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USING EYE TRACKING TECHNOLOGY TO EVALUATE FOCAL ATTENTION LOCATION AND ITS RELATIONSHIP TO HAZARD RECOGNITION

Hardison, Dylan[1,2], Sears, Matthew[1], Hallowell, Matthew[1], and Goodrum, Paul[1]
[1] University of Colorado at Boulder, United States
[2] dylan.hardison@colorado.edu

Abstract: Recent evidence indicates that construction workers fail to recognize many safety hazards that arise during construction activities. Previous research has focused hazard recognition skill but has not examined if the proportion of hazards *viewed* correlates with hazard recognition *performance*. To study this topic 18 subjects were fitted with mobile binocular eye tracking glasses, presented with a random sequence of three photographs of construction work spaces, and asked to recognize all of the safety hazards present in each photograph. Voice narrations and eye tracking data were collected as participants identified hazards and were used to compare the proportion of hazards viewed with the proportion of identified safety hazards. The results reveal that there is no correlation between the proportion of fixations on hazards and hazard recognition despite assumptions made in previous research. This study departs from the current body of knowledge by providing a metric to evaluate locational attentional fixation data and attempts to recognize the optimum proportion of focused and distributed attention for obtaining an appropriate level of situational awareness necessary for complex hazard recognition tasks.

1 Introduction

Construction worker safety is an important aspect of project sustainability and is imperative for project success. The concept of sustainability is centered on developing projects to meet today's needs without compromising future generations. Among the many aspects of sustainability in construction, social sustainability relates to how projects affect the surrounding neighborhoods, local communities, and the broad expanse of workers within the industry (Rajendran and Gambatese 2009 and Toole and Carpenter 2012a). Construction workers are a valuable part of the construction industry and the communities served by projects. For this reason, their wellbeing is integral to project sustainability (Rajendran and Gambatese 2009).

Construction sites are inherently dangerous environments that expose workers to a variety of safety hazards that stem from many causes. It is because of this that workers must maintain appropriate levels of situational awareness of their environments to identify hazards and stay safe (Lu et al. 2011). Research shows that hazard recognition performance, defined as the ability to correctly recognize safety hazards, remains low (Carter and Smith 2006; Lopez del Puerto et al. 2013; and Albert et al. 2014a). For this reason, we must understand how workers process visual information during hazard recognition tasks. One method of investigating how individuals process visual information is using eye tracking technology. These systems allow researchers to investigate a user's visual information acquisition processes and have begun to gain popularity for hazard recognition research.

The purpose of this study is to investigate the extent to which the proportion of focused and distributed attention during hazard recognition tasks relates to the proportion of safety hazards identified. Using eye tracking technology, the proportion of focused and distributed attention was compared to hazard recognition performance scores for 18 subjects across three photographs in quasi-experimental trials. The research question of interest is: "*Do the proportions of focused and distributed attention during hazard recognition tasks effect the proportion of hazards identified in simulated work environments*?" By knowing the proportions of hazard signals fixated upon and their relationship to hazard recognition performance, researchers and practitioners can begin to understand how to improve workers' situational awareness in construction environments.

2 Literature Review

2.1 Signal Detection and Construction Safety

Construction workers' safety performance depends largely on their ability to recognize hazards in their environment (Albert and Hallowell 2012). Detecting the presence of hazardous signals is known as signal detection (Parasuraman et al. 2000; Lu et al. 2011). Signal detection has previously been researched in the arena of construction safety (Parasuraman et al. 2000; Adbelhamid et al. 2011; and Lu et al. 2011). Traditional signal detection theory places a significant division of real world truths into two main distinct and non-overlapping categories. These categories are "signal" and "noise." Signals are present when the situation of interest is present. On the other hand, noise occurs when the situation of interest is not present. In the context of construction safety, a signal is the presence of a safety hazard and noise is considered to be everything else in the environment (Parasuraman et al. 2000; Lu et al. 2011). Eye tracking technology was used to measure users' attention to hazard signals and noise by employing traditional signal detection theory.

