Recognizing Mine Site Hazards: Identifying Differences in Hazard Recognition Ability for Experienced and New Mineworkers

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Abstract. To perform a successful workplace examination, miners must be able to find and fix hazards. The goal of the current research project was to identify differences in how workers with varying amounts of work and safety experience search and identify hazards. The NIOSH research team created true-to-life panoramic images that safety professionals, experienced miners, inexperienced miners, and students searched for hazards. The effects of the image context and experience level of the participants on the overall accuracy are explored. The research findings suggest that safety experience and hazard familiarity play a large role in a miner's ability to identify hazards. Findings from this study will be incorporated into training programs focused on improving hazard recognition ability for surface stone, sand, and gravel miners.

Keywords: Eye tracking · Hazard recognition · Virtual reality

1 Introduction

Metal/nonmetal (M/NM) mining saw an increase in the number of fatalities between October 2013 and January 2015 [1]. During this period, 37 miners were fatally injured; that is twice the number of fatalities that occurred in each of the previous two years. Quickly following in July 2015, the Mine Safety and Health Administration (MSHA) issued a program policy letter (P15-IV-01) suggesting that, "miners would benefit from rigorous workplace examinations conducted by experienced and trained examiners." As data collection for this study was completed, in January 2017, MSHA issued a final rule amending the standards for workplace examinations [2]. The amended rule increases regulation of examination recorded content, logistics, and availability. Specifically, the final rule mandates that in addition to a record that an exam has taken place, mine operators must include the location of the exam, hazards found, and mitigation(s) completed. However, this rule does not provide additional guidance for what qualifies a miner to be a "competent person," that is required to complete each exam.

D.N. Cassenti (ed.), *Advances in Human Factors in Simulation and Modeling*,
Advances in Intelligent Systems and Computing 591, DOI 10.1007/978-3-319-60591-3_10

The competent person is defined within the Code of Federal Regulations (30 CFR 56.2) as a person having abilities and experience that fully qualify him or her to perform the duty to which he or she is assigned [3]. In the case of workplace exams, a competent person's primary assignment is to find and fix hazards. Therefore, the skills required for hazard recognition are of key interest. Although the workplace exam regulation is currently under review by the new administration, hazard recognition still poses a safety issue for all M/NM miners. Hazard recognition and mitigation represent a special challenge for the miner because of diverse worker activities that take place in a dynamic environment [4]. Given the complexities and dynamism of the mining environment, it is critical to understand how miners recognize worksite hazards so that NIOSH researchers can identify strategies for how to improve hazard recognition ability and therefore increase the safety and efficacy of workplace examinations.

2 Literature Review

The National Safety Council defines a hazard as "an unsafe condition or activity that, if left uncontrolled, can contribute to an accident" [5]. Hazard recognition is the realization that a condition or behavior can cause harm [6]. Successful hazard recognition requires an individual to possess a complex set of competencies. For instance, knowledge of general and site-specific hazards equips a worker to be better prepared to recognize hazards [7]. An accurate understanding of risk is another critical competency. Inaccurate risk perception can lead workers to ignore or misinterpret cues that signal a hazardous event or activity [8]. Other competencies include the ability to mitigate hazards and communicate risk to others. Mastery of several competencies is therefore critical for miners to be able to successfully recognize worksite hazards. In tasks designed to test hazard recognition abilities, a recognition rate of at least 90% has previously been used as the standard for mastery [9]. Using this criterion, in previous studies testing hazard recognition abilities workers tend to underperform [6, 9, 10].

Prior research suggests that there are factors that may affect hazard recognition ability; one of these factors is experience. Burke et al. [11] show that workers who have experience with a near-miss incident are better able to perceive a similar high risk or hazardous event. Perlman et al. [10] investigated the influence of experience on hazard recognition within the construction industry by comparing the hazard recognition performance of groups with different types [or amounts] of workplace experience. Counter to the authors' prediction that superintendents would successfully identify the most hazards, safety directors outperformed both superintendents and civil engineering students. Perlman et al. attribute this difference to experience and formal safety training, which the superintendents and students did not have [10]. Similarly, results from the mining industry suggest that a lack of *recent* experience working in a particular environment—e.g., because of layoff or filling in for an absent employee—also impacts hazard recognition abilities [9].

