The Effect of Work Experience on Risk Assessment Skills

Jennica Bellanca, MS; Brianna Eiter, PhD; Jonathan Hrica, MS
National Institute for Occupational Safety and Health (NIOSH), Pittsburgh, PA
JBellanca@cdc.gov, BEiter@cdc.gov, JHrica@cdc.gov

Terry Weston; Robert Weston
South Central College
Mankato, MN
Terry.Weston@southcentral.edu, Robert.Weston@southcentral.edu

ABSTRACT

Identifying and assessing the risk of hazards is critical to avoiding accidents and injuries. However, studies indicate that workers have difficulty accurately assessing risk (Carter & Smith, 2006) and that there is a lot of variability in how people define and perceive risk (Perlman, Sacks, & Barak, 2014). Specifically, it has been reported that untrained workers tend to only consider severity as opposed to both the severity and probability of an accident occurring when assessing overall risk. Between the fourth quarter of 2013 through 2016, 72 mineworkers were fatally injured at metal/nonmetal mines in the United States (MSHA, 2017). A significant portion of these fatalities appear to be linked to a lack of task and site experience, with 22 fatalities involving mineworkers performing an activity with which they had less than one year experience, and 20 fatalities involving contractors. The focus of this research effort is to expand our understanding of how mineworkers with varied experience and employment backgrounds assess the risk of worksite hazards. Initially, researchers at the National Institute for Occupational Safety and Health (NIOSH) collected hazard recognition and risk assessment data from 24 mineworkers, 13 safety professionals, and 14 students while performing a simulated workplace examination in NIOSH Pittsburgh's virtual immersion and simulation laboratory. Researchers then packaged four hazards from the laboratory study into a risk assessment training module, specifically looking at severity, probability, and overall risk. Researchers used the training module to collect risk assessment data from over 1,200 mineworkers during mandatory, annual refresher training. The training data collection provided a larger, more general sample that specifically included contractors. This paper compares risk assessments from the laboratory and training data, and it reports on the differences between risk components, groups, and experience in order to identify future training needs.

ABOUT THE AUTHORS

Jennica Bellanca is a Biomechanical Engineer with the National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Mining Research Division (PMRD). She earned her Bachelor's degree in Bioengineering and Master's degrees in Bioengineering and Mechanical Engineering from the University of Pittsburgh in 2009 and 2011, respectively. She has worked for PMRD for 6 years, focusing her research on human factors issues related to informational needs, hazard recognition, and proximity detection. Her work has involved virtual reality (VR) environment development and training tool development.

Brianna Eiter is a Behavioral Scientist with NIOSH PMRD. She holds a doctorate in Cognitive Psychology from Binghamton University, with concentrations in visual attention and eye tracking. She has worked for PMRD for 7 years, focusing her research on understanding mineworker hazard recognition ability and identifying strategies, such as training, to be used to improve this ability. Her recent work has involved creating VR work environments.

Jonathan Hrica is a Mining Engineer with NIOSH PMRD. He earned his Bachelor's degree in Mining Engineering from the University of Arizona and Master's degree in Technology from Arizona State University. He has worked for PMRD for 2 years, focusing his research on hazard recognition, risk perception, and training tool development.

Terry Weston is a Safety and Health professional with the Center for Business and Industry (CBI) division of South Central College in North Mankato, MN. He is a Certified Safety Professional (CSP) and Certified Mine Safety Professional (CMSP). He is a subject matter expert in OSHA and mine safety training. He has established working partnerships with other leaders in the safety field, including NIOSH, PowerLift, Select International, and others.

Robert Weston is a Safety Professional with CBI of South Central College in North Mankato, MN. He earned his Bachelor's degree in Organizational Management and Communications from Concordia University, St. Paul, MN, in 2004, and is a CSP; CSMP; and Certified Environmental, Safety, and Health Trainer. He has worked at South Central College for 13 years—designing, developing, and delivering safety solutions to business and industry.

The Effect of Work Experience on Risk Assessment Skills

Jennica Bellanca, MS; Brianna Eiter, PhD; Jonathan Hrica, MS
National Institute for Occupational Safety and Health (NIOSH), Pittsburgh, PA
JBellanca@cdc.gov, BEiter@cdc.gov, JHrica@cdc.gov

Terry Weston; Robert Weston
South Central College
Mankato, MN
Terry.Weston@southcentral.edu, Robert.Weston@southcentral.edu

BACKGROUND

Recently, the metal/nonmetal mining industry has seen an increase in occupational fatalities. This began with a sharp increase between October 1st, 2013 and December 31st, 2014, which consisted of 38 fatalities (MSHA, 2017). As a result, the Mine Safety and Health Administration (MSHA) issued a program policy letter (Merrifield, 2015) announcing an increased focus on workplace exams. This focus ultimately resulted in amending the workplace examination rule in an effort to improve hazard identification and increase hazard mitigation. The final rule mandates that in addition to creating a record that an exam has occurred, as previously required, mine operators must also include the location of the exam, the hazards found, and the date when the mitigation(s) were completed. The final rule goes into effect June 2, 2018 (MSHA, 2018). In the meantime, fatalities have still remained relatively high, with an additional 34 occurring in 2015 and 2016 (MSHA, 2017). Furthermore, a large portion of these 72 fatalities appear to be linked to a lack of task and site experience, with 22 involving mineworkers performing an activity for which they had less than one year experience and 20 involving contractors.

Hazard identification is only the first step in reducing accidents and fatalities. Mineworkers must be able to assign the appropriate level of risk to hazards to prioritize mitigation efforts and ensure everyone's health and safety. As evidence of its importance, poor risk management has been linked to 84% of construction accidents (Haslam et al., 2005). Research has also shown that risk assessment can influence mitigation behaviors (Hunter, 2002). In industries such as healthcare, driving, aviation, construction, and assembly plants, an increased level of risk perception has been linked to a decrease in risky activities (Brewer et al., 2007; Brown & Groeger, 1988; Hunter, 2002; Khandan, Koohpaei, & Tabar, 2017; Perlman et al., 2014). However, studies indicate that workers have difficulty accurately assessing risk (Carter & Smith, 2006), and there is a lot of variability in how people define and perceive it (Perlman et al., 2014).

Brown and Groeger (1988) define risk as "the ratio between some measure of adverse consequences of events and some measure of exposure to conditions under which those consequences are possible." It is important for workers to consider both probability and severity when assessing risk, as both catastrophic events and everyday slips, trips, and falls require attention. Therefore, it is common practice in many industries, including mining, to assess risk by multiplying the severity of an event by the probability of it happening (Joy, 2004; Perlman et al., 2014). However, in the field workers may only rely on their perception of risk, which has been shown to change based on the situation and experience. Rottenstreich and Hsee (2001) found that the weight of probability in perceived risk depends on the nature of the outcome. Perlman et al. (2014) found that untrained construction workers tend to only consider severity when assessing overall risk. Finally, Slovic (1987) argued that experienced workers tend to favor probability when determining risk, as their estimates of risk correlate highly with annual fatality data, whereas lay people's risk ratings relate more to hazard characteristics.