2.2 Eye Tracking Technology

Eye tracking is a research technique used to model how subjects acquire information from visual stimuli (Bass et al. 2016). The systems capture data related to eye-movement that explain information acquisition, decision making processes, and attentional processes. Additionally, eye-tracking data provides evidence relating to eye position and movements of individuals as they process visual stimuli in real time (Duchowski 2002 and Bass et al. 2016). These systems have been accepted as a viable method to test for usability of human-computer interfaces (Goldberg and Kotval 1999; and Rashid et al. 2013), text based reading research (Rayner 1998), scene perception research (Henderson and Hollingworth 1998), and investigations into the patterns of visual search processes (Findlay and Gilchrist 1998).

Eye tracking technology is used to measure fixations, saccades, and eye scan paths of research participants. (Bass et al. 2016). Fixations are defined as aggregations of eye gaze points and saccades are defined as rapid eye movements between fixations. Scan paths are thereby defined as the sequence of alternating fixations and saccades. These measurements are useful for determining what stimuli participants view, how long they view them, and the order in which the stimuli are viewed. Heat maps can also be generated from eye tracking data to show researchers the density of fixations over a general area of interest. These heat maps are used as a quantitative evaluation metric to identify the information within visual stimuli that is viewed the most times and/or for the longest periods. (Blascheck et al. 2014). For this research, focal attention is the primary metric of investigation. Focal attention occurs when a user focuses on a location within a visual stimulus with the intent of acquiring information. Eye tracking technology provides a platform for researchers to identify the proportion of a user's focal attention within predetermined locations of visual stimuli. This allows for the evaluation of eye gaze locations over time and can be used to generate a variety of inferences.

2.3 Eye Tracking use in Construction Safety Research

Eye tracking technology has become popular in construction safety research as it provides a method to better understand how individuals acquire safety information from static scenes (Dzeng et al. 2016; Hasanzadeh et al. 2016; and Pinherio et al. 2016). Dzeng et al. (2016) used eye-tracking to evaluate search patterns of novice and experienced workers as they searched for hazards. The results show that work experience was not a significant factor in performance in terms of accuracy of hazards identified. Additionally, eye trackers have been used to evaluate hazard perceptions from real construction photographs and ultra-realistic 3D models (Pinherio et al. 2016). The results show that the use of construction photographs and ultra-realistic 3D models can be used for hazard recognition training. Research conducted by Hasanzadeh et al. (2016) suggests that eye-tracking technology can also be used to investigate situational awareness by using construction photographs. Their results show that workers with high levels of situational awareness spent less time dwelling on one particular location and more time searching the entire environment for safety hazards (Hasanzadeh et al. 2016). These preliminary results suggest that an optimum proportion of focused to distributed focal attention may be required for workers to assess construction photographs for safety hazards and differentiate hazard signals from noise in the environment.

3 Research Objectives, Hypotheses, and Point of Departure

The aim of this study is to investigate focal attention and its relationship to hazard recognition performance. Specifically, the objectives were to (1) develop a set of three construction scenes for hazard recognition quasi-experiment trials; (2) evaluate hazard recognition performance in terms of proportions of hazards identified; and (3) evaluate the proportions of both focused and distributed focal attention and their relationship with hazard recognition. This is the first attempt to draw a correlation between focused and distributed focal attention and hazard recognition performance. The corresponding null hypothesis is:

H_0: The proportion of focused to distributed attention does not predict hazard recognition performance.

H_1: The proportion of focused to distributed attention does predict hazard recognition performance.

4 Experimental Methods

4.1 Recruiting Participants

For this exploratory study, 18 construction engineering and management students were recruited. We used students as subjects because we were able to conduct a controlled experiment, which would not have been possible in the field. Each subject was fitted with an SMI Inc. head-mounted eye-tracking system and asked to scan a series of three construction scenes and identify **all** the safety hazards present in each image. Given that each subject scanned 3 individual scenes, 54 observations were obtained for hypothesis testing. All participants had normal or corrected-to-normal vision (e.g., contact lenses), which was important because the head-mounted system restricts users' ability to simultaneously wear eye glasses with the eye-tracking device.

