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Health and Safety Outcomes of Active Learning-Based Mining Training Programs

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ABSTRACT

Objective: To evaluate the effectiveness of augmented training programs implemented at two surface and one underground metal mines.

Methods: Partner A implemented our Mine Safety and Health Administration (MSHA) New Miner and Annual Refresher training program and a hazards recognition card game. Partner B developed and deployed a warm-up exercise training program. Partner C used the same training program as Partner A, and an interactive computer game based on an underground coal mine fire scenario. For the pre- and post-intervention periods average quarterly injuries and days lost per 100,000 hours worked, data were obtained from the MSHA website and compared for each partner, mines controlled by the partners' companies (Companies A, B and C), and all other metal mines of the same type (excluding abandoned mines).

Results: Partner A reported decreases in average injuries (-6.3%) and days lost (-75.5%) per 100,000 hours worked, respectively, as compared to increases of 95.1% in injuries and 54.5% in days lost in Company A. Partner B reported decreases in average injuries (-39.8%) and days lost (-71.3%) per 100,000 hours worked, as compared to decreases of 18.6% in average injuries and 35.6% in days lost in Company B. Partner C reported decreases in average injuries (-38.4%) and days lost (-40.9%) per 100,000 hours worked, while Company C observed increases in both (28.1% and 1,814%, respectively).

Conclusion: Injury and days lost rates decreased following implementation of the partner-selected training interventions.

Keywords: training, safety, health, active learning, serious games

Funding: U60OH010014, National Institute for Occupational Safety and Health

Conflicts of interest: None

Code availability: Not applicable

INTRODUCTION

Despite great strides made in reducing mining injuries and illnesses, recent year-over-year decreases have slowed or even reversed. For example, mining lost-time injury rate (LTIR) and occupational illness incidence rate (OIIR) in 19 western states in United States declined markedly from 2000 through 2010 and to a lesser degree thereafter (see Figure 1). Occupational illness incidence rates at western mines increased during 2010-2015, and rates since 2018 have trended upward (MSHA, 2022). Interventions to further reduce mining injuries and illnesses are clearly needed.

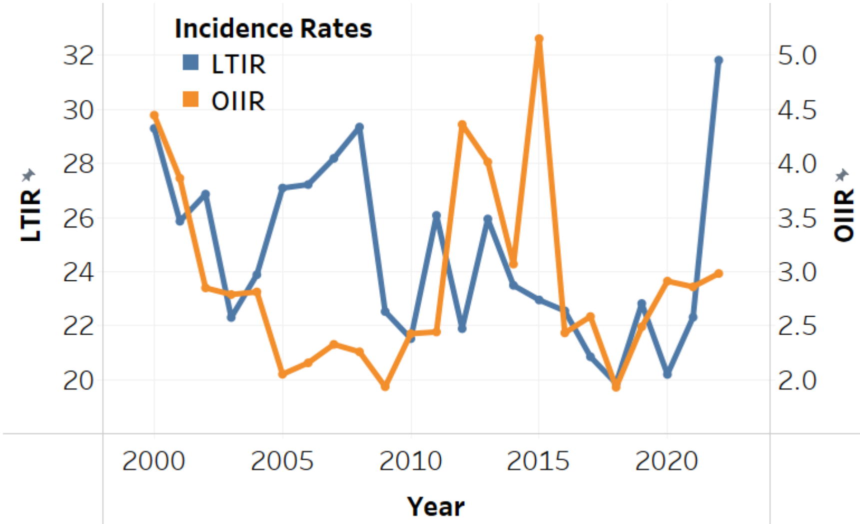

Figure 1. Lost-time incidence rate (LTIR) and Occupational illness incidence rate (OIIR) for mines in 19 states in the western US from 2000-2022, excluding abandoned mines.