Experience has also been shown to modulate the absolute level of perceived risk. In general, novices tend to rate hazards as less risky than their experienced counterparts. Perlman et al. (2014) found that students assessed the level of overall risk lower than construction superintendents. Inexperienced drivers have been shown to rate risk lower than experienced drivers, but only for specific situations (Jonah, 1986). Brown and Groeger (1988) concluded that novice drivers lack the necessary experience required to properly assess hazards and are unaware of this shortcoming. Experience allows drivers to improve their cognitive representation of hazards and the relative risk. It has been also been shown that novices lack the ability to predict hazards and an understanding how their skills align with those needed to mitigate a hazard (Hutton & Klein, 1999). Similarly, Hunter (2002; 2006) found that aviation pilots with more experience and higher qualifications displayed lower levels of risk perception due to a higher level of perceived ability to overcome hazards that is inseparable from the risk of the hazard itself.

Specific experience has been shown to modulate perceived risk. Weyman and Clarke (2003) found that mineworkers who are more familiar—work closer—with a particular hazard tended to rate the risk higher. In this case, mineworkers actually rated the risk higher than the superintendent. In other cases, task familiarity has been shown to lead to complacency and habituation to risk (Östberg, 1980; Zimolong & Elke, 2006). For example, construction workers were found to underestimate the risk associated with working on ladders and scaffolding. However, this only applied to one's self; the workers tended to rate the same hazard as more risky for a co-worker (Zimolong & Elke, 2006).

Lastly, age is sometimes used as a proxy for experience because they are difficult to separate. However, numerous studies describe the reasons why younger drivers are involved in more incidents, such as not recognizing hazards (Jonah, 1986), underestimating the danger (Elander, West, & French, 1993), and taking more risks (Sicard, Jouve, Couderc, & Blin, 2001). Additionally, some researchers propose that young drivers overestimate their skill (Deery, 1999), while other researchers found that young drivers are more optimistic relative to their more seasoned counterparts at assessing the outcome of a given action (McKenna, 1993).

As the literature demonstrates, risk perception and experience tend to be domain and situation specific. Therefore, the current study aims to investigate the effect of mineworker experience on risk perception of general mine site hazards. Using a combination of laboratory and in-training data collections, researchers explored the effects of overall mining experience, site experience, and age on risk and its principal components, probability and severity.

METHODS

Laboratory Data Collection

As part of a larger study designed to systematically characterize hazard recognition and risk perception, mineworkers participated in a simulated workplace exam laboratory study. First, all participants were asked to identify as many hazards as possible in 32 panoramic pictures displayed in a 360° immersive environment (Bellanca et al., 2017; Eiter et al., 2018). Next, participants performed risk assessments on all of the hazards. This paper focuses on the risk assessments of a sub-set of hazards that were also used in the training data collection described later.

Participants

After providing informed consent, a total of 51 individuals participated in this institutional review board-approved laboratory study. Participants were volunteers with varying levels of experience working at surface mining operations. The participants were categorized by experience, ranging from safety professionals, experienced miners, inexperienced miners, and students, where safety professionals had at least two years of experience in an environmental, health, or safety position for a mine operator or government agency; experienced miners had more than two years of experience as a mineworker or supervisor; inexperienced miners had some but less than two years of experience as a mineworker or supervisor; and students were defined as a person enrolled in a mining-related program that is not otherwise classified. The subject demographics are summarized in Table 1.

Table 1: Subject Demographics

Group		N	Age [yrs]		Total Mining Experience [yrs]		Site Experience [yrs]		Contractor*
			Median	**Mode**	**Median**	**Mode**	**Median**	**Mode**	**N**
Lab Study	**Safety Professionals**	13	40–49	40–49	11–20	11–20	3–10	3–10	N/A
	Experienced	11	40–49	40–49	11–20	3–10	3–10	0–2	N/A
	Inexperienced	13	18–29	18–29	0–2	0–2	0–2	0–2	N/A
	Students	14	18–29	18–29	0–2	0–2	0–2	0–2	N/A
Training – General		1,232	40–49	50–59	3–10	3–10	3–10	0–2	382

* Contractor status of the laboratory participants is not available

Hazard Depictions

A total of 101 hazards across 32 panoramic images were used for the risk assessment task. Images were of typical locations at a surface limestone mining operation, including the pit, plant, shop, and roadway. There were between zero (control) and seven hazards in each image. Hazards in the images were selected to represent the type, severity, and prevalence of hazards found in MSHA's accident and injury database. Hazard placement and inclusion was vetted by subject matter experts. Hazards were staged to the extent possible and otherwise edited or enhanced (see Bellanca et al., 2017). An example panoramic image and the two hazards analyzed in this paper can be seen in Figure 1.

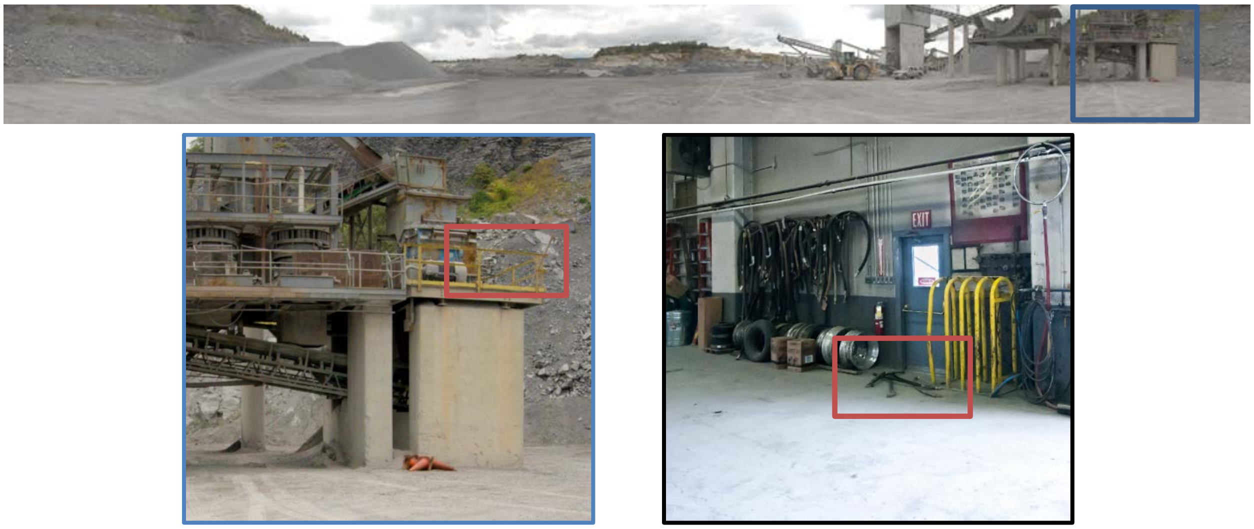

Figure 1: The top image depicts an unwrapped panoramic image used in the laboratory study with the blue rectangle showing Hazard 1. The lower left image shows the zoomed view of Hazard 1. The red rectangle identifies the missing mid rail hazard. The lower right image displays Hazard 2. The pipes and cables are also a slip, trip, and fall hazard.

Risk Assessment

In order to maximize engagement and optimize participant viewing, the risk assessment task took place in a classroom-style display theater. The display screen is a curved panoramic screen situated along one wall of a 10 x 10 meter room. Participants were first presented with each unwrapped panoramic image and then zoomed in on each hazard. Participants received a brief description of each hazard. Then, participants were asked to rate: (1) how *severe* you think the likely resulting accident would be, (2) the *likelihood* that an accident will occur, and (3) your *overall risk* assessment on a 5-point scale. The risk assessment scales were adapted from Perlman et al. (2014), as seen in Table 2. Participants were instructed to go with their first instincts and rate as quickly as possible.