Context is another factor that affects the way workers recognize objects in their environment [12]. Objects appearing in a consistent or familiar environment are found more accurately and detected more quickly than objects appearing in an ambiguous or unfamiliar environment [13]. This finding is relevant to hazard recognition because of the way that miners are typically trained to recognize hazards. During hazard recognition training, miners are oftentimes shown close-up pictures of hazards. While these close-up pictures are helpful at highlighting specific aspects of a hazard (e.g., insufficient berm), the context in which that hazard occurs is absent (e.g., location with respect to the highwall); this information is critical for the miner to learn so that he can successfully search for and find these hazards in his own work environment. Kowalski-Trakofler and Barrett (2003) trained miners with pictures showing only the hazard and with pictures showing the same hazard within the context in which it typically occurs [14]. The results of the study show that miners found fewer hazards following training with pictures that show only the hazard. This suggests that learning about hazards in the context in which they occur (e.g., location or work activity) helps miners recognize them more often later. At a more basic level, larger context pictures have also been linked to increased and easier information extraction, which could better facilitate the understanding of hazards [15].

Context is also important with respect to scene complexity. A number of factors have been identified that reduce visual search performance and make the hazard recognition task more difficult. These factors include area, density, and, most importantly, the number of background items in a scene [16]. Experienced workers may be better able to cope with changes in scene complexity through learned variance in attention. For example, the driving literature shows that experienced drivers increase their visual scanning as the complexity of the roadway increases, suggesting that experienced drivers' improved recognition performance may be due to improved situational awareness that is more necessary and evident in complex scenes [17]. Increased context also leads to improved scene realism, which has been shown to lead to improved training transfer and performance results [18]. Additional items in an image add to the background noise, but also provide realism through reasoning for an action to occur or hazard to be present.

Given that previous research on hazard recognition often used artificial and limited materials, the purpose of the current study was to create a hazard recognition task that more closely parallels—or simulates—the workplace examination. To do this, NIOSH researchers created panoramic images with ample context and asked safety professionals, miners, and students to search the images for hazards as if they were performing a workplace examination at their own worksite. Using this setup, researchers aimed to identify differences in workers' ability to recognize hazards based on context and experience. Findings from this study will be incorporated into training programs focused on improving hazard recognition ability for miners.

3 Methods

3.1 Participants

Fifty-two participants volunteered to take part in the study, but three participants were excluded due to technical difficulties. All participants traveled to the NIOSH research facility in Bruceton, PA. None of the participants received payment for their participation in the study. All participants were screened to verify that they are free of degenerative vision disorders, have full peripheral vision (−45 to 85°) in both eyes, and have a visual acuity of 20/40 or better [19]. Participants were also screened using Ishihara Plates for color blindness. Participants that were found to have mild or severe colorblindness did not perform significantly worse than the rest of the sample, and were therefore included in the analysis.

For the purposes of this study, participants were divided into four groups: safety professionals, experienced miners, inexperienced miners, and students. Researchers created the groups based on total mining experience (total mining) and experience in current mining position (current position). According to the National Survey of the Mining Population conducted in 2012, the average stone miner has approximately 12.5 years of experience in mining and 7.8 years of experience in their current position; similarly, the average metal and non-metal miner has 10.7 and 12.0 years of total experience and 4.7 and 6.7 years in current position respectively [20]. However, because of sampling constraints, researchers used the following group definitions. Safety professionals had at least 2 years of experience in an environmental, health, or safety position for a mine operator or government agency. Experienced miners had more than 2 years of experience as a laborer, equipment operator, sample taker, foreman, or supervisor. Inexperienced miners had some but less than 2 years of experience as a laborer, equipment operator, sample taker, foreman, or supervisor. Finally, students were defined as a person enrolled in a mining-related program that is not otherwise classified. Any participant pursuing a higher-level degree was grouped as a student regardless of mining experience. All participants, except for students, also reported having completed at least 24 h of MSHA New Miner Training (30 CFR Part 46), and those categorized as experienced miners and safety professionals reported having completed the additional 8 h of MSHA Annual Refresher Training as necessary (30 CFR Part 46) [21]. The demographics of the study participants are shown in Table 1 below.