Lack of effective safety and health training contributes to mining injuries and illnesses. Lack of training was a root cause or contributing factor to 40% of the 32 fatalities from 2021 for which a final report was available (MSHA, 2021). Obstacles may include lack of or ineffective training, training gaps regarding occupational illnesses, lack of training outcome evaluation, not addressing larger workforce issues, and lack of ideal mechanisms for aggregating and disseminating best practices and outcomes across mining sectors. National Institute for Occupational Safety and Health (NIOSH) surveillance data (McWilliams et al, 2012) showed that most trainers were using lecture-based training materials, which have been shown to be less effective for adult learners (Armbruster et al., 2017). The National Safety Council (NSC, 2018) reported that in 2017, 92% of safety trainers used instructor-led classroom training and those top challenges were covering a large amount of material in a short time, keeping workers engaged, overcoming complacency, balancing production and safety training, getting management to do more than compliance, keeping materials fresh, and meeting needs of younger generations and English-as-a-second-language (ESL) learners. For MSHA Part 46 and Part 48 training requirements, miners need to know how to recognize hazards and safely perform a task. Competency-based training, which includes hazard recognition and safe working knowledge, is a method of instructional design and delivery that aligns training objectives and content to an individual’s job roles and responsibilities. A major challenge to improve safety is moving companies away from a compliance-based approach, which focuses on seat time in the classroom and once-per-year training, to a competency and outcomes-centered approach that focuses on continuous improvement and constant reinforcement.

Measurement of training effectiveness is a major gap in improving mining safety and health. Most research to date on training effectiveness has lacked in-depth study of training practices and their interrelationship with other elements in the organization’s health programs (Cohen & Colligan, 1998). Properly designed, systems-level evaluation methods are key to assessing miner competency, yet impact level evaluation is often lacking in training programs. Evaluation of corporate training has shown that 94% of training programs remain at level 1 in Kirkpatrick's four-level evaluation framework (Kirkpatrick, 1994; Rossett, 2010). Learning, if measured at all, is often assessed using simple instruments, such as confidence surveys, multiple-choice tests, or job task analyses (JTAs) conducted under sterile observational circumstances. Such approaches are unable to adequately evaluate learner capability because they do not evoke flow state (Gee, 2003; Lieberman, 2006) and lack reality-based context (Brown & Poulton, 2019; Cannon-Bowers & Bowers, 2009). Improved training effectiveness metrics, including measurement of health outcomes (e.g., injuries and illnesses) are critical to comparing training tools and programs.

Since 2010, the University of Arizona Western Mine Safety and Health Training Resource Center (TRC) has been working in partnership with the mining industry to deploy a continuum of competency-based active learning resources that enhance the capabilities of trainers across the mining industry in western states (add our website). The training resources include digital and paper-based active learning exercises to computer-based serious games, as well as sharing of effective industry generated programs. The TRC is also developing systems-level frameworks to evaluate training at the level of results. The focus of this work is on three resource types: active-learning exercises; tabletop and computer-based serious games, implemented by select TRC partners; and programs developed separately by industry that have demonstrated efficacy. The TRC is currently in the process of developing 'learning laboratories' in partnership with industry to further develop and evaluate the effectiveness of training products. An important part of the learning laboratories is also to share effective injury prevention programs. The objective of this study was to evaluate the effectiveness of unique training resources implemented at three different TRC partners using workplace safety outcomes.

METHODS

Partner A: Partner A is a large surface metal mine. During the summer of 2018 TRC personnel met with Partner A's mine safety and health trainers to conduct a training needs assessment, as well as describe and demonstrate the TRC's available safety training resources. The mine site opted to incorporate the TRC's MSHA New Miner and Annual Refresher Training Program Guide (TPG) and the Very Good Day (VGD) card game into the site's MSHA New Miner and Annual Refresher trainings. For each adopted resource, Partner A's mine safety and health trainers were enrolled in and completed a comprehensive train-the-trainer workshop which lasted one month and consisted of three days of on-site training and several days of virtual training and follow-up. This workshop is a condensed version of our Higher-Level Training Clinic, which addresses four key issues that derive from established theories of adult learning: 1) Competency-based instructional design, 2) Active learning techniques, 3) Assessment of training transfer, and 4) Coordinated strategies for engaging English Language learners. In the workshop, trainers apply a competency-based learning approach aimed at increasing their skills for instructional design and delivery. Theory is translated to practice through activity design exercises and ready-to-use examples that were compiled from the Center's many active learning resources, including guides, tabletop activities, and serious games. Additional information is available at [REDACTED].