Table 2: Risk Assessment Rating Scales

Scale	Numerical Value				
	1	2	3	4	5
Accident Severity	No Injury	Minor Injury No Leave	Injury ≥ 3 Days Leave	Non-fatal Major Injury	Fatal
Accident Probability	Very Unlikely	Fairly Unlikely	Average Likelihood	Fairly Likely	Very Likely
Overall Risk	Very Low	Low	Medium	High	Very High

Training Data Collection

In order to target a larger, more general audience, the second data collection was completed as a part of MSHA-mandated annual health and safety refresher training (30 CFR § 46/48). Data collection was facilitated by the fourth and fifth authors of this paper. The researchers collected data using a convenience sample as part of their training with mine companies, mine service companies, engineering firms, and public classes.

Participants

A total of 1,508 participants across 52 training sessions and 2 instructors were recruited. Of that, 66 participants declined to participate and another 210 were eliminated due to missing data, leaving 1,232 participants. Data was collected from training participants via an audience response system (clickers). Voluntary participation was indicated by an affirmative response. Participants responded to a series of multiple-choice questions about their total mining experience (0–2, 3–10, 11–20, 21–30, 30+ years), site-specific experience (0–2, 3–10, 11–20, 21–30, 30+ years), contractor status (yes, no), and age (18–29, 30–39, 40–49, 50–59, 60+ years). Subject demographics are summarized in Table 1. The demographics are similar to the mining industry in general with an average 12.9 years of mining experience, 9.0 years of site experience, and age of 43.3 years (McWilliams, Lenart, Lancaster, & Zeiner, 2012).

Hazard Depictions

Four hazards from the laboratory study were selected to be included in the training data collection. Only two of the hazards will be discussed and used in this analysis. In order to optimize the probability and severity ratings, researchers selected a hazard with high severity and low probability (Hazard 1) and a hazard with low severity and high probability (Hazard 2) as defined by the average ratings of the safety professionals in the laboratory study. The safety professionals were chosen as independent domain experts since no objective or gold standard exists. Participants were presented with the zoomed in images of the hazards depicted in Figure 1.

Risk Assessment

The training data collection took place at a variety of locations, but all sessions included the presentation of materials via Microsoft PowerPoint as displayed using a portable projector or site-provided television. Participants were sequentially presented with the hazards and risk assessment scales. The hazard descriptions were: Hazard 1: In this picture, you can see that the mid rail is missing from the crusher platform; Hazard 2: In this picture, you can see the pipes and cables in front of the main entrance to the shop. The rating scales (Table 2) were presented individually. All participants were required to finish each rating before moving on to the next scale or hazard as a class.

Statistical Analysis

For both the laboratory and training data, all rating data was treated as ordinal. Correlation coefficients were calculated between both severity and probability and overall risk. Due to violations in normality and the ordinal nature of the data, Spearman's Rank-Order Correlation coefficient was used. The effect of experience was tested using multinomial modeling. In order to preserve each hazard, but account for the within-subject variance, the risk assessment ratings (overall risk, probability, and severity) were modeled using generalized estimating equations (GEEs) with a multinomial distribution and a cumulative logit link function. An independent correlation structure was assumed. For the laboratory data, a full factorial model of group and hazard was used. Odds ratios were calculated for any significant effect with the safety professional as the reference. Post-hoc pairwise comparisons of estimated marginal means were calculated for any significant interaction effect. For the training data, a 2nd order factorial model was used, including age, mining experience, site experience, contractor, and hazard. Again, estimated marginal means were calculated for any significant interaction. All data was analyzed using IBM SPSS Statistics Software (Cary, NC). The alpha was set to 0.05 for all multivariate models and post-hoc comparisons.

RESULTS

Risk Correlations

Table 3: Correlation Coefficients with Overall Risk by Group

Group		Probability		Severity	
		Coefficient	p-value	Coefficient	p-value
Lab Study	**Safety Professionals**	0.450	0.123	0.322	0.283
	Experienced	**0.741***	**0.009***	0.575	0.064
	Inexperienced	0.315	0.294	0.466	0.108
	Students	0.260	0.369	0.500	0.069
Training – General		**0.586***	**<0.001***	**0.194***	**<0.001***

* Indicates significance at α = 0.05

The dominant predictor of overall risk is probability. Correlation coefficients for the lab and training data are displayed in Table 3. Only the experienced and training groups had significant correlations, but both displayed a large positive correlation of probability with overall risk. For the training group, there was also a significant, moderate, positive correlation of severity with overall risk; however, this effect was much smaller.

Laboratory Groups

Analyzing the effect of experience using the recruitment groups in the laboratory data generally indicated that both group and hazard play a significant role in the subject's risk assessment. The GEE model for severity found significant group ($p = 0.047$) and hazard ($p < 0.001$) effects, where inexperienced miners were 5.165 (95% CI 1.11 to 23.92) times more likely to rate the severity of a hazard lower than safety professionals ($p = 0.036$) and Hazard 2 was 56.017 (95% CI 11.63 to 269.71) times more likely to be rated as lower severity than Hazard 1 ($p < 0.001$). Similarly, the GEE model for probability found both hazard ($p = 0.003$) and the interaction of group and hazard ($p = 0.050$) to be significant, where Hazard 1 was 10.63 (95% CI 3.45 to 32.74) times more likely to be rated lower in probability than Hazard 2 ($p < 0.001$). Post-hoc analysis revealed experienced miners' average probability to be significantly higher than that of the students for Hazard 1 only ($p = 0.023$). The GEE model for risk showed that both group ($p = 0.011$) and hazard ($p = 0.043$) were significant, where students were 3.57 (95% CI 1.17 to 10.85) times more likely to rate the overall risk of a hazard lower than safety professionals ($p = 0.025$). These effects are demonstrated in Figure 2.

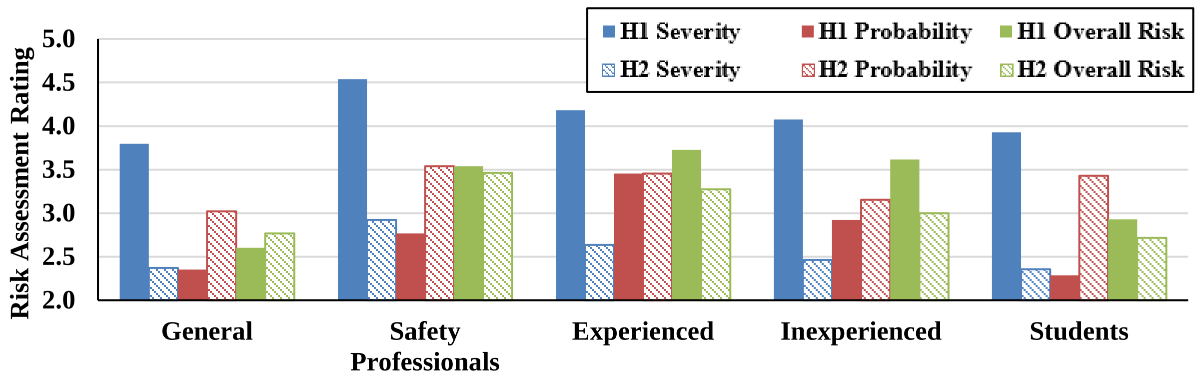

Figure 2: Laboratory group marginal means of the risk assessment ratings where the solid bars represent Hazard 1 (H1) and lined bars represent Hazard 2 (H2). The graph depicts a significant group and hazard effect for severity (blue), group and group x hazard effect for probability (red), and group and hazard effect for overall risk (green).