4.2 Construction Scenes

Construction scenes were used to simulate construction environments by showing actual construction tasks that were being performed by real construction workers. The images were carefully selected to balance realism and challenge. For example, the images were detailed but simple in that many years of construction experience was not required to recognize hazards. The safety hazards present in each image were catalogued to ensure that an exhaustive and comprehensive list covered all possible safety hazards that research participants could identify during the experiment. Safety hazards that are not visible in the photographs were not included in analysis. To provide a clear indication of the location of each hazard in a scene, an Area of Interest (AOI) was drawn around each hazard. The AOI's were used in the analysis to evaluate the proportion of focal attention within AOI's (focused) and focal attention outside of AOI's (distributed).

For the purposes of this study, safety hazards were identified as "*any source of potential damage, harm, or adverse health effects to someone under certain conditions at work*." Participants were asked to identify "*ways that workers could become injured, ill, or be fatally killed in the work situation*" and were asked to "*disregard citing infractions of safety and health regulations*." In addition, participants were asked to "*identify* *the hazard associated with the safety and health rule infraction, rather than the infraction itself*." For example, if a worker in a photograph was operating a circular saw without the use of safety glasses, the lack of safety glasses would not be the hazard. Rather, participants were instructed to indicate that flying debris that could contact the operator's eyes resulting in injury. The flying debris would be the safety hazard of interest.

Table 1: Hazards and Associated AOI (Rooftop Skylight Installation)

Hazard Type	Probable Outcome	Identifier
Trip Hazard	Fall to Same Level	1
Electric Hazard	Electrocution	2
Fall Hazard	Fall to Lower Level	3
Fall Hazard	Fall to Lower Level	4
Sharp Tools	Laceration	5
Rotating Equipment	Laceration	6
Trip Hazard	Fall to Same Level	7
Sharp Edges	Laceration	8

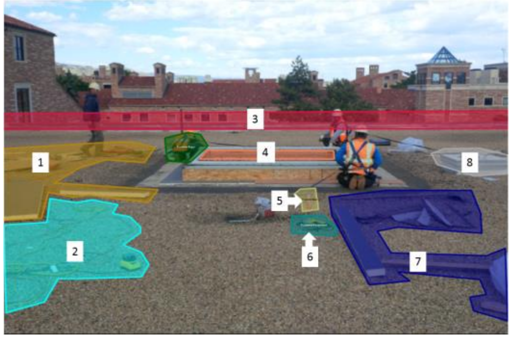

Figure 1.0: Case Image and Encased AOI

The selected images included scopes of work such as: roof top skylight installation, concrete wall sawing, and underground utility installation. The photographs were selected due to their wide range of work scopes and associated safety hazards. Additionally, photographs were selected to ensure that the AOI regions were discrete and did not overlap in area. This was done to ensure that the data obtained from the eye-tracking technology corresponded to only one hazard at one time. For example, an electric hand drill may present multiple hazards from electrical shock, rotational components, and flying debris. To account for this, participants were asked to narrate hazards as they were identified and these narrations were used to ensure that the correct safety hazard was being represented in the associated AOI.

4.3 Random Assignment and Order of Research Scenarios

For this experiment, three photographs of construction tasks were organized into six photographic scenarios that create an exhaustive set of comprehensive and non-repetitive combinations. A comprehensive and non-repetitive set of presentation scenarios was chosen due to its ability to normalize the learning curve that can be attained by viewing subsequent photographs. Each scenario was presented to three different research participants. In total, eighteen subjects participated. This allowed for a total of 54 observations to be aggregated for statistical analysis. This process allowed for the greatest extent of the randomization of both ordering and assignment to normalize the learning curve among participants and provide a large enough opportunity for the statistical significance of research findings.