<u>Training Resources</u>: The TPG encompasses all required topics for MSHA 30 CFR Part 48 New Miner and Annual Refresher training. The TPG includes Trainer (466 pages) and Student (171 pages) Handbooks, as well as digital modules, templates and a suite of active learning exercises that provide a standardized yet flexible framework around which trainers can build their training to suit their organization's training needs. Examples of some active learning exercises include a group communication activity, group discussions, create-a-quiz exercises, haul-truck-blind-spot and silicosis-straw activities, etc. The guide also provides knowledge checks and quizzes for evaluation and group discussion.

The VGD card game was developed to augment higher-order thinking skills for hazard mitigation. The game uses a three-way matching game mechanic that incentives competitive play during which players think critically to control safety and health hazards found in all mining sectors (see Figure 2 below). Players are assigned supervisory roles over specific areas of a fictional mine and, as they encounter hazards on their turn, must attempt to select and describe the most effective control for the hazard. Players' scores are based on the nature of the hazard and effectiveness of the proposed control. At the end of the game their score represents their performance on a safety index, with higher scores indicating increased competency. The average VGD game session lasted 50 minutes. The TPG and associated active learning exercises, as well as the VGD card game, were used to train 1,244 learners over 20 Annual Refresher and New Miner training sessions.

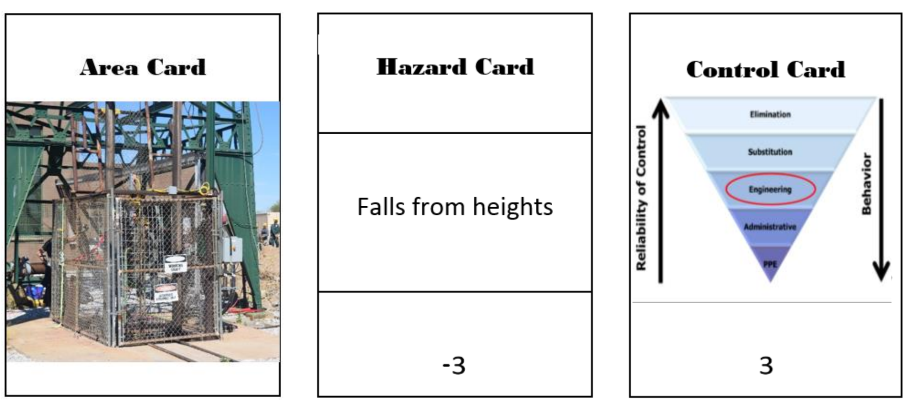

Figure 2. Sample playing cards from the *Very Good Day* card game, including Area Card (*left*), Hazard Card (*center*), and Control Card (*right*). Note safety index scores listed at bottom of cards.

Partner B: The second partner (Partner B) was a mineral processing department at a medium surface metal mine. In mid-2017 Partner B implemented a warm-up exercise program that was developed in-house with the aim to better prevent injuries by increasing workers' blood flow and muscle temperature. After initial training, supervisors facilitated their crew's sessions before work and during breaks. Each training session lasted approximately 15 minutes.

Training Program: The warm-up program consisted of a poster with visualizations of each exercise, an instructor observation checklist, and user guide. The program's 11 exercises included ankle rotations, arm circles, arm raises and crosses, back and side stretches, calf raises, hip circles, knee circles, neck tilts, shoulder shrugs, and squats. Posters were placed in line-out areas and break rooms. Front-line supervisors received train-the-trainer training and were periodically evaluated using the instructor observation checklist. Initially, a single site (Partner B) piloted and then fully implemented the warm-up program. Later, other Company B sites adopted the program at differing times.

Partner C: The third partner (Partner C) was a medium underground metal mine. In early 2019 Partner C opted to use and implemented our TPG (see description above) and Harry's Hard Choices computer-based game for New Miner and Annual Refresher training. For each adopted resource, Partner C's mine safety and health trainers were enrolled in and completed a comprehensive three-day train-the-trainer workshop.

