and more frequent. The poor hazard-identification ability or risk perception of novice drivers might explain why novice drivers are involved in more accidents (Ciceri and Ruscio, 2014).

2 EXPERIMENT DESIGN

To extract the difference between the hazard-identification ability of experienced workers and that of novice workers, we prepared four snapshots from the 3D virtual construction site model that was developed specifically for this research. The virtual model allows the experiment to accommodate a variety of hazards that are infeasible to see on a single construction site in real life as most construction sites would already corrected hazards if they allow us to conduct the experiment there. The model contains various hazards that were identified as the most frequently occured hazards in the construction industry (MOL, 2014). The participants were presented with the images sequentially, and they were asked to identify potential hazards. The identification accuracy and time were recorded for further analysis. An eye-tracker was used to record each participant's fixation. Each participant was interviewed following the experiment.

We collected cases of 350 construction industry accidents in Taiwan from 2009 to 2011 (MOL, 2014). We limited our scope to building construction, and identified 178 accidents fitting that category. We selected 14 hazards of 6 accident types, including falls, collapses, electric shocks, lacerations, explosions, and unsafe actions.

We used Google SketchUp version 8 (Trimble Navigation, Ltd) (Trimble Navigation, 2014) to create a virtual three-story building construction site featuring 8 workplaces that contain 21 hazards. Among those hazards, snapshots of 14 hazards, as shown in Fig. 1 (e.g., H1-1, H1-2, and H1-3 in Workplace 1) located in four workplaces were taken to be used as the test hazards in this experiment. Table 1 details the hazards.

Twenty-five paid volunteers participated in the experiment. Ten participants were experienced construction workers with an average of 5 years working experience and 6 hours formal safety training, which is required annually by the regulation, and 15 were graduate students studying construction engineering and management at National Chiao-Tung University, Taiwan, who had no work experience and safety training in construction. The construction workers represented experienced workers, whereas the graduate students represented novice workers. All participants had normal or corrected-to-normal vision, and passed an eye-tracking calibration test.

A 19-inch liquid-crystal display (LCD) monitor with a resolution of 1280 × 1024 pixels was connected to a laptop to display the images. We recorded eye movement by using the EyeFrame SceneCamera System model of the ViewPoint EyeTracker, manufactured by Arrington Research, Inc. (Arrington Research, 2014) (Figs. 2-1 and 2-2) at a sampling rate of 30/60 Hz, spatial resolution of 0.15 degrees of the visual arc, and accuracy between 0.25 and 1.00 degrees of the visual arc.

The experiment facilitator assisted each participant in fitting and calibrating the eye-tracker. Subsequently, the participant started the experiment by inspecting the snapshots and using a mouse to identify potential hazards sequentially from Workplaces 1 to 4 without time limitations, and without knowing the total number of target hazards. A successful identification was recorded only when a participant clicked on a hazard and correctly explained the reason for the spot to be a hazard. The participants' head and eye movement were unrestricted during the experiment. An interview followed the experiment to clarify how the participants searched for and identified potential hazards.

We calculated the identification accuracy, miss rate, and identification time to evaluate the participants' hazard-identification ability. We also developed a computer program to analyze the search pattern based on the participants' fixation, to identify the difference between the hazard-identification ability of experienced and novice workers. The program was written in Visual Basic for Applications and run on Microsoft Excel. In this study, fixations with durations longer than 500 ms were retained as attention points.

3 RESULTS

Table 2 shows the identification accuracy, miss rate, and identification time of the experienced and novice workers for the four workplaces. Table 3 shows the independent t-test results for comparing the ability of the experienced and novice workers in identifying hazards. Regarding the identification accuracy or miss rate, the experienced workers outperformed the novice workers on average (i.e., 86.71% versus 80.39% or 30.00% versus 49.17%). However, the difference was statistically nonsignificant. Regardless, the experienced workers required significantly less time compared with the novice workers in identifying hazards ($t = -4.16$, $p < 0.001$).

The following lists our findings pertaining identification accuracy, miss rate, and identification time.