Table 1. Participant demographic counts and means (standard deviation).

Group	N	Age [yrs.]	Total mining [yrs.]	Current position [yrs.]
Safety professionals	12	47.7 (11.0)	20.3 (13.5)	8.0 (5.7)
Experienced miners	11	39.1 (11.2)	13.8 (11.0)	9.2 (11.1)
Inexperienced miners	12	26.2 (8.2)	0.6 (0.5)	0.3 (0.3)
Students	14	22.9 (2.8)	0.7 (1.1)	N/A

3.2 Materials

The research materials for this study are 32 panoramic images of four locations at a typical surface stone operation: pit, plant, roadway, and shop. There are eight panoramic images taken at each of the four locations. Six images for each location are experimental images, containing hazards, while the other two images are control images, containing zero hazards. The number of hazards per experimental image ranges from two to seven, totaling 101 hazards. The overall breakdown of the hazards is 19 in the pit, 25 at the plant, 26 on the roadways, and 31 in the shop.

The scope of the hazards included in the panoramic images was determined using incident data and subject matter experts. First, NIOSH researchers considered Mine Safety and Health Administration (MSHA) fatal and nonfatal days lost (NFDL) data. Table 2 includes a summary of incidences that occurred at United States M/NM mine sites during the years 2009–2015 compared to classifications of the hazards used in the study. As evident by the numbers, specific hazards were included in the panoramic images in order to represent as many of the accident classifications in as realistic a way as possible as well as mirror the prevalence found in the data. Final decisions on the specific hazards to be included in the images were made with the support of subject matter experts (SME). SME support included feedback from former MSHA inspectors, mine safety professionals, and NIOSH researchers familiar with surface stone mining techniques.

Table 2. Incidence of metal/non-metal mining accidents by classification for years 2009–2015 compared with hazards included in the panoramic images.

MSHA classification	Accident severity			Study hazards
	Fatal	NFDL	Total	
Electrical	5	110	115	8
Entrapment	0	1	1	0
Exploding vessels under pressure	1	65	66	0
Explosives and breaking agents	2	10	12	0
Falling, rolling, or sliding rock	22	65	87	5
Fall of face, rib, pillar, side, or highwall	2	11	13	7
Fire	0	32	32	6
Handling material	0	6473	6473	8
Handtools	0	1851	1851	2
Non-powered haulage	0	55	55	1
Powered haulage	30	1340	1370	32
Hoisting	0	17	17	1
Ignition or explosion of gas or dust	1	23	24	1
Impoundment	0	1	1	0
Inundation	0	2	2	0
Machinery	18	1488	1506	2
Slip or fall of person	14	4641	4655	23
Stepping or kneeling on object	0	378	378	1
Striking or bumping	1	133	134	3
Other	5	475	480	1
Totals	101	17171	17272	101

NIOSH researchers worked with corporate and mine safety professionals from a surface limestone mine site to take the panoramic images. The panoramic images included hazards that were staged onsite at the mine as well as hazards that were enhanced or created using photo editing software. Of the 101 hazards included in the panoramic images, 58 hazards were staged, 22 were enhanced (e.g., rope was brightened to improve visibility), and 21 were created through photo editing (e.g., a stair or part of a berm were removed from an image). Figure 1 is a panoramic image of the shop; Table 3 includes a description of the seven hazards included in the image, the MSHA classification of the hazards, as well as how the hazards were created. Prior to use in the hazard recognition task, panoramic images were reviewed and evaluated by the aforementioned SME support.