Training Resources: Harry's Hard Choices (HHC) is an engaging, story-driven serious game that is set in a mine disaster and features training for many MSHA required topics, including hazards recognition, communications, mine gases, and miner health. Players take control of an underground coal mine supervisor and, faced with an emergency mine fire, must make critical decisions to get their crew out safely while balancing morale, health, and safety. The average game session lasts approximately 45 minutes.

Data Analysis: Publicly available data were retrieved from MSHA's Open Government Initiative Portal (MSHA 2022), including the Accident Injuries, Employment/Production, and Mines data sets. Datasets were cleaned, filtered, and joined using Tableau Prep Builder (2020.1; Tableau Software; Mountain View, CA), figures were prepared using Tableau Desktop (2020.2, Tableau Software; Mountain View, CA), and statistical analyses were conducted using IBM SPSS Statistics (26.0; International Business Machines Corp.; Armonk, NY). The quarterly rate of injuries and days lost per 100,000 hours worked were computed and compared between pre- and post-intervention for each partner, other sites operated by the same company, and all other surface (Partners A and B) and underground (Partner C) metal mines (excluding abandoned mines and those with zero pre-intervention measures). Because Partner B's warm-up program was implemented for Tankhouse employees only, its analysis included the subunit 'Mill Operation/Preparation Plant' only. Rank order differences were tested using the one sample sign rank test and an alpha error threshold of 0.05.

The pre- to post-intervention periods for Partners A, B and C were Q1 2017 to Q3 2018 and Q4 2018 to Q2 2020 (seven quarters each), Q3 2014 to Q2 2017 and Q3 2017 to Q2 2020 (12 quarters each), and Q1 2018 to Q1 2019 and Q2 2019 to Q2 2020 (five quarters each), respectively.

RESULTS

Partner A: From Q4 2018 to Q2 2020 Partner A trained 1,244 learners, an undetermined number of which were repeat learners, using TRC resources.

From the pre- to post-intervention period, Partner A reported a decrease of 1.12 to 1.05 (-6.3%) average injuries and 30.2 to 7.4 (-75.5%) average days lost per 100,000 hours worked. Company A's other mines observed increases of 95.1% (1.44 to 2.81) in injuries and 54.5% (19.4 to 30.0) in days lost per 100,000 hours worked from pre- to post-intervention. A decrease from 4.17 to 2.82 (-32.4%) injuries and 49.8 to 23.7 (-52.4%) days lost per 100,000 hours worked was reported by surface metal mines. See Table 1 and Figure 3 for a summary of findings regarding average injury and days lost rates.

Table 1. Average injuries and days lost per 100,000 hours worked for the Partner A mine, three other Company A-controlled mines, and all other surface metal mines (n=62; excluding abandoned mines). The 'Pre'-intervention period includes Q1 2017 to Q3 2018. 'Post'-intervention period includes Q4 2018 to Q2 2020.

Measure	**Partner A**		**Company A**		**Surface Metal**	
	Injuries	Days Lost	Injuries	Days Lost	Injuries	Days Lost
Pre-Intervention	1.12	30.2	1.44	19.4	4.17	49.8
Post-Intervention	1.05	7.4	2.81	30.0	2.82	23.7
One sample sign rank (p-value)	--	--	0.50	0.50	0.823	0.534

