The Role of Work Experience on Hazard Identification: Assessing the Mediating Effect of Inattention Under Fall-Hazard Conditions

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ABSTRACT

One of the main contributors to the human errors that lead to catastrophic injuries in the construction workplace is the failure to identify hazards as a result of poor attention or cognitive lapses. To address this safety concern, the present study used eye-tracking technology to assess how the association between work experience and hazard identification may be mediated due to inattention. A mediation analysis was conducted and tested using a bias-corrected bootstrapping technique with 5000 resamples. The results estimate the direct and indirect effects of work experience on the hazard identification skills of construction workers observing varying hazardous conditions. The results of the mediation analysis confirm that inattention—demonstrated via inattentiveness toward hazards—mediates the relationship between work experience and hazard identification. Specifically, though work experience and dwell time positively correlate with hazard identification, the direct effect of work experience on hazard identification is attenuated with the inclusion of the mediator variables in the model, thus suggesting attentional impairment offsets the benefits of work experience. The outcomes of this study will enable researchers and safety practitioners to harness real-time eye-movement patterns to identify the precursors of cognitive failure, deficient attentional allocation, and poor visual search strategies, all of which may put workers at risk on construction sites. The results also facilitate the provision of personalized safety feedback to workers and the design of training interventions that will address unique performance deficiencies in workers to prevent the human errors that cause injuries in dynamic environments.

INTRODUCTION AND BACKGROUND

The construction industry has consistently held the unenviable position of having one of the highest records of injuries and fatalities among all industries. This title is in large part due to the inability of workers to effectively identify hazards on construction sites. Given

the unpredictable nature of construction worksites, such an inability exposes the majority of construction workers to higher risks of injuries and fatalities.

Failure to notice hazards or misperceptions about hazards' associated risks are among the most important human factors that lead to accidents (Hasanzadeh et al. 2017b). As workers' limited capacity for attention is an inherent human deficiency, questions remain as to the extent of the impact attention has on workers' ability to identify active and potential hazards in rapidly changing environments—a pressing concern since construction workers are required to divide their attention properly throughout a scene to identify current and potential hazards at a jobsite (Hasanzadeh et al. 2018). The breakdown of such attentional control has proven to be a contributing factor in many construction injuries (Hasanzadeh et al. 2018), raising the stakes for understanding—and mitigating—this attentional factor.

In parallel, while an appreciable amount of experience working on construction sites appears to improve the hazard-recognition skills of some workers, others may not recognize potential hazards due to inexperience, short sightedness, inherent human fallibility, ignorance, or a combination of these factors (Knoll, 2014). While traditional training programs attempt to improve safety knowledge among workers, such training models are not designed to maximize hazard-recognition performance, since every specific challenge a construction worker may face cannot be comprehensively exhausted in a training manual. Therefore, when confronted with hazards, it is expected that workers will highly rely on their own observation and experience (Fang et al, 2016). For this reason, work experience appears to play an influential role in hazard-recognition performance (Hasanzadeh et al. 2017b).

Recent studies have utilized eye-tracking metrics—dwell time, first fixation, etc.—to investigate the visual search patterns employed by experienced and inexperienced individuals when scanning for hazards in various static and dynamic environments (e.g., Underwood et al. 2005; Segall et al. 2007; Hasanzadeh et al. 2017a, 2017b, 2018, 2019; Borys and Plechawska-Wójcik, 2017; Sun and Liao, 2019). However, hardly any study has examined the extent to which inattention mediates the demonstrated positive relationship between work experience and the identification of fall-related hazards. As a result, to address this research gap, the present study utilized eye-tracking technology to assess the mediating role of inattention—also known as 'impaired attention'—on the association between work experience and hazard identification. The research team evaluated the extent to which the eye movement metrics that indicate cognitive impairment mediate the relationship between work experience and the hazard identification skills of construction workers. Subjects wore the eye-tracking apparatus in an experimental laboratory while identifying various fall hazards in randomly ordered construction scenario images. Then, in order to measure the attentional allocation of construction workers, various eye-tracking metrics, such as dwell time, dwell percentage, and first fixation were utilized and put into relationship with subjects' work experience. The methodology, analyses, and results appear below.