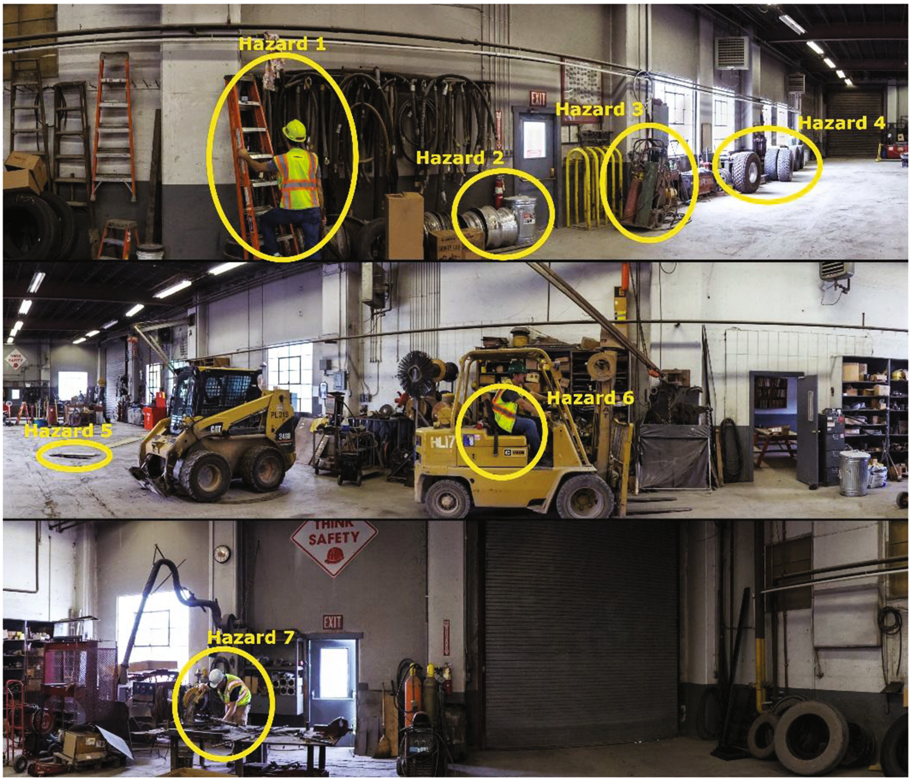

Fig. 1. Panoramic image of the shop (Please visit the following website to view 4 of the NIOSH panoramic images: https://www.cdc.gov/niosh/mining/hazrec.). The NIOSH identified hazards are circled in yellow and labeled Hazard 1–7. Note: the panoramic image is shown in three panels for space purposes.

Table 3. Example hazard descriptions, classifications, and creation method

Hazard	Hazard description	MSHA classification	Creation method
Hazard 1	Incorrect use of ladder	Slip or fall of person	Staged
Hazard 2	Obstructed fire extinguisher	Fire	Staged
Hazard 3	Unsecured gas cylinders	Non-powered haulage	Edited
Hazard 4	Unsecured tires	Handling material	Staged
Hazard 5	Uncovered floor opening	Slip or fall of person	Staged
Hazard 6	Operating without a seatbelt	Powered haulage	Staged
Hazard 7	Working without safety glasses	Machinery	Enhanced

3.3 Virtual Immersion Simulation Laboratory (VISLab)

All testing took place in NIOSH's Virtual Immersion Simulation Laboratory (VISLab) that houses the several display theaters. The system, used to perform the hazard identification task, features a 360-degree panoramic front project display that is roughly 10 m in diameter by 3 m tall. Six high-definition projectors (Titian 1080p 3D, Digital Projection, Kennesaw, GA) create a seamless image that surrounds the user in digital imagery. A motion-tracking camera system (T20, Vicon, Oxford, UK) above the screen provides the capability to track participants and objects within the display space. The 60 Hz data from eye-tracking glasses (ETG 2.0, SensoMotoric Instruments, Teltow, Germany) are used in concert with 120 Hz data from the motion tracking system to calculate the user's gaze point in screen coordinates as the participant moves about the display space. The stimulus images are rendered using an in-house Unity application (Unity technologies, San Francisco, CA). A detailed discussion of the development process for the panoramic images, the calibration of the screen space, the synchronization of the hardware, and the software is described by Bellanca et al. [22].