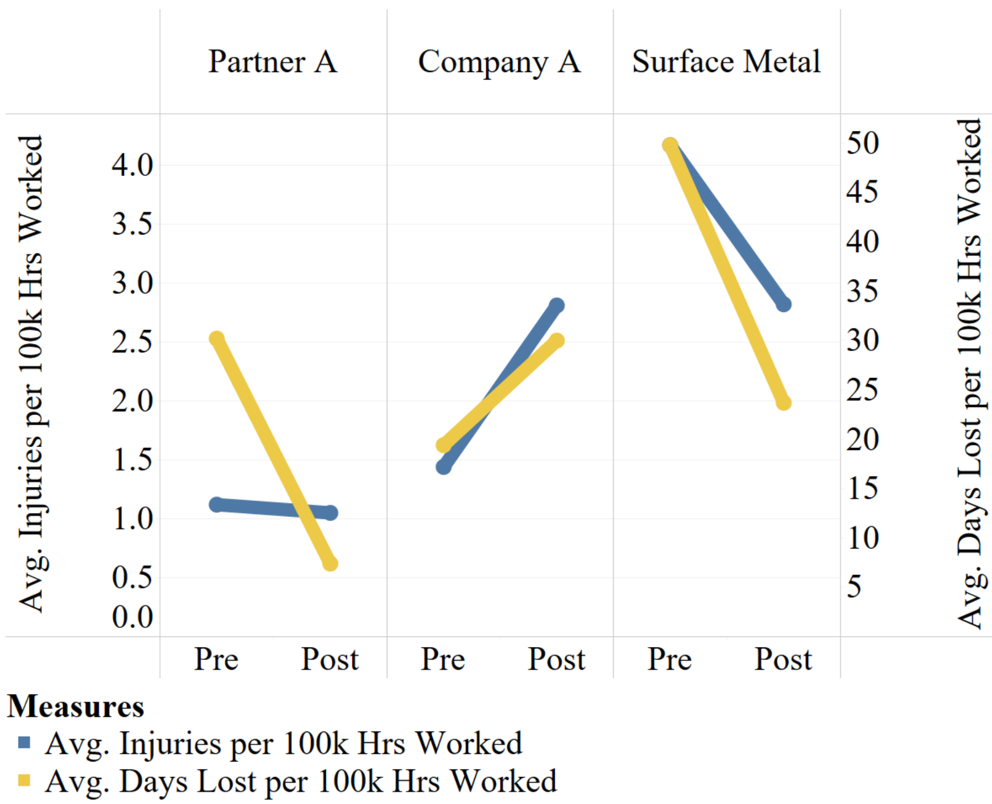

Figure 3. Average injuries and days lost per 100,000 hours worked for the Partner A mine, three other Company A-controlled mines, and all other surface metal mines (n=62; excluding abandoned mines). The 'Pre'-intervention period includes Q1 2017 to Q3 2018. 'Post'-intervention period includes Q4 2018 to Q2 2020.

Partner B: Preliminary outcomes reported by Partner B demonstrated year-over-year (2017 to 2018) decreases of 85.7% (seven to one), 100% (one to none) and 50% (four to two) in first aid, medical treatment and lost time injuries, respectively.

From the pre- to post-intervention period, Partner B reported decreases of 2.49 to 1.50 (-39.8%) average injuries and 70.3 to 20.2 (-71.3%) average days lost per 100,000 hours worked. Company B's other mines observed decreases of 18.6% (2.31 to 1.88) in average injuries and 35.6% (62.4 to 40.2) in average days lost per 100,000 hours worked from pre- to post-intervention. A decrease from 8.58 to 4.66 (-45.7%) in average injuries and increase of 60.4 to 89.4 (48.0%) average days lost per 100,000 hours worked was reported by surface metal mines. See Table 2 and Figure 4 below for a summary of findings regarding average injury rate.

Table 2. Average injuries and days lost per 100,000 hours worked for the Partner B vs seven other Company B-controlled mines and all other surface metal mines (n=69; excluding abandoned mines, subunit 'Mill Operation/Preparation Plant' only). 'Pre'-intervention period includes 2012 to 2017. 'Post'-intervention period includes 2018 to Q1 2020.