- The experienced workers did not perform significantly better than the novice workers did, indicating that years of construction experience did not necessarily assist the experienced workers in identifying hazards.
- General work experience is not equivalent to safety-specific experience, and may not necessarily improve workers' accuracy in identifying hazards.

Figure 3 shows the fixation frequency for all attention points inspected by the participants, where H and N represent hazards and non-hazards, respectively. The mean fixation frequency among the novice workers fixations was more than that of the experienced workers for most attention points, except for N1-2 and H2-2 in Workplaces 1 and 2, respectively. Regarding Workplace 3, the mean fixation frequencies among the novice workers on H3-1, H3-2, H3-3, and H3-4 were significantly more than those of the experienced workers ($p = 0.002$–0.049). Regarding Workplace 4, the difference between the fixation frequency of the experienced and novice workers was marginally non-significant for N4-1, N4-2, N4-3, and N4-4 ($p = 0.067$–0.103).

The following lists our findings pertaining fixation frequency.

- The novice workers were less confident than their experienced counterparts when determining whether an attention point was a hazard, whereas the experienced workers typically decided sooner, as indicated by the shorter identification times.
- The fixation frequency of the novice workers was significantly more than that of the experienced workers only for non-hazards because of the complexity involved in Workplace 4, where non-hazards might have distracted both novice and experienced workers.
- The attention points involving ladders typically received a high number of fixations, and thus for which the participants required more time to decide whether they were hazards, and they can thus be considered key points in hazard-identification training courses.

Two exceptions to the aforementioned finding are observable in N1-2 of Workplace 1 (i.e., unconnected rebar) and H2-2 in Workplace 2 (i.e., obstacles impeding access), where the mean number of the novice workers' fixations was less than that of the experienced workers. An explanation is that the experienced workers did not perceive the rebar because injuries related to this hazard are comparatively minor; for example, lacerations only accounted for 15% (90 of 599) and 0.8% (1 of 115) of serious injuries and fatalities in Taiwan, respectively (MOL, 2013). By contrast, obstacles impeding access are so obvious that even the novice workers were aware of the hazard.

In addition to the identification time, fixation frequency was an indicator of the difficulty perceived by the participants. Except for Workplace 3, the attention points with the highest number of fixations (H1-1 in Workplace 1, N2-2 in Workplace 2, and H4-1 in Workplace 4) were identical for both the experienced and novice workers. Based on Fig. 3, the attention points involving ladders typically received a high number of fixations. The hazards receiving comparatively more fixations indicate hazards for which the participants required more time to decide whether they were hazards, and they can thus be considered key points in hazard-identification training courses.