METHODOLOGY

Participants: This study recruited construction workers by distributing flyers at construction sites. Visits were also scheduled at construction companies to describe the research. From these invitations and visits, a combination of moderately and highly

experienced workers were recruited. Concurrently, students that took construction-safety classes in George Mason University constituted the inexperienced group of workers. Taken together, a total of 50 construction workers were recruited to participate in the research experiment. All participants had normal or corrected-to-normal vision. The experiment was conducted in a single 15-minute session for each worker. All participants received a gift card as compensation.

Experimental Design: First, the subjects were asked to fill out a questionnaire regarding their demographic information, including age, gender, race, nationality, years of experience, obtained certifications, and training. Then, the experiment was conducted with a head-mounted Eyelink II eye tracker. This device facilitates the tracking of eye movement patterns in real time using corneal reflections and pupil tracking. It also provides excellent visualization outputs for investigative purposes in various fields of study (SR Research, 2009).

The experimental design involved the display of 35 randomly ordered images that included a wide range of safety risks such as fall hazards, housekeeping, electrocution, material storage and struck-by hazards. To limit the scope of this study, our analysis was restricted to ladder fall hazards. Images appeared for a maximum of 20 seconds. Within this time, the participants were expected to scan the scenes exhaustively to identify active and potential hazards and report on the number, type, likelihood, and severity of the safety hazards in each image. They made a selection of 'A' on a response pad when they identified a hazard, and 'B' otherwise. The investigators took notes of the identified hazards and recorded the observations of the participants on a voice recorder. Subsequently, the hazard identification index for each subject was derived by dividing the number of hazards s/he identified by the total number of potential and active hazards in the collection of images.

At the end of the eye-tracking experiment, the eye movements of each participant were linked to the number of years of experience they had working on construction sites. This step enabled the research team to examine whether eye movement metrics indicative of cognitive impairment mediate the association between work experience and the hazard identification index of the workers.

Statistical Analysis: Five participants were eventually excluded from the experiment due to calibration issues that resulted in missing values for obtained eye metrics from the eye tracker; consequently, a total of 45 experimental trials (M=36, F=9) were successfully executed and included in the analysis. Participants were then divided into three groups: no experience, moderately experienced (<10 years), and highly experienced (>10 years). The hazard identification index for each worker was derived by dividing the number of hazards identified by each worker by the total number of potential and active hazards. The attentional distribution (i.e., eye movement metrics) of each participant were linked to his/her years of experience. This step enabled the research team to examine if eye movement metrics indicative of cognitive impairment would mediate the association between work experience and the hazard identification index of the workers.

Mediation analysis is an analytical concept used to examine whether an independent variable conveys an impact on a dependent variable through an intermediate variable (Tofighi and Thoemmes, 2014). Accordingly, an indirect effect may be confirmed when the influence of a predictor variable on an outcome variable is shown to

be carried out via a mediator (Preacher and Hayes, 2008). This investigative statistical technique has proven to be valuable in investigating causal relationships among variables. It has found wide applicability in various fields of psychology (Norman and Conner, 2006); neuroscience (Boelen and Klugkist, 2011); medicine (Tibu et al, 2016); and a variety of organizational, behavioral, and digital research (Cheung and Lau, 2008; Tofighi and Thoemmes, 2014; UCLA, 2016), to mention a few.

In the present study, the authors assumed that the total effect of the independent variable (work experience) on the dependent variable (hazard-identification performance) is composed of both the direct effect of work experience on hazard identification and the indirect effects of work experience as attenuated via inattention. As the direct effect is the uninterrupted impact of the independent variable on the outcome without the inclusion of the intervening variables (Tofighi and Thoemmes, 2014), and as past studies have demonstrated 1) the significant, direct relationship between work experience and hazard-identification performance (Underwood et al, 2005) and 2) which eye metrics best indicate *attention vs. impaired attention* (Borys and Plechawska-Wójcik, 2017, this analysis approach enables our study to evaluate the reasonableness of our hypothesis that inattention mediates the relationship between work experience and hazard identification.