3.4 Procedure

Upon arriving at the VISLab, researchers obtained informed consent from the study participants to participate in the institutional review board approved protocol. Participants first completed a demographics questionnaire about their training and mining experience and completed the vision screening. Participants were then outfitted with the eye-tracking glasses and a hand-held joystick in their dominant hand. The participants also wore a small backpack to carry the eye-tracking laptop. Lastly, researchers affixed reflective markers to the participants' C7, acromioclavicular joints, sternum, right scapula, and eye tracking glasses frames.

To start the hazard identification portion of the study, participants performed a two-minute simple reaction time test, followed by a static calibration of the motion capture system, and a 3-point calibration using the SMI iView software. Next, an additional 4-point, 10-degree calibration was performed to orient and synchronize the motion capture and eye-tracking systems in order to calculate the point of regard on the 360 screen. After the calibrations, participants reviewed two practice panoramic images to adapt to the setup.

For actual data collection, participants were presented with four blocks of eight panoramic images grouped by location (pit, plant, shop, and roadway). The block orders were distributed across groups, and individual images within the block were randomized per participant. Participants were given up to two minutes to view each image and were instructed to press the joystick button to identify a hazard as quickly and as accurately as possible. Subjects were also instructed to only press the button once per hazard and to assume that all belts and conveyors we in motion. If a participant finished the identification early, they could end the image. Participants were given a break between each block. After all 32 images were completed, the participant was de-instrumented. The hazard identification task typically took about 45 min to 1.5 h to complete.

3.5 Data Post Processing

For each of the 101 identified hazards, regions of interest (ROIs) were defined in the panoramic images using SME support. ROIs were defined as polygons, containing only the hazard. Eye-tracking data was transformed into image data according to the process described by Bellanca et al. [22]. The image scan path data was then processed to identify fixations (e.g., when the eye remains still), using a dispersion algorithm such that the minimum duration is 75 ms and the maximum dispersion is 50 pixels [23]. Given the set ROIs and fixation data, researchers evaluated each button press as a hit or miss based on the central gaze position of the fixation prior. To be a hit, the button press fixation must be (1) within 170 pixels, (2) have at least one fixation prior within 75 pixels of the ROI, and (3) the prior scan path must match the shape of the ROI. Alternatively, a button press could be a late hit, as depicted in Fig. 2. A late hit is defined as a scan path where the last one or two fixations that are no more than one second after the button press meet the hit criteria. The late hit criteria was chosen based on common choice reaction time timing across age and subject variability in order to account for decision making and motor delay [24]. However, no late hits later than 0.5 s were observed. All button presses were visually verified and, if necessary, reviewed by a second person.

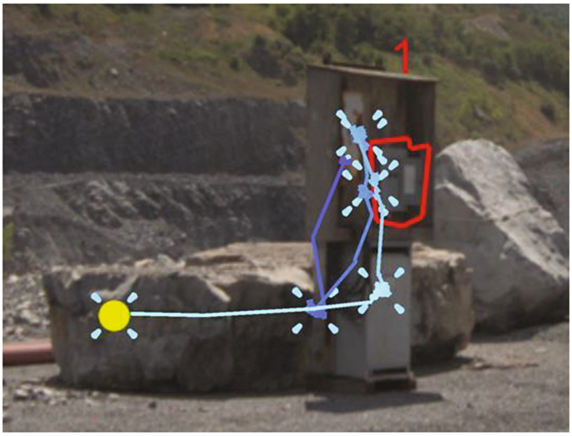

Fig. 2. An example scan path data of a late hit button press identifying the electrical hazard of the open electrical box. The ROI is outlined in red. The scan path before the button press is in blue and gets lighter as time gets closer to the button press. The click icons in blue indicate fixations, and the yellow circle represents the fixation associated with the button press. In this image, the yellow circle is 280 pixels from the edge of the ROI.