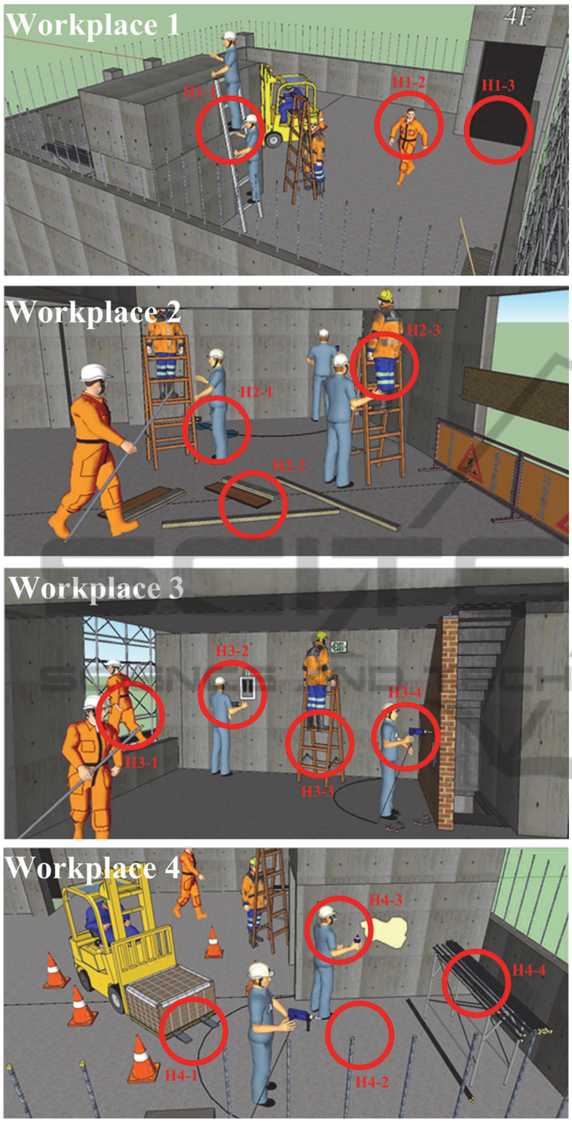

Figure 1: Workplace scenarios.

Fig. 2-1 Fig. 2-2

Figure 2: Eye-tracking system.

Table 2: Identification accuracy, miss rate, and time of the experienced workers and novice workers.

Group	Accuracy (%)	Miss rate (%)	Time (sec)
Experienced	86.71	30.00	40.19
Novice	80.39	39.17	74.91

Table 1: Hazard description.

Hazard	Accident type	Description
Workplace 1		
H1-1	Falls	Two workers ascended the same ladder simultaneously.
H1-2	Unsafe actions	The worker did not wear a helmet.
H1-3	Falls	The opening should have a guardrail.
Workplace 2		
H2-1	Electric shocks	When using electronic equipment, the wire should be elevated in wet environment.
H2-2	Collapses	The work area should be unimpeded and clear of obstacles.
H2-3	Falls	The worker should not use the ladder within 2m to the hazard that requires a guardrail.
Workplace 3		
H3-1	Falls	The opening between structure and scaffold should have a guardrail.
H3-2	Electric shocks	The worker did not wear insulating gloves during live-line operation.
H3-3	Falls	The ladder should be open completely to have fixed support.
H3-4	Collapses	The demolition of the brick wall did not follow a strict top- down sequence.
Workplace 4		
H4-1	Collapses	The wire overlapped with the moving path of the forklift.
H4-2	Laceration s	Each rebar should be capped.
H4-3	Explosions	Smoking is prohibited during paint-spraying or welding.
H4-4	Collapses	Rebar should be tied and placed in secured fashion.

Table 3: Independent t-test comparison of identification accuracy, miss rate, and time for identifying hazards between the experienced workers and novice workers.

Source	*N*	*Mean*	*SD*	*t*	*p*
Accuracy (%)					
Experienced	10	86.71	11.31	1.19	0.247
Novice	15	80.39	14.03		
Miss rate (%)					
Experienced	10	30.00	11.46	-1.70	0.102
Novice	15	39.17	14.18		
Time (sec)					
Experienced	10	40.19	9.85	-4.16	0.000
Novice	15	74.91	24.96		

4 CONCLUSIONS

The experimental results indicated that the experienced workers exhibited similar identification accuracies and miss rates compared with the novice workers, and their experience assisted them only based on the speed at which they identified hazards.