4.4 Experimental Procedure

The experimental procedure involved three main steps: (1) selection and assignment, (2) calibration and fitting, and (3) testing. Each participant was placed in a controlled environment during the experiment to ensure that distractions were minimized. Participants were not restricted by time in the experiment to reduce the distraction of feeling rushed to complete the tasks. Upon selection and assignment of the research scenario, participants were briefed about the experimental procedures. Participants were then fitted with a head mounted SMI Inc. eye tracker and a three-point calibration was conducted. Participants were positioned 27" away from the images that were placed at eye level. Each image was approximately 16" x 12" in dimension. This is an important aspect of experimental design as the eye tracker may not be able to detect eye movements that are within a user's 1-degree field of view. This is because the eye is not required to shift fixations within a 1-degree field of view. The images were sized accordingly and participants were placed far enough away from each image to ensure that the eye was required to move to shift focal attention between hazard signals in each photograph. Additionally, body position was accounted for and held consistent across all participants to ensure 0.5-degree accuracy of the eye tracking system.

Participants were asked to verbally describe safety hazards as they were detected and were asked to tell the researchers when they had completed the hazard recognition tasks for each image. Upon initiation of the experiment, researchers transcribed the hazards narrated by research participants for later use in data analysis. Each participant's proportion of correctly identified hazards were catalogued for each photograph. The eye tracker was calibrated for each individual photograph to ensure a consistent level of accuracy.

5 Results

The data analysis occurred in three distinct phases: (1) calculating the Hazard Recognition Index; (2) calculating the proportion of focal attention or fixations within AOI's; and (3) using a Spearman Rank Correlation to test the hypothesis. The following sections discuss the three-step analysis procedures.

5.1 Hazard Recognition Index and Normalization of Data

The objective of this research was not to compare hazard recognition performance levels of participants across the three individual photographs. Rather, the objective was to determine if a correlation exists between the proportion of fixations upon hazards and hazard recognition performance. For this reason, the data for all three individual photographs were aggregated into one repository. A total of 18 subjects viewed three images each yielding a dataset of 54 discrete observations (considering the photograph as the unit of analysis).

The Hazard Recognition index (HR_{index}) previously developed by Albert et al. (2014a) is a viable method to evaluate hazard recognition performance levels of construction workers. The HR_{index} results in proportion data. The numerator in the equation is the total number of hazards that participants correctly identified from the image. The denominator of the index is the total number of AOI specific hazards in each photograph (HR_{index}) [Eq. (1)]:

$$[1]\ \mathrm{HR}_{index} = \frac{\mathrm{H\ recognized}}{\mathrm{H\ total}}$$

The results show that participants are able to recognize approximately 42 - 54% of all the hazards in the photographs. This value is similar to the performance of workers from past research studies (Carter and Smith 2006; Bahn et al. 2013; Lopez del Puerto et al. 2013; and Albert et al. 2014a).

Table 2: Average Hazard Recognition Index

Photograph	Average HR_{index}
A	50%
B	54%
C	42%
Average	**49%**

The variability within the HR_{index} is primarily due to the complexity of the images, subjectivity of AOI assignment, and the difficulty in recognizing hazards. Although images were chosen to represent a variety of work tasks and safety hazards, the differences in work tasks may be a factor in the variability in HR indices among participants. To account for the variability in the difficulty of assessing the individual photographs for hazards, the data set was normalized following the recommendations of (Han and Kamber 2000) [Eq. (2)]:

$$[2]\ \mathrm{P}_{norm} = \frac{\mathrm{P}_{raw} - \mathrm{P}_{raw\,\mathrm{min}}}{\mathrm{P}_{raw\,\mathrm{max}} - \mathrm{P}_{raw\,\mathrm{min}}}(\mathrm{P}_{norm\,\mathrm{max}} - \mathrm{P}_{norm\,\mathrm{min}}) + \mathrm{P}_{norm\,\mathrm{min}}$$

In [Eq. (2)], P_{norm} = normalized hazard recognition; P_{raw} = raw hazard recognition values; $\mathrm{P}_{raw\,\mathrm{min}}$ and $\mathrm{P}_{raw\,\mathrm{max}}$ = minimum and maximum raw hazard recognition values, respectively; and $\mathrm{P}_{norm\,\mathrm{min}}$ and $\mathrm{P}_{norm\,\mathrm{max}}$ = minimum and maximum normalized hazard recognition values, equal to 0 and 1, respectively (Han and Kamber 2000).