Isolating mediating variables can be challenging, so a number of strategies exist to evaluate the strength and significance of indirect effects of predictor variables on a dependent variable when in the presence of a mediating variable. They include the "causal steps strategy," the "product-of-coefficient" approach, the "distribution of the product" approach, and "bootstrapping" (Boelen and Klugkist, 2011; Prakash et al. 2015). As a result of a non-normal sampling distribution in the present study, the bootstrapping approach was utilized due to its widely acknowledged ability to surmount such problems (Preacher and Hayes, 2008). Bootstrapping is a resampling method of a nonparametric nature that utilizes a current data set as the basis for generating multiple resamples with replacement. Accordingly, bootstrapping generates a robust sampling distribution that avoids problems associated with power in a non-normal population and establishes confidence intervals for both direct and specific indirect effects (Boelen and Klugkist, 2011; Preacher and Hayes, 2008; Raes et al. 2013). Since the assumption of normality was not met for a moderately sized sample for the study (N= 45), other strategies were not guaranteed to give credible results when conducting inferential tests.

In the present analysis, the nonparametric bootstrapping technique was used to generate 5000 bootstrap samples to estimate the direct and indirect effects of work experience on the hazard identification skills of construction workers. Thereafter, the bias-corrected confidence interval was used to locate values defining the lower and upper 2.5% of the 95% confidence interval of the distribution (at $p < 0.05$) for a range of probable values for the population's indirect effect. Confidence intervals that do not include zero indicate statistical significance and the presence of indirect effects, thereby enabling our analysis to proceed. The model in Figure 1 shows how impaired attention is proposed to mediate the relationship between work experience and hazard identification.

RESULTS

The model under study in this paper reflects a causal sequence in which work experience affects hazard identification indirectly through mediator variables. Here, we treat proven eye-movement metrics as indicators of impaired attention (Segall et al, 2007;

Goldberg et al, 2002), which we in turn interrogate to determine whether they show mediating effects on the relationship between work experience and hazard identification. The model demonstrated excellent global fit (CFI = 1.000, TLI = 1.000, RMSEA = 0.000, SRMR = .000). It also explained a significant percentage of the variance accounted for by each of the mediators and outcome variable: 1.1% for dwell percentage, 7.4% for first fixation, 9.7% for dwell time, and a significant percentage (54.1%) for hazard identification. There was a significant association between work experience and hazard identification (r = .654).

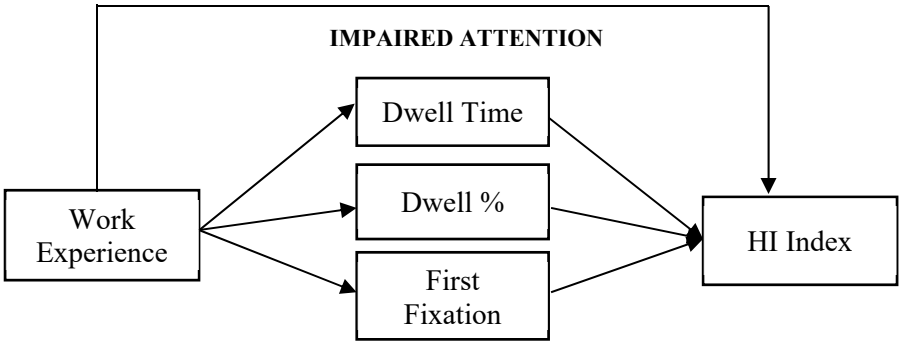

Figure 1. Model Showing Impaired Attention Mediating the Relationship Between Work Experience and Hazard Identification.