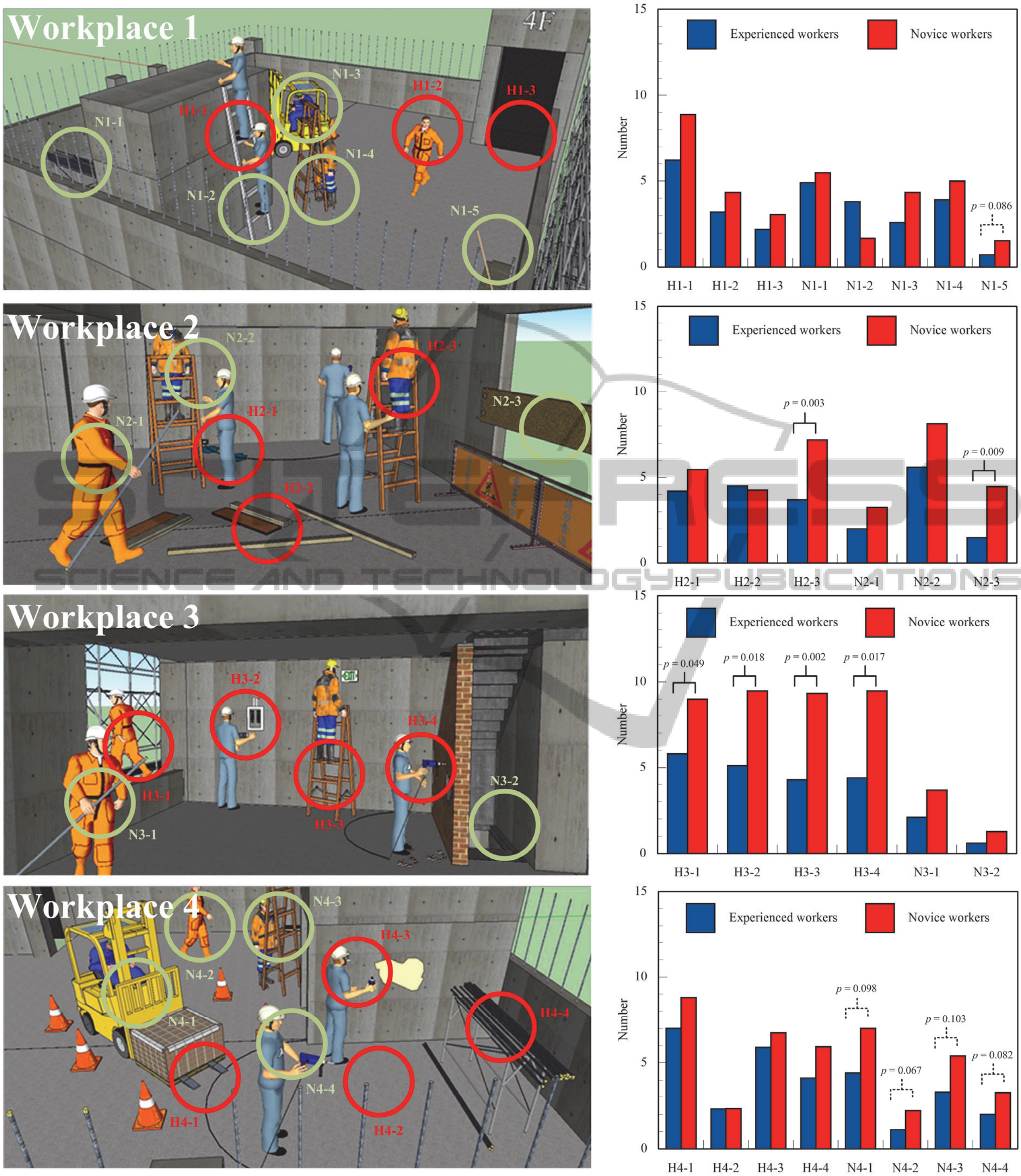

Figure 3: Fixation frequency for attention points of the experienced workers and novice workers.

The experienced workers spent significantly less time than the novice workers did in identifying hazards ($p < 0.001$).

The search pattern analysis results showed that the novice workers were less confident in determining whether an attention point was a hazard, and they exhibited more fixations on almost every attention point compared with the experienced workers. By contrast, the experienced workers typically made faster decisions, thereby resulting in shorter identification times.

Based on the findings, general work experience is not equivalent to safety-specific experience, and may not necessarily improve workers' accuracy in identifying hazards. The experienced and novice workers exhibited similar hazard-identification abilities and search patterns, apart from the identification time and numbers of fixations, potentially because hazard identification requires both sufficient knowledge and experience. However, site supervisors and managers were not necessarily experienced in directly conducting safety inspection or safety training; though they had considerably more on-site work experience, this additional experience or self-confidence only accelerated their inspection processes; their identification ability was comparable to that of the novice workers.

The search pattern analysis results could provide valuable information for safety trainers and educators. Both the experienced and novice workers exhibited a high number of fixations on attention points involving ladders, implying that they require more time to determine whether these situations are hazards.

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