Measure	**Partner B**		**Company B**		**Surface Metal**	
	Injuries	Days Lost	Injuries	Days Lost	Injuries	Days Lost
Pre-Intervention	2.49	70.3	2.31	62.4	8.58	60.4
Post-Intervention	1.50	20.2	1.88	40.2	4.66	89.4
One sample sign rank (p-value)	--	--	0.75	0.75	0.276	0.364

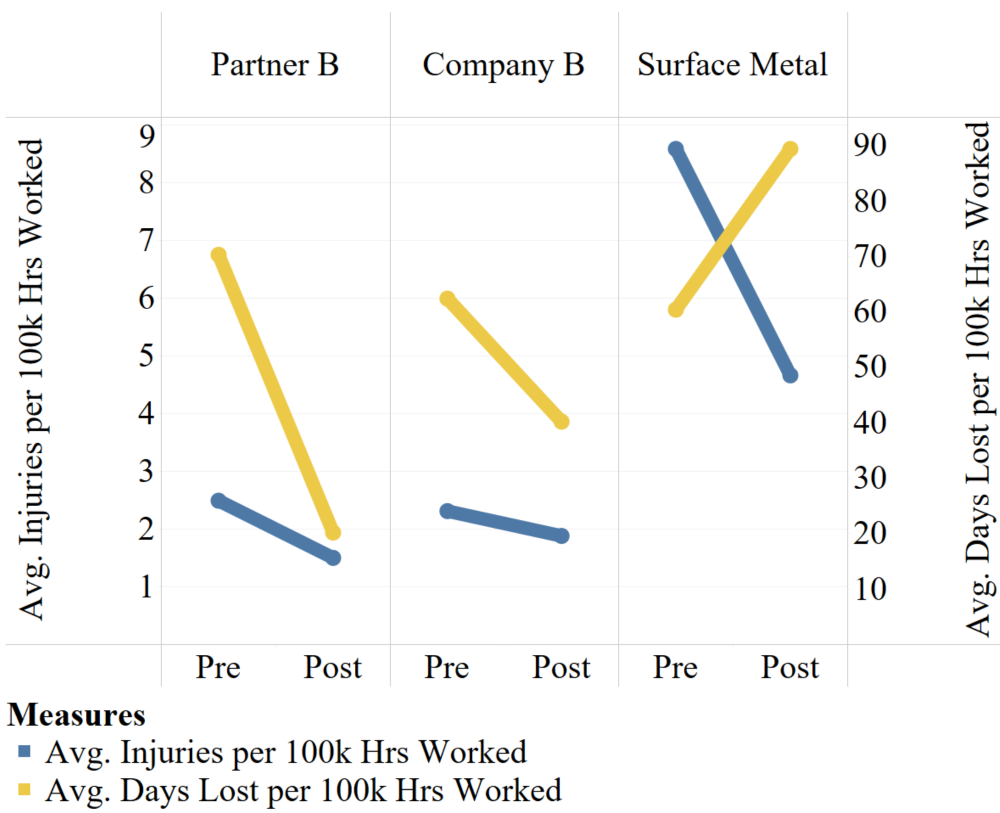

Figure 4. Average injuries per 100,000 hours worked for Partner B vs seven Company B-controlled mines and Surface Metal mines (n=65; excluding abandoned mines, including subunit 'Mill Operation/Preparation Plant' only). 'Pre'-intervention period includes Q3 2014 to Q2 2017. 'Post'-intervention period includes Q3 2017 to Q2 2020.

Partner C: From the pre- to post-intervention period, Partner C reported increases of 1.59 to 0.98 (38.4%) average injuries and 10.0 to 5.92 (40.9%) average days lost per 100,000 hours worked. Company C's other mines observed increases of 28.1% (0.81 to 1.05) in average injuries and 1814% (2.92 to 55.9) in average days lost per 100,000 hours worked from pre- to post-intervention. An increase from 6.23 to 6.48 (4.0%) in average injuries and decrease from 255.6 to 18.6 (92.7%) average days lost per 100,000 hours worked was reported by underground metal mines. See Table 3 and Figure 5 below for a summary of findings regarding average injury rate.

Table 3. Average injuries and days lost per 100,000 hours worked for the Partner C vs two other Company C-controlled mines and all other underground metal mines (n=37; excluding abandoned mines). 'Pre'-intervention period includes Q1 2018 to Q1 2019. 'Post'-intervention period includes Q2 2019 to Q2 2020.