Using Mplus software, (Muthén & Muthén, 2012), the research team conducted a mediation analysis to ascertain the magnitude and significance of the mediating effects of impaired attention on the relationship between work experience and hazard identification. The unstandardized estimate is a measure of the resultant change observed in the dependent variable by reason of a unit change in the independent variable. The standardized output is also presented in parallel to show the corresponding change in the outcome variable as a result of a unit change in the predictor variable when the model estimates have been standardized to a variance of 1 and a mean of 0. The lower and upper values of the 95% bias-corrected confidence intervals obtained from the bootstrapping technique employed are also presented. Values that do not contain zero confirm the presence of direct and indirect effects.

Correspondingly, the model results show that work experience has a significant and positive relationship with hazard identification (B=0.015, β= 0.535). Similarly, dwell time appears positively correlated with hazard identification (B=0.223, β = 0.268). These relationships are statistically significant because zero was not included in their confidence intervals. First fixation also appears positively associated with hazard identification (B= 0.048, β = 0.184), though at a lower confidence. On the other hand, a negative relationship manifests between dwell percentage and hazard identification (B= -2.041, β = -0.133). Though dwell percentage and first fixation indicate a negative and positive relationship with hazard identification, respectively, these relationships are not statistically significant because their confidence intervals straddled zero.

The results also reveal the effects of the predictor variable (work experience) on each of the mediator variables (eye-movement metrics). Work experience has a positive and significant relationship with dwell time (B=0.011, β = 0.311). Interestingly, no relationship appears between dwell percentage and work experience (B=0.000, β =

0.107), which indicates that the time spent viewing specific areas of interest for the total duration of the trial expressed as a percentage did not vary significantly as a result of the years of experience of the workers. Finally, although first fixation displays a positive relationship with work experience, this relationship was not statistically different from zero (B=0.030, β = 0.272).

The extent and magnitude of the total direct and specific indirect effect of the predictor variable (work experience) on the outcome variable (hazard identification) through each of the mediator variables is explained in Table 1. The direct effect is the uninterrupted impact of the independent variable on the outcome without the inclusion of the intervening variables. The specific indirect effects, on the other hand, each shows the significance of the unique mediator paths in influencing the relationship between work experience and hazard identification.

Table 1. Confidence Intervals for the Direct and Specific Indirect Effects of Work Experience on Hazard Identification.

Variables			Point Estimates		Bootstrapping Bias-Corrected 95% CI	
Outcome	**Predictor**	**Mediator(s)**	**Unstandardized**	**Standardized**	**Lower**	**Upper**
		Direct Effect				
Hazard Identification	Work Experience		0.015	0.535	0.007	0.031
		Total Indirect Effects				
Hazard Identification	Work Experience	Dwell Time Dwell Percentage First Fixation	0.003	0.119	0.000	0.008
		Total Effect				
			0.019	0.654	0.009	0.034
		Specific Indirect Effect				
Hazard Identification	Work Experience	Dwell Time	0.002	0.083	0.000	0.005
		Dwell Percentage	0.000	-0.014	-0.002	0.001
		First Fixation	0.001	0.050	-0.001	0.006

Considering the total effect (both direct and indirect influence) of work experience on hazard identification, a unit increase in work experience is associated with a 0.019 unit increase in hazard identification. This total effect is statistically different from zero (B=0.019, β = 0.654). The outcome of the analysis also provides evidence that suggests work experience has a positive and very significant direct effect in predicting hazard identification (B=0.015, β = 0.535). Interestingly, this effect is attenuated and no longer significant with the inclusion of the mediator variables in the model (B=0.003, β = 0.119). This result suggests that including considerations of attention/inattention significantly mediated the positive effect of work experience on the hazard-identification performance of workers.

This study also assessed the specific indirect effect of each of the mediator variables on hazard identification using the model outcomes to evaluate the significance of the mediator variables' unique paths. The specific indirect effect of each of the

mediator paths (dwell time, first fixation and dwell percentage) is not statistically significant, because the range of their confidence intervals straddled zero.