5.2 Calculating Proportion of Focused and Distributed Focal Attention

The eye-tracking software provided a count of fixations in an AOI for each image for each subject's scan. These data were used to quantify the proportion of attentional fixations that occurred within all AOIs. This proportion is referred to as the Hazard Fixation index (HF_{index}), which is the total number of fixations in hazard AOIs over the total number of fixations in the entire scan. That is, the numerator in the equation 3 is the total number of fixations that occurred within all hazard AOI's for one specific image. The denominator is the total number of fixations within the entire scene. This proportion simply allows for the quantification of the number of fixations within the all the combined AOI's present within an image (HF_{index}) [Eq. (3)]:

$$[3]\ \mathrm{HF}_{index} = \frac{\text{Total \# of Hazard AOI Fixations}}{\text{Total \# of Scene Fixations}}$$

Table 3: Hazard Fixation Indices

Photo A Participant	Photo A HF_{index}	Photo B Participant	Photo B HF_{index}	Photo C Participant	Photo C HF_{index}
1	0.67	1	0.60	1	0.55
2	0.66	2	0.64	2	0.55
3	0.75	3	0.56	3	0.60
4	0.68	4	0.55	4	0.57
…	…	…	…	…	…
…	…	…	…	…	…
18	0.70	18	0.59	17	0.49
Average	**0.69**	**Average**	**0.61**	**Average**	**0.57**

5.3 Spearman Rank Correlation for Hypothesis Testing

The research hypothesis was "*The proportion of focused to distributed attention does not predict hazard recognition performance*." To test this hypothesis, a Spearman Rank Correlation test was performed in MVPstats. This was selected due to the ordinal nature of the $\text{Hazard Fixation}_{index}$ and the interval nature of the $\text{Hazard Recognition}_{index}$. The Spearman rank correlation test was performed for the aggregate of all data points collected for the three individual photographs. This provided 54 observations for hypothesis testing. It was because of the counterbalancing of photographs that allowed for the aggregation of all data points as any confound resulting from a learning curve through subsequent trials was eliminated.

The results of the analysis show that there is no definitive correlation between the proportion of distributed focal attention and hazard recognition performance for the aggregate of the 54 total observations. The Spearman Rank Correlation resulted in a r(s) value of 0.137. This value is too low to be able to definitively state any association. The resulting P-Valve does not provide sufficient statistical significance to reject the null hypothesis. Thus, the practical conclusion is that hazard recognition skill cannot be measured by the number of fixations, which previous researchers have implied in their analyses.

Table 3: Spearman Rank Correlation Results

$\text{Hazard Fixation}_{index}$ vs. $\text{Hazard Recognition}_{index}$
N (Pairs) = 54
r(s) = 0.137, p = 0.323

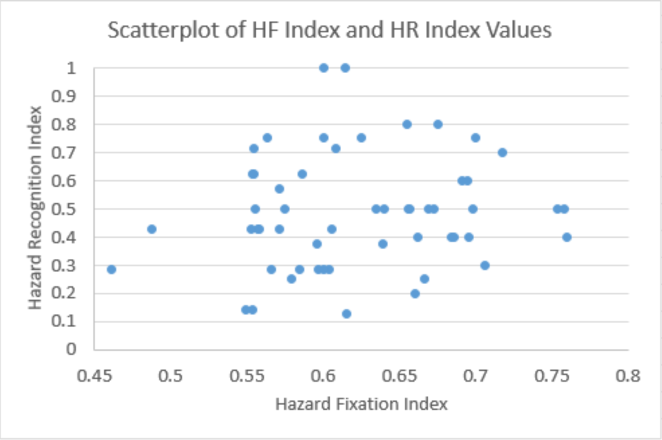

Figure 3.0: Data Point Scatterplot

The correlation test results and scatterplot figure support the lack of correlation between the proportion of hazard fixations and hazard recognition performance, with a weak correlation between HF_{index} and HR_{index} (r(s)= 0.137). Further data collection to increase sample size may improve the statistical significance of correlation test results.