From the hit and late hit data, identification accuracy was computed across location and hazard classification for each subject. Because hazards were staged to be as realistic as possible without over saturating an image, it was not possible to achieve equal distributions of hazard classifications across the locations. Therefore, the context variables of location and hazard classification are being analyzed separately. A full factorial, least squares regression was performed with group and location, and group and classification accounting for participant random effects (JMP, SAS, Cary, NC). For both analysis all statistical assumptions were met.

4 Results

4.1 Location

As was the case in previous studies [6, 9, 10], participants under-performed in the hazard recognition task. With a high score of 78% correct, the average group scores were only 61%, 56%, 50%, and 47% for the safety professionals, experienced miners, inexperienced miners, and students respectively. There were main group ($p = 0.0115$, $F(3, 45) = 4.1$) and location ($p = <0.0001$, $F(3, 135) = 8.2$) effects. As depicted in Fig. 3, accuracy trended downward as safety experience decreased such that the safety professionals performed significantly better than the students did ($p = 0.002$, $F(1, 135) = 10.7$).

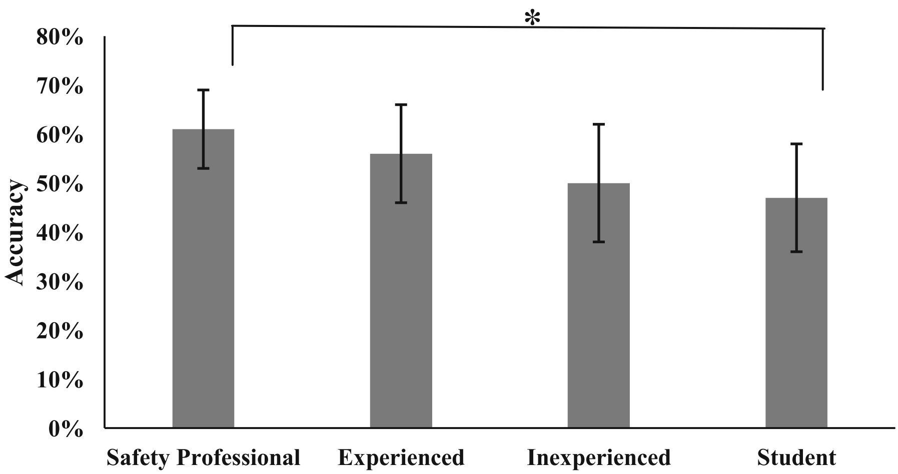

Fig. 3. Bar graph depicting the across subject averages for accuracy, where the error bars represent the standard deviation and the * indicates significance at $\alpha < 0.05$.

The location average accuracy scores were 53%, 55%, 56%, and 48% for the pit, plant, shop, and roadway respectively. Exploring the location effect further, Tukey's range test indicated that the roadway was significantly different from the other three locations with $p < 0.05$.

4.2 Classification

When looking at context versus experience related to hazard classification, only a classification effect was significant ($p = <0.0001$, $F(14, 630) = 31.4$). Figure 4 depicts the average hazard classification accuracy by group, where ignition or explosion had the lowest success rate, followed by fire, striking or bumping, stepping on object, and electrical all under 50% correct. The top three classification were machinery, handtools, and hoisting, all around 80%.