General Mining Population

Table 4: Generalized Estimating Equations Results for Risk Assessment Ratings

Effects	Severity		Probability		Overall Risk	
	Wald Chi-Square	Sig.	Wald Chi-Square	Sig.	Wald Chi-Square	Sig.
Age	5.550	0.235	**13.604***	**0.009***	**51.327***	**<0.001***
Mining Experience	**20.187***	**<0.001***	7.208	0.125	**22.577***	**<0.001***
Site Exp.	**13.389***	**0.010***	**9.684***	**0.046***	5.376	0.251
Contractor	**10.002***	**0.002***	0.770	0.380	**4.391***	**0.036***
Hazard	**664.004***	**<0.001***	**97.234***	**<0.001***	1.806	0.179
Age X Mining Experience	**31.013***	**0.006***	**38.710***	**<0.001***	**54.658***	**<0.001***
Age X Site Experience	**27.155***	**0.018***	**71.889***	**<0.001***	**42.230***	**<0.001***
Age X Contractor	7.681	0.104	2.892	0.576	2.584	0.630
Age X Hazard	**34.082***	**<0.001***	8.906	0.063	**15.809***	**0.003***
Mining X Site Experience	**35.486***	**0.002***	18.369	0.244	**62.355***	**<0.001***
Mining Experience X Contractor	3.081	0.544	7.185	0.126	3.309	0.508
Mining Experience X Hazard	7.848	0.097	2.605	0.626	1.930	0.749
Site Experience X Contractor	8.113	0.088	2.301	0.681	2.488	0.647
Site Experience X Hazard	3.329	0.504	7.990	0.092	6.059	0.195
Contractor X Hazard	0.060	0.806	**5.605***	**0.018***	0.964	0.326

* Indicates significance at $\alpha = 0.05$

The GEE models for the training data revealed significant main effects for all the experience variables as well as some interactions across the three risk assessment rating scales. The model results are displayed in Table 4 below. As expected from the selection of the hazards, Hazard 1 was rated as significantly more severe that Hazard 2 ($p < 0.001$), and Hazard 2 was rated as significantly more probable than Hazard 1 ($p < 0.001$) with no significant differences in overall risk. Additionally, Hazard 1 was rated as less severe (3.77 versus 4.54), Hazard 2 as less probable (3.12 versus 3.54), and overall risk for both hazards (H1: 2.65 versus 3.54; H2: 2.75 versus 3.46) was lower than for the safety professionals in the laboratory study.

Experience Effects

The main effect of mining experience was significant for the severity and overall risk ratings. Severity peaked at 11–20 years of mining experience with 0–2 and 3–10 being significantly lower. Conversely, overall risk is significantly lower for 0–2 and 21–30 years of mining experience, while probability does not significantly change (Figure 3).

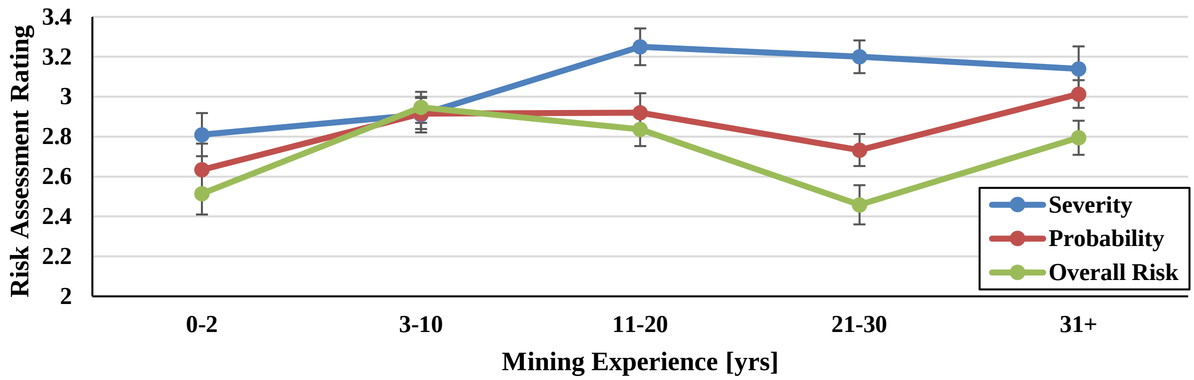

Figure 3: Mining experience marginal means for severity (blue), probability (red), and overall risk (green) ratings. Error bars represent standard error. It displays the significant main effect of mining experience for severity and overall risk.

Site experience was also found to have a significant main effect on severity and probability ratings. The severity ratings of the participants with 0–2 years of site experience were significantly higher than the other groups. The probability ratings of the participants with 31+ years of site experience were significantly higher than the other groups. Both of these effects are depicted in Figure 4.

There was also a significant interaction effect between site and mining experience for severity and overall risk. Participants with 0–2 years of site experience and 21–31 years of mining experience rated the severity of the hazards significantly higher than all other participants with 0–2 years of site experience regardless of mining experience level (Figure 5). Additionally, participants with 11–20 years of site experience and 31+ years of mining experience rated the overall risk of the hazards significantly higher than all other groups across all ages and experience levels with the exception of participants with 21–30 and 30+ years of mining experience and 0–2 years of site experience (Figure 5). However, these two groups were also trending towards significance with p-values of 0.088 and 0.096, respectively.

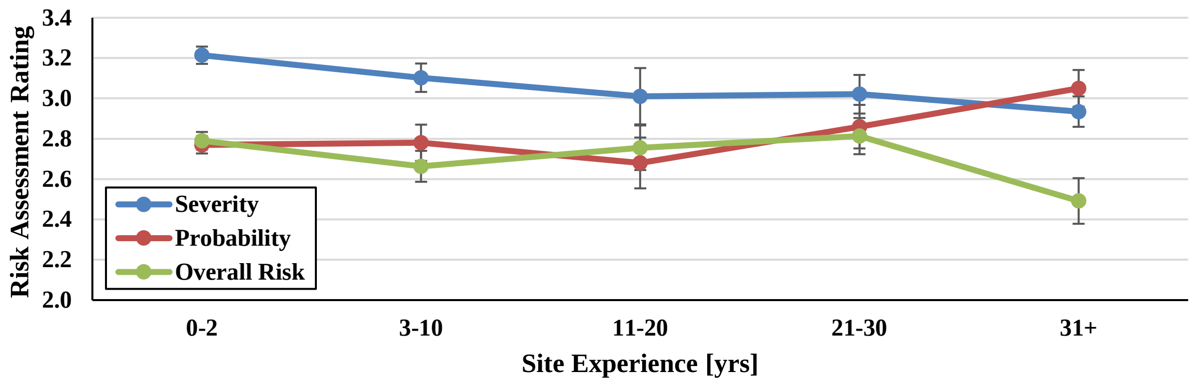

Figure 4: Site experience estimated marginal means for severity (blue), probability (red), and overall risk (green) ratings. Error bars represent standard error. The graph displays a significant effect for both severity and probability.