6 Potential Limitations and Methods to Improve Reliability

One of the major limitations of eye tracking research using AOI's as a metric of quantitative evaluation is the subjectivity of AOI region assignment. For the HF_{index} to be useful for the quantification of AOI fixation proportions, both the number of fixations within AOI's and fixations outside of AOI's are required. It is the subjective nature of the AOI region around the hazard signal that allows for fixations to lie either inside or outside of the assigned AOI. Photographs that contain many hazards within proximity to each other have a greater density of areas of interest thus potentially allowing for more fixations to occur within the areas of interest. Photographs containing hazards that cover a large proportion of the photograph may receive a higher number of fixations within AOI's than photographs with less coverage of AOI's. Furthermore, photographs that contain many hazards may have a much larger proportion of the picture covered by AOI's than photographs with a low number of hazards. This will directly effect the proportion of hazard fixations within AOI's. For example, a photograph of a congested work space with multiple hazards throughout the image may have an AOI coverage of 90 percent. In this case, it would be safe to assume that the proportion of attentional fixations within AOI regions would be high. This was accounted for by selecting images with equivalent balance of AOI coverage.

Another important limitation to address with eye tracking research is the calibration of head mounted systems and the overall accuracy obtained during data collection. Although a three-point calibration procedure was conducted at the beginning of each experimental trial, some variability in calibration post test was observed when participants did not follow strict body position protocols. When this occurred, the participant was removed from the data set. Participant body movements and facial movements such as scrunching of the nose, movement of the jaw, and hard squinting which can affect the calibration points of the head mounted unit. To address this limitation, participants should sit in the upright position with feet shoulder width apart directly in front of the participant. Hand and arm movements should also be limited. This is especially true when researchers aim to detect smaller radii of precision. Outliers in eye tracking data may be a result of calibration error and the sensitive nature of the glasses to human movement.

7 Discussion and Conclusions

Sustainability is of the upmost importance in ensuring the continuance of the construction industry. One of the facets of sustainability is the social component of construction labor workforces. Construction workers must remain cognizant of safety hazards in their work environment to ensure they remain situationally aware to protect themselves from the wide variety of safety hazards inherent to construction work. Protecting the safety and health of todays workforce is imperative and a useful focus of industry and research efforts (Rajendran and Gambatese 2009 and Toole and Carpenter 2012a). Although much research has strived to evaluate workers' safety hazard recognition performance levels among a variety of trades and disciplines, no research to date has compared the proportion of safety hazards viewed in construction environments and its relationship to hazard recognition performance.

This is the first study to evaluate the relationship of focused and distributed attention and its effect on hazard recognition performance. The findings of this study suggest the proportion of safety hazards viewed in construction environments is not a predictor of hazard recognition performance. This is an important research finding as it suggests that simply viewing objects in an environment does not lead to increased hazard recognition. These research findings are limited due to the sample size of an observed population. However, the research methodology proved to be successful and further investigation is warranted by increasing sample size and testing actual construction workers.

The analyses conducted in this study were limited, but the collected eye tracking data is a rich source of information waiting to be processed. This study was purposefully limited by treating participants' focal attention as being either hazard fixations or non-hazard fixations. In future work, the authors will analyze the individual hazard fixations to determine whether hazard energy type or severity of potential injury outcome are related to hazard recognition performance. Additionally, hazard fixation sequence will be investigated to compare the scan paths of high hazard recognition performers with low performers. Understanding these aspects of hazard recognition processes will help to identify knowledge gaps relating to safety hazards that have the potential to cause injuries and illnesses to workers.

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