Taken together, the result of the mediation analysis confirm the mediating role of impaired attention in the relationship between work experience and the identification of fall hazards. This result appears graphically in Figure 2.

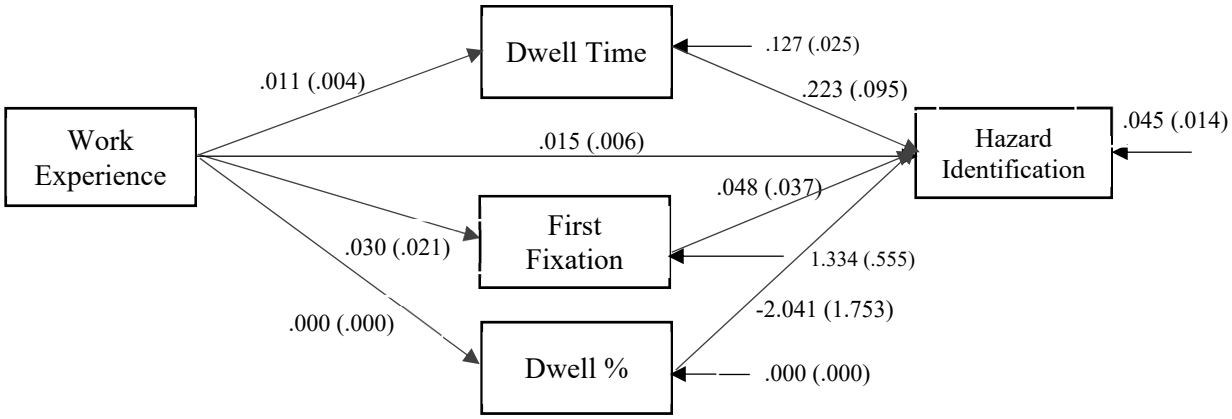

Figure 2. Mediation Model Showing the Unstandardized Estimates (SEs) for Each Path as well as the Total Effect of Work Experience on Hazard Identification: 0.019, 95% CI [0.009, 0.034]; Note: **p < 0.01

DISCUSSION OF FINDINGS

The purpose of the current study was to test whether impaired attention mediated the relationship between work experience and hazard identification. Mediation analysis was conducted and tested using the bootstrapping technique, which provides an empirical approximation of sampling distributions of an indirect effect (Brock et al, 2017). When the effect of the dependent variable on the independent variable is weakened or significantly reduced as a result of the inclusion of intervening variables in the model, mediation is confirmed (Tibu et al. 2016).

The results reveal that work experience and dwell time are positively correlated with hazard identification. One of the most important and commonly used eye-tracking data points for usability purposes is dwell time on areas of interest (AOIs) (Goldberg et al. 2002; Majaranta et al. 2006), since longer dwell times show a greater level of interest in the AOI and enable the processing of more information. How different workers dwell on specific areas in a scene indicates the differences in their underlying cognitive processes about the scene. Among experienced workers and novices, such differences can signal information about the directed search strategy employed by knowledgeable workers. This directed visual search is usually driven by higher-order processes such as skill, experience and familiarity (Underwood et al. 2005), and suggests that experienced workers perceive a scene as being generally more dangerous than inexperienced workers do. A core area of interest in the present study was to identify which less predictable properties of expertise are exhibited in the eye-movement patterns of construction workers. In line with the outputs of the model, elements that were observed more often and for longer periods of time were deemed more important to experienced workers (Segall et al. 2007). In addition, as dwell time durations impact the accuracy of certain levels of visual perception (Majaranta et al. 2006), shorter dwell times may present comprehension difficulties, particularly for inexperienced workers—as a general rule of

thumb, cognitive scientists hold that dwell times of less than 100 milliseconds generally mean the participant processed a limited amount of information (Tulis and Albert, 2003). Consequently, the short dwell times of inexperienced workers may explain their poor comparative hazard identification index.