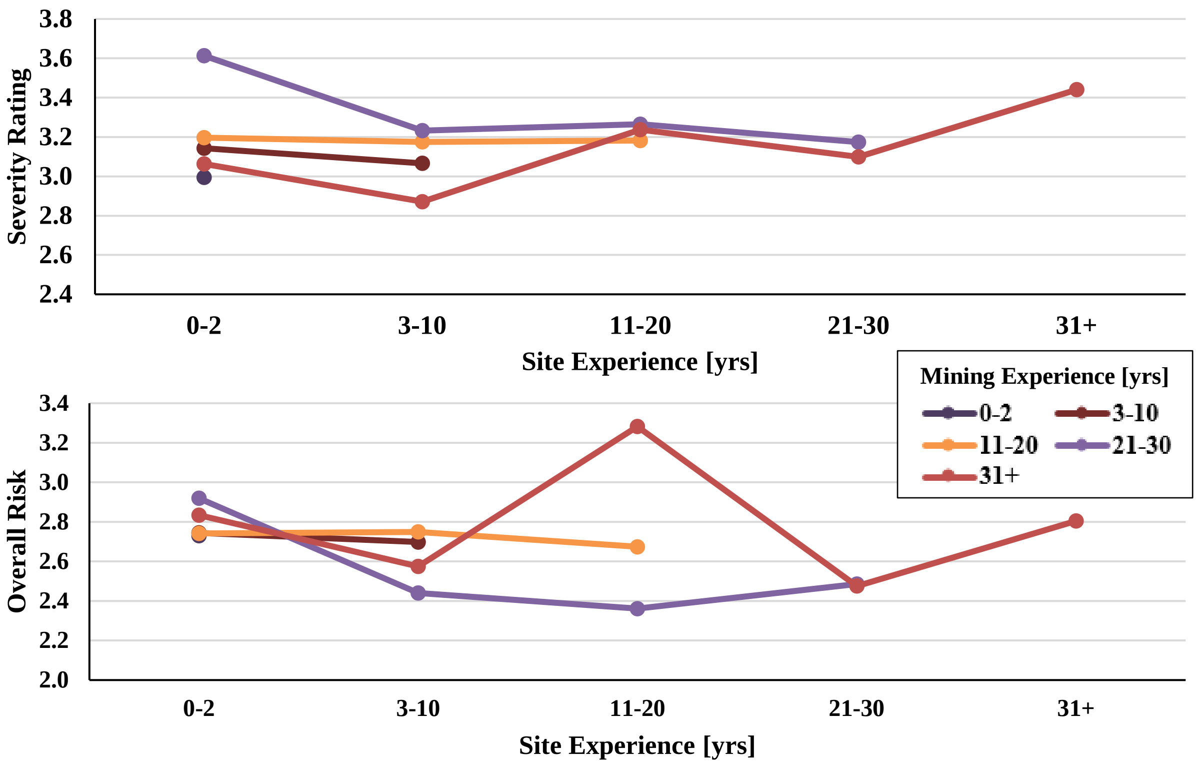

Figure 5: The graphs displays marginal means for site experience by mining experience for severity (top) and overall risk (bottom). Data is not displayed for groups with less than 20 participants.

Age Effects
Age overall was the dominant effect on the risk assessment ratings. Age had a significant main effect on probability and overall risk, but not on severity. In general, probability and overall risk increased with the participants' age group, demonstrating significant differences between every other step, with the exception of probability for 50–59 at $p < 0.01$ for all comparisons (Figure 6).

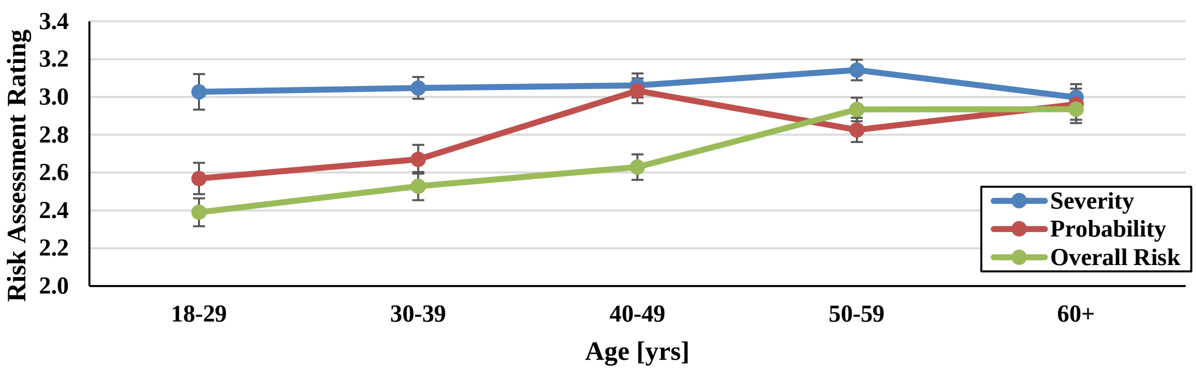

Figure 6: Age group estimated marginal means for severity (blue), probability (red), and overall risk (green) ratings. Error bars represent standard error. The line graph displays the significant age effect for probability and overall risk.

The interaction between hazard and age was significant for both severity and overall risk. The severity rating of the two hazards moderates with age, where the rating of Hazard 1 decreases with age and Hazard 2 increases with age (Figure 7). The overall risk ratings of the two hazards switch with age, where Hazard 2 is rated significantly lower than Hazard 1 for the 18–29 age group ($p < 0.001$) and significantly higher for the 40–49 ($p = 0.018$) and 50–59 ($p < 0.001$) age groups (Figure 7).

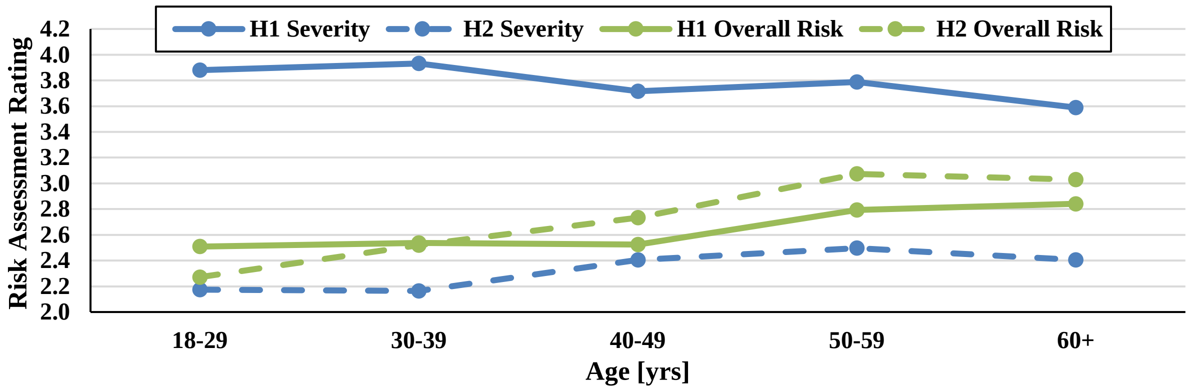

Figure 7: Age group estimated means of severity (blue) and overall risk (green) ratings for Hazard 1 (H1, solid) and Hazard 2 (H2, dashed). The line graph displays the significant age x hazard interaction effect for severity and overall risk.