Measure	**Partner C**		**Company C**		**Underground Metal**	
	Injuries	Days Lost	Injuries	Days Lost	Injuries	Days Lost
Pre-Intervention	1.59	10.0	0.82	2.92	6.23	255.6
Post-Intervention	0.98	5.92	1.05	55.9	6.48	18.6
One sample sign rank (p-value)	--	--	0.999	0.667	0.474	0.586

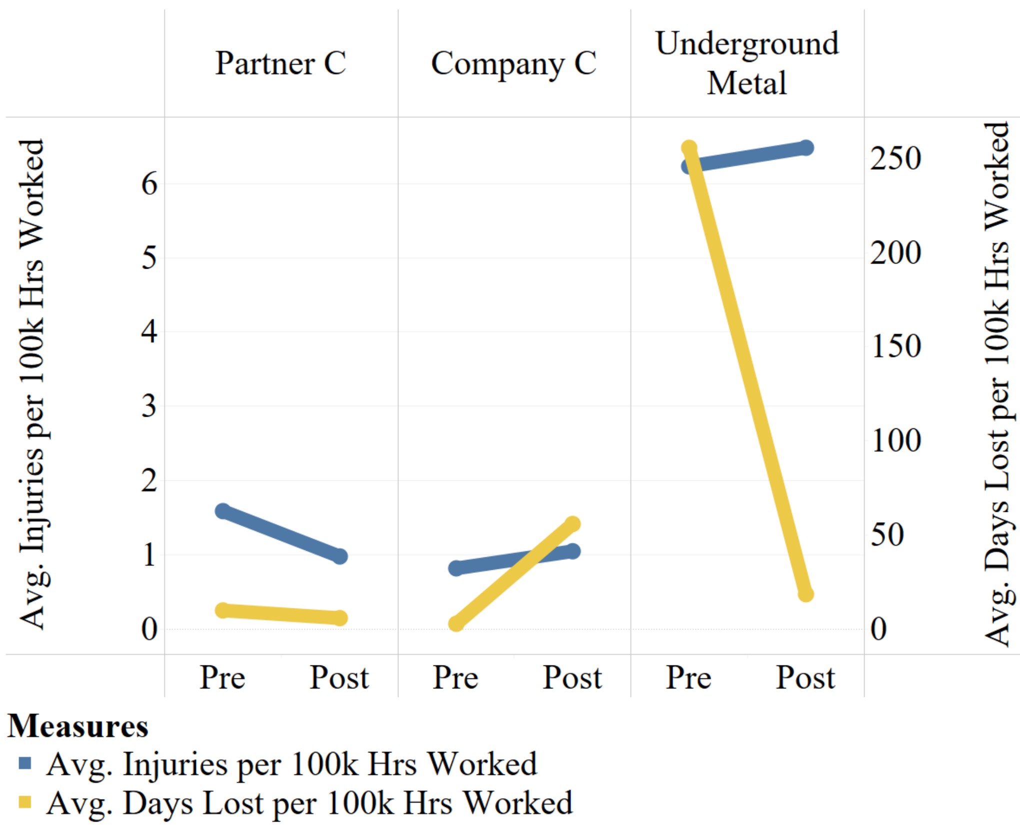

Figure 5. Average injuries and days lost per 100,000 hours worked for the Partner C vs two other Company C-controlled mines and all other underground metal mines (n=37; excluding abandoned mines). 'Pre'-intervention period includes Q1 2018 to Q1 2019. 'Post'-intervention period includes Q2 2019 to Q2 2020.

Comparisons: Compared to Company B, Partner B saw the smallest improvement in pre-post change for injuries at (-21.1%) and days lost (-35.7%) per 100,000 hours worked. Partner A observed consistent improvements compared to Company A in injury (-101.4%) and days lost (-130.1%) rates. Partner C outperformed Company C's performance for injuries (-66.4%) and days lost (-1855%) per 100,000 hours worked. On average, our partners' pre-intervention injury (9.0%) and days lost (39.3%) rates were higher than the other sites of the same company. Surface metal mines outperformed Partners A (26.1%) and B (5.1%) on injury rate, but each partner outperformed the industry in terms of days lost rate (-23.1% and -119.3%, respectively). Partner C outperformed underground metal mines in terms of injury rate (-42.4%) but observed a relatively smaller reduction for days lost (51.9%) rate. On average, our partners' pre-intervention injury (-270%) and days lost (-836%) rates were lower than other mines of similar type.