A positive relationship was observed between first fixation and hazard identification. This outcome is in line with the findings of Borys and Plechawska-Wójcik (2017), who discovered that novice participants made multiple visits to an AOI and found it difficult to recognize a hazard. Our results show that when scanning a scene, experienced workers timely identified the dangerous conditions in each image. However, inexperienced workers visited the areas of interests several times but failed to identify potential hazards. Consequently, though their gazes fell on the hazards a number of times, they failed to process the scene adequately. Examination of the scan paths of the participants revealed that these inexperienced workers were barely able to identify active hazards and mostly judged a scene dangerous when an individual was in the image and in close proximity to a hazard. This outcome was in sharp contrast with the performance of experienced workers, who were able to identify both active and potential hazards across the trials.

Regarding the effects of the predictor variable (work experience) on each of the mediator variables, dwell time and first fixation were positively correlated with work experience. This finding is a pointer to the fact that successful identification of hazards in a complex and actively changing environment requires a considerable level of skill and experience. In addition, taking time to critically study a scene while searching for a hazardous object or situation will result in localized learning of the intricacies of an environment in the long run, which is necessary to maintain safety at all times.

The variables derived from the eye tracking experiment provided an insight into the decision-making process of construction workers with varying degrees of experience when navigating a scene in search of fall-related hazards. The eye metrics revealed that experienced workers maintained a more useful field of view, critically assessed each scene, and analyzed both active and potential hazards more, as compared to the novices, which supports the observed association between work experience and the extent of hazards recognized in areas of interest. A reasonable explanation is that the experienced workers have had more opportunity for involvement in dangerous site conditions and more involvement in near misses, injuries, and fatalities over the years. Their greater experience will have exposed them to an appreciably larger number of hazards than relatively inexperienced workers. As such, they may be able to recognize not only active hazards, but potential sources of danger.

The results of the mediation analysis confirmed the mediating role of impaired attention in the relationship between work experience and hazard identification. The direct effect of work experience on hazard identification was attenuated with the inclusion of the mediator variables in the model, thus suggesting significant mediation occurs between the independent and dependent variables. Work experience is reasonably expected to correlate with a high hazard-identification index. However, the dynamic and active nature of construction sites signals why attention must couple experience to yield safe outcomes. When attention is impaired, the positive influence of work experience, reasonably expected to be present as the ability to identify potentially dangerous situations, becomes significantly reduced. As such, hazard identification becomes a

complex and multidimensional cognitive process that necessitates vigilance to avoid unsafe actions or resulting catastrophic injuries and fatalities.

CONCLUSION

Humans are finite beings with a limited capacity to sustain attention for relatively long periods of time. The inability to exert attentional control has proven to be a contributory factor in catastrophic injuries on construction sites. As a result, this study used eye-tracking technology to assess the mediating role of impaired attention in the relationship between work experience and the hazard-identification performance of workers. The results of the mediation analysis confirmed that impaired attention mediates the positive relationship between work experience and hazard identification. The results of this study strengthen ongoing work seeking to understand which visual search patterns employed by workers are predictive of superior hazard recognition and safer worksite performance, and—in turn—which predict unsafe behaviors. Consequently, this study supports researchers and safety practitioners attempting to harness real-time eye-movement patterns to identify 1) precursors of human cognitive failure and deficient attentional allocation, and 2) the visual search strategies that may put workers at risk from active and potential hazards on construction sites.

Furthermore, the recorded viewing performance of each worker in this study presents a beneficial tool for building personalized feedback systems regarding inadequately distributed attention across a scene. Though such feedback systems are long-term goals, the result of this study also facilitates the design of appropriate training interventions in the short term to address unique performance deficiencies in workers to prevent the human errors that cause injuries in dynamic environments. The findings of the present study provide evidence that workers at risk of injuries can be identified using measurable indicators of eye-movement metrics that signal their cognitive processes. This concept presents a valuable injury-prevention mechanism that advances the current reactionary practice in risk management and occupational safety. Consequently, this project contributes to academia and industry a huge potential to advance current safety practices by surmounting the challenges of human limitations and imperfections in the construction environment.

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