There was also a significant interaction effect between age and mining experience for all the risk assessment ratings. As displayed in Figure 8, the 60+ year-old participants with 0–2 years of experience rated the hazards significantly lower in severity, probability, and overall risk than their other 60+ year-old counterparts. Probability and overall risk ratings were also significantly higher for participants 60+ with 3–10 years of mining experience than almost all other participants (excluding groups with mean probabilities above 2.9 and overall risk above 3.0).

Similarly, the interaction between age and site experience highlighted differences for the 60+ age group for all three scales (Figure 9). Participants in the 60+ age group with 3–10 and 31+ years of site experience rated the hazards as significantly less severe than all other age groups. Participants in the 60+ age group with 21–30 years of site experience rated the hazards as significantly more probable than all other age groups. Lastly, participants in the 60+ age group with 0–2 years of site experience rated the hazards as significantly riskier than all others with the same site experience.

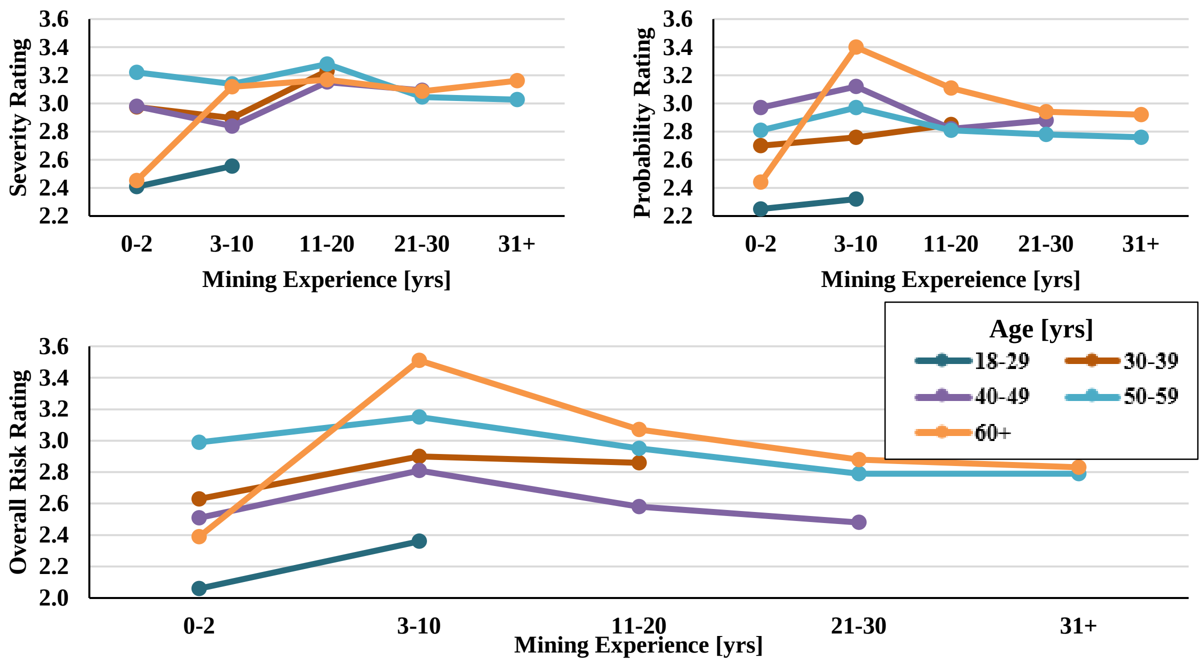

Figure 8: Age group and mining experience estimated marginal means for severity (top left), probability (top right), and overall risk (bottom). Data is omitted for groups with less than 20 participants. The line graphs display the significant age x mining experience interaction effect for all three risk assessment scales.

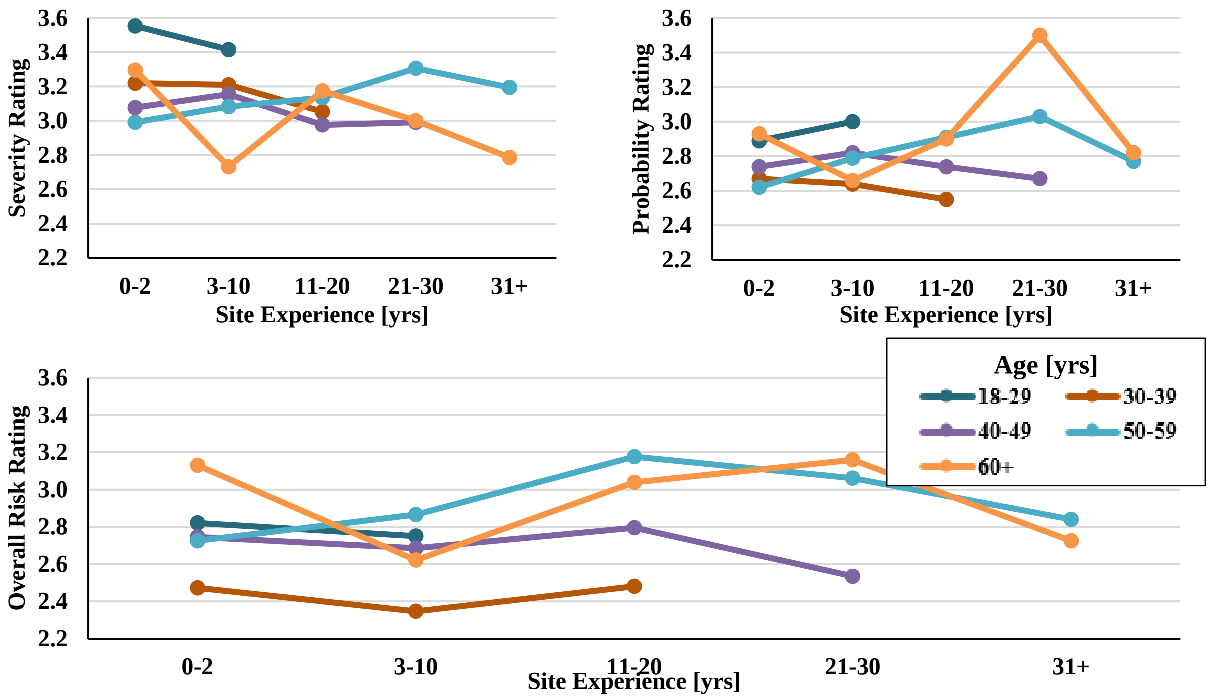

Figure 9: Age group and site experience estimated marginal means of severity (top left), probability (top right), and overall risk (bottom). Data is not displayed for groups with less than 20 participants. The line graphs display the age x site experience significant interaction effect for all three risk assessment scales.

Contractor Effects

Lastly, contractor status was a significant main effect for severity and overall risk. Contractors rated the hazards as significantly more severe (3.15 versus 2.96) and risky (2.76 versus 2.64), but similar in probability (2.85 versus 2.81). The probability of the hazards were also rated differently between noncontractors and contractors. The difference between the probability rating of Hazards 1 and 2 is smaller for noncontractors (2.57 and 3.05) than for contractors (2.51 and 3.18). Though these differences are small (0.48 and 0.67), they are both statistically significant ($p < 0.001$).