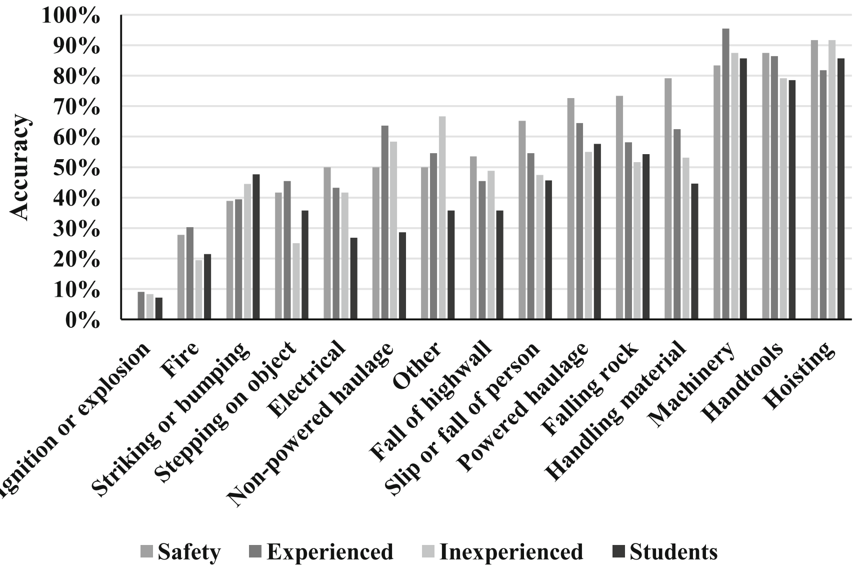

Fig. 4. This bar graph depicts across subject average accuracy by hazard classification.

5 Discussion and Conclusion

A primary goal for this study was to create a hazard recognition task that simulates a workplace examination that a miner would perform. Given the true-to-life images and large projection space, researchers were able to accomplish this goal. Furthermore, because of the realistic content, the panoramic images can be used directly by the industry. However, the applied nature of the images posed analytic challenges. Namely, since the hazard and background content were not evenly distributed, only generalizations of context effects could be examined.

As hypothesized, experience was found to be significant when modeled with location, but interestingly was not significant when analyzed with hazard classification. This weak relationship may suggest that the experience that differentiates location and classification context may be different from that which is being captured by the groups. Dzeng et al. [25] suggested similar reasoning to explain a lack of accuracy differences in their work on visual strategies used by experienced and inexperienced construction workers; where in their case, they suggest that general work experience is not equivalent to safety-specific experience. The current study data aligns with this suggestion, as safety professionals and students have the greatest difference in safety experience and display the only significant result. It may also be possible that the experience difference between the groups in general was not big enough. Specially, the variance of total mining experience for the experienced miners group was large, as some of the participants were very similar to those classified in the inexperienced miners group. A closer look at the type and quantities of experience may help clarify the lack of significance.

The observed location effect was also not as expected; the results did not align with the hypothesis that scenes that are more complex reduce performance. In the current study, it was predicted that hazard recognition in the shop would be worse than in other locations because the shop images are more enclosed and cluttered. Counter to this prediction, the roadway performance was significantly worse than the other locations. One possible explanation for the reduction in the roadway performance may be due to decreased experience performing exams in this location. As mentioned in the public comments for the workplace exams rule, mine operators are not accustomed to examining roadways as a place of work [2]. The roadway images also tended to include more of the low accuracy hazard classifications such as fire and electrical hazards, possibly leading to an average overall lower score.

The effect of hazard classification may also be due to participants' exposures to hazards. The top three most accurately identified hazards also happened to be the most prevalent in the industry as indicated by MSHA's injury and illness data. Furthermore, trainers typically use the injury and illness data to prioritize their training and safety communications. The data in this study supports the need for training in routine as well as non-routine hazards to eliminate major weaknesses in hazard recognition ability.

As researchers move to translate the work from this study into training, it will be important to incorporate a safety-specific focus that covers common and uncommon hazards. Future work will also include a more in-depth analysis of the scan path, reaction time, and hazard review data to capture a fuller picture of hazard recognition.

Acknowledgments. NIOSH would like to thank Holly Tonini for her help in taking and editing the panoramic images. The findings and conclusions are those of the authors and do not necessarily represent the views of NIOSH.

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