DISCUSSION

As metal/nonmetal mining operators prepare for the upcoming changes to the workplace examination rule, it is important that mineworkers are able to consistently and effectively identify and assess hazards. Mitigation must be conducted to both meet regulatory standards and minimize risk. This study examined how individual characteristics, primarily experience, affect risk assessment and perception that are believed to drive mitigation activities. The results of this study support four main conclusions: mineworkers weighted probability more heavily in their assessment of risk, inexperienced mineworkers rated risk lower, experienced site workers rated severity lower and probability higher, and older workers rated probability and risk higher.

Mineworkers weighted probability more heavily in their risk assessment

In order to achieve consistency, it is important to understand how standard risk assessment compares to mineworkers' perceptions. This study found that, in general, mineworkers' overall risk ratings were more strongly correlated with probability despite larger differences in severity between the two hazards. This result is congruent with the findings of Slovic (1987) that experienced workers tend to favor probability. Mineworkers are required by MSHA to participate in annual hazard training (during which this data collection occurred), which aids in setting a knowledge base that may not be present in other industries. Likewise, the student group, lacking hazard training and practical experience, trended towards a higher severity correlation. Additionally, the laboratory data failed to produce a significant correlation between overall risk and either probability or severity for the safety professional group, suggesting a lack of consistency across sites as previously demonstrated in the literature (Basha & Maiti, 2013). This finding suggests that site-specific experience can impact risk perception of common mining hazards, further emphasizing the importance of this required training (30 CFR § 46/48) regardless of previous mining experience. Trainers should ensure that all workers, regardless of mining experience be thoroughly briefed on the site-specific hazards at their site. Trainers can also teach a standardized risk assessment method and give workers the opportunity to practice using that method, both in the classroom and in the field (Grossman & Salas, 2011). To maximize the effectiveness of practice, trainer should also provide feedback on performance (Komaki, Heinzmann, & Lawson, 1980). Combined, these training strategies can be used to ensure that workers evaluating hazards similarly and, in turn, act upon them similarly.

Inexperienced workers rated risk lower

The laboratory risk assessment data demonstrated that the students' overall risk assessment level was significantly lower than those with more experience. The only aspect where the students were similar to mineworkers was the probability of the slip, trip, and fall risk of Hazard 2. It is likely that the students had a greater familiarity with this type of hazard as it is relevant to daily life. These results agree with the hazard recognition literature in that less experienced workers rate risk lower (Perlman et al., 2014). This finding reinforces the need for practical risk assessment training for new employees. A potential way to improve risk assessment knowledge and skill is through demonstration-based training, where workers can either observe the trainer or shadow a colleague (Rosen, Salas, Pavlas, Jensen, Fu & Lampton, 2010). This technique can be used to increase knowledge of worksite hazards and encourage discussion about the actual probability and severity of accidents.

Overall, mineworkers rated the hazards as less severe, less probable, and less risky than the safety professionals. Since a fully objective measure of risk does not exist, safety professionals were chosen as a reference point, as they are the people responsible for health and safety at mine sites. The lower risk assessment rating suggests that mineworkers may not recognize or understand the hazards and, therefore, be less inclined to take corrective action than the safety professionals. However, since the mining environment is constantly changing (Scharf et al., 2001), it is important that all mineworkers, not only understand the risk associated with their work environment, but are also actively engaged in their own safety. Therefore, training should focus on knowledge, skills, and abilities associated with risk and highlight why personal responsibility is critical for mineworker safety. In addition, previous research indicates that learning about hazards in the context in which they occur, e.g., location or work activity, improves hazard recognition ability (Kowalski-Trakofler & Barrett, 2003).

The training risk assessment data also supported the fact that mineworkers with little to no experience rate hazards lower. This was true for severity and overall risk, but not for probability. The ratings for severity and risk generally increase until 11–20 years of experience and then roughly plateau. However, contrary to previous findings (Hunter, 2002), experts' risk assessment level was not different from mineworkers in general. The lack of an expert effect may be related to the fact that the hazards examined here are general environmental hazards unrelated to one's skill at a particular task. Together, these findings reinforce that it is important to understand the context in which a hazard is assessed. As evidenced by the significance of the hazard, the hazard itself plays a role in how mineworkers rate it. A potential way to reinforce understanding is to provide workers with the hazards' context and then encourage discussion about possible outcomes. This could include talking about who may be exposed to the hazard, why the hazard occurred, and what steps should be taken to eliminate or mitigate the hazard (Rosen et al., 2010).

Experienced site workers rated severity lower and probability higher

Severity ratings decreased with an increase in site experience. The decrease in severity ratings may be related to hazard habituation and salience. As workers work at a location for a longer period of time, their perception of the severity of common hazards may attenuate (Zimolong & Elke, 2006). Additionally, as workers gain seniority they are often able to take less hazardous positions with less direct exposure to the outcomes of an accident. Being further removed from the outcome of a hazard makes the hazard less salient (Tversky & Kahneman, 1974), possibly explaining the reduction in severity ratings. The increase of probability could be explained similarly. As mineworkers are increasingly exposed to these hazards (both directly and indirectly), they tend to over-represent the probability (Weyman & Clarke, 2003), leading to the increase in probability assessment with site experience. To combat this effect, trainers can incorporate regular discussions about accident and injury data into toolbox talks or pre-shift safety meetings in order to ground probability and severity perceptions. Trainers can also remind mineworkers of the danger associated with critical hazards and that whether it is something you see all the time or do not see very often, it still has the potential to harm.

Contractors demonstrated the same effect, but in the opposite direction. The results showed that contractors, workers that typically work at one or more sites for a short period of time, rated the hazards as more severe and riskier than noncontractors. Contractors may be working around these common hazards more than other mineworkers and are disproportionally involved in accidents (MSHA, 2017), thus increasing the outcome salience (Weyman & Clarke, 2003) resulting in higher ratings. To ensure that contractors are knowledgeable of mine site hazards and understand the potential risks, trainers can provide contractors with site-specific hazard training that includes the standardized risk assessment process and risk mitigation practices that are used by employees at the mine site.

The interaction of mining and site experience may be similarly be explained by familiarity, but is unclear in this data. The significance of the interaction effects indicate that a more specific investigation into position and experience may be necessary. Experience effects have been shown to be context and exposure specific (Weyman & Clarke, 2003; Perlman et al., 2014; Ostberg, 1980). While general experience information can support trends on the whole, a more detailed exploration of specific hazard experiences, occupational duties, and organizational constructs is required.

Older workers rate probability and risk higher

Age appears to have had the most dominant effect on risk assessment, where probability and overall risk increased with age while severity remained constant. This result suggests that mineworkers have a consistent understanding of severity, but gain a better (more similar to safety professionals) understanding of the probability and overall risk as they age. Similar to students, it is possible that age is more dominant than mining or site experience because slip, trip, and fall hazards are common outside the mining setting, with falls on the same level (Hazard 2) being more translatable. The results of this study also suggest that older adults may be more sensitive to changes in experience. This may be attributed to increased morbidity and mortality of older adults (Fries, 1980) or the fact that older adults are more risk adverse (Sicard, et al., 2001). As one of the leading accident causes within the mining industry (Nasarwanji, 2016), slips, trips, and falls should remain a training focus. Again, it is important that trainers recognize differences in risk perception with age and standardize assessments to improve consistency.

CONCLUSIONS

In order to ensure consistent and effective risk assessment and mitigation practices, trainers should consider the following when developing and implementing training programs: emphasizing site-specific training regardless of previous experience and contractor status, highlighting personal responsibility, including specific examples of critical hazards such as slips, trips, and falls, presenting data to base severity and probability ratings of hazards, standardizing risk assessment to combat experience and age biases.

DISCLAIMER

The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of NIOSH. Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention.

REFERENCES

Basha, S.A. & Maiti, J. (2013). Relationships of demographic factors, job risk perception and work injury in a steel plant in India. *Safety Science*, *51*(1), 374–381.

Bellanca, J.L., Orr, T.J., Helfrich, W., Macdonald, B., Navoyski, J., & Eiter, B. (2017). Assessing hazard identification in surface stone mines in a virtual environment. In: Duffy V. (ed.) *Advances in Applied Digital Human Modeling and Simulation.* Advances in Intelligent Systems and Computing, vol. 481. Springer, Cham.

Brewer, N.T., Chapman, G.B., Gibbons, F.X., Gerrard, M., McCaul, K.D., & Weinstein, N.D. (2007). Meta-analysis of the relationship between risk perception and health behavior: the example of vaccination. *Health Psychology*, *26*(2), 136.

Brown, I.D., & Groeger, J.A. (1988). Risk perception and decision taking during the transition between novice and experienced driver status. *Ergonomics*, *31*(4), 585–597.

Carter, G., & Smith, S.D. (2006). Safety hazard identification on construction projects. *Journal of Construction Engineering and Management*, *132*(2), 197–205.

Deery, H.A. (1999). Hazard and risk perception among young novice drivers. *Journal of Safety Research*, *30*(4), 225–236.

Eiter, B.M., Bellanca, J.L., Helfrich, W., Orr, T.J., Hrica, J., Macdonald, B., & Navoyski, J. (2018). Recognizing mine site hazards: Identifying differences in hazard recognition ability for experienced and new mineworkers. In: Cassenti D. (ed.) *Advances in Human Factors in Simulation and Modeling.* AHFE 2017. Advances in Intelligent Systems and Computing, vol. 591. Springer, Cham.

Elander, J., West, R., & French, D. (1993). Behavioral correlates of individual differences in road-traffic crash risk: An examination of methods and findings. *Psychological bulletin*, *113*(2), 279.

Fries, J.F. (1980). Aging, natural death, and the compression of morbidity. *The New England Journal of Medicine*, *303*(3), 130–135.

Grossman, R., & Salas, E. (2011). The transfer of training: What really matters. *International Journal of Training and Development*, *15*, 103–120.

Haslam, R.A., Hide, S.A., Gibb, A.G., Gyi, D.E., Pavitt, T., Atkinson, S., & Duff, A.R. (2005). Contributing factors in construction accidents. *Applied Ergonomics*, 36(4), 401–415.

Hunter, D.R. (2002). Risk perception and risk tolerance in aircraft pilots (No. DOT/FAA/AM-02/17). Federal Aviation Administration, Washington DC Office of Aviation Medicine.

Hunter, D.R. (2006). Risk perception among general aviation pilots. *International Journal of Aviation Psychology*, 16(2), 135-144.

Hutton, R.J., & Klein, G. (1999). Expert decision making. *Systems Engineering: The Journal of The International Council on Systems Engineering*, *2*(1), 32–45.

Jonah, B.A. (1986). Accident risk and risk-taking behaviour among young drivers. *Accident Analysis & Prevention*, *18*(4), 255–271.

Joy, J. (2004). Occupational safety risk management in Australian mining. *Occupational medicine*, *54*(5), 311–315.

Khandan, M., Koohpaei, A., & Tabar, H. H. (2017). Chemical Risk Perception and Safety Behaviors as Key Factors toward Safer Chemical Industries-A Case Study in Iran. *Iranian Journal of Health, Safety and Environment*, *4*(4), 844–850.

Komaki, J., Heinzmann, A. T., & Lawson, L. (1980). Effect of training and feedback: Component analysis of a behavioral safety program. *Journal of Applied Psychology, 65*, 261-270.

Kowalski-Trakofler, K. M., Barrett, E. A. (2003). The concept of degraded images applied to hazard recognition training in mining for reduction of lost-time injuries. National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory, Pittsburgh, PA.

McKenna, F.P. (1993). It won't happen to me: Unrealistic optimism or illusion of control?. *British Journal of Psychology*, *84*(1), 39–50.

McWilliams, L.J., Lenart, P.J., Lancaster, J.L., & Zeiner, J.R. Jr. (2012). *National survey of the mining population. Part I: employees* (IC 9527). Pittsburgh, PA: National Institute for Occupational Safety and Health.

Merrifield, N.H. (2015). *Examination of working places (30 C.F.R. § 56/57.18002)* (P15-IV-01). Arlington, VA: Mine Safety and Health Administration.

MSHA. (2017). Overview of deaths in metal and nonmetal mining from October 2013 to December 2016. Mine Safety and Health Administration. Retrieved from http://MSHA.gov

MSHA. (2018). Examinations of Working Places in Metal and Nonmetal Mines: Final rule. *Federal Registrar*, 83(68), 15055–15065.

Nasarwanji, M.F. (2016). Contributing factors to slip, trip, and fall fatalities at surface coal and metal/nonmetal mines. In: *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 60(1), 1666–1670.

Östberg, O. (1980). Risk perception and work behaviour in forestry: Implications for accident prevention policy. *Accident Analysis & Prevention*, *12*(3), 189–200.

Perlman, A., Sacks, R., & Barak, R. (2014). Hazard recognition and risk perception in construction. *Safety Science*, *64*, 22–31.

Rosen, M.A., Salas, E., Pavlas, D., Jensen, R., Fu, d., & Lampton, D. (2010). Demonstration-based training: A review of instructional features. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 52(5), 596-609.

Rottenstreich, Y., & Hsee, C.K. (2001). Money, kisses, and electric shocks: On the affective psychology of risk. *Psychological Science*, *12*(3), 185–190.

Scharf, T., Vaught, C., Kidd, P., Steiner, L., Kowalski, K., Wiehagen, B., Rethi, L., & Cole, H. (2001). Toward a typology of dynamic and hazardous work environments. *Human and Ecological Risk Assessment*, *7*(7), 1827–1841.

Sicard, B., Jouve, E., Couderc, H., & Blin, O. (2001). Age and risk-taking in French naval crew. *Aviation, Space, and Environmental medicine*, *72*(1), 59–61.

Slovic, P. (1987). Perception of risk. *Science*, *236*(4799), 280–285.

Training and Retraining of Miners, 30 C.F.R. § 48 (2017).

Training and Retraining of Miners Engaged in Shell dredging or employed at sand, gravel, surface stone, surface clay, Colloidal Phosphate, or Surface Limestone Mines. 30 C.F.R. § 46 (1999).

Tversky, A., & Kahneman, D. (1974). Judgement under uncertainty: Heuristics and biases. *Science*, 185, 261–275.

Weyman, A.K. & Clarke, D.D. (2003). Investigating the influence of organizational role on perceptions of risk in deep coal mines. *Journal of Applied Psychology*, *88*(3), 404.

Zimolong, B. & Elke, G. (2006). Occupational health and safety management. *Handbook of Human Factors and Ergonomics*, 673–707.