DISCUSSION

Training has long been recognized as an important intervention for mine operators' approach to managing and mitigating safety and health risks (Vaught et al, 2008). The current work observed that, for each metric evaluated, our partners outperformed other sites from the same company from the pre- to post-intervention period. Results were mixed for comparisons with the broader industry, where our partners were outperformed in two of six instances. However, the large differences between pre-intervention positions in some instances makes a meaningful comparison between our partners and the broader industry more difficult.

Our partners observed greater decreases in days lost per 100,000 hours worked in five of six instances. We believe that more effective safety and health training has tremendous potential for preventing the most serious injuries, such as those that lead to days lost. An interrupted time-series analysis evaluating the effect of MSHA training regulations introduced in 1999 showed a marked decrease (risk rate = 0.591, 95% confidence interval = 0.529, 0.661) in permanently disabling injuries, while medical treatment, restricted duty and lost-time injuries were consistent with temporal trends (Monforton and Windsor, 2010).

Mining Safety and Health Training: Training and education continue to be a major component of MSHA's approach to mine safety and health. Mining companies are required to develop and implement MSHA-approved safety and health training plans (30 CFR parts 46 and 48). New or inexperienced miners must receive 24 (surface) or 40 (underground) hours of training on specific topics, including miners' rights, self-rescue and respiratory devices, transportation and communication systems, introduction to the work environment, mine tour, escape and emergency plans, hazard recognition, ground control, electrical hazards, explosives, first aid, health and safety aspects of the assigned job, mine map (30 CFR part 48 only), mine gases (underground only), ventilation (underground only), and cleanup and rock dusting (underground coal only). Experienced miners must receive training on these topics for at least eight hours, upon initial hire or return from absence. The Annual Refresher training is provided for all miners and contains many of these topics in at least eight hours of training (30 CFR parts 46 and 48). In addition, the research agenda released by the National Occupational Research Agenda's Mining Sector Council (2015), which establishes objectives related to emerging issues in mine safety and health, identifies its fifth objective as to 'Improve Health and Safety Through Behavioral Research', where most sub-objectives address training.

NIOSH continues to dedicate substantial effort to the investigation of safety and health training effectiveness (Kowalski, et al., 2001; Peters, 2002; Peters, Vaught, and Mallett, 2008). Much of the research conducted by NIOSH and others demonstrates that, when done properly, safety and health training can lead to practically and statistically significant improvements in safety and health outcomes. One mine in Alabama worked with NIOSH to develop a specialized hazard recognition program, which was associated with a decline in lost-time injuries soon after it was implemented (Kowalski-Trakofler and Barrett, 2003). Haul truck operators who were enrolled in a self-management training demonstrated significantly more safety-related behaviors than before the intervention (Hickman and Geller, 2003). In a study conducted by NIOSH, an experimental group received initial and regular supplementary training and practice using a self-contained self-rescuer (SCSR), while the control group received only the initial training (Vaught et al, 1993). After nine months no miners in the control group could proficiently don his or her SCSR, while 65% of the experimental group could perform the procedure without error.

Occupational Safety and Health Training: Outside of mining, effective safety and health training has also demonstrated substantial reductions in negative safety and health outcomes. Occupational training that includes active learning methods, worker participation and problem-solving exercises has proven promising (Becker & Morawetz, 2004; Cole & Brown, 1996; Luskin et al., 1992; Thomas et al., 1994). Active learning methods have demonstrated superior effectiveness for learning over passive methods (Caparaz et al., 1990; Cohen and Colligan, 1998; Prince, 2004; Armbruster et al., 2017). A meta-analysis of 113 primary studies found highly engaging safety training methods were considerably more effective in both knowledge acquisition and safety performance (Burke et al, 2011). Knowledge transfer rates can reach as high as 90% via experiential learning, whereas retention rates associated with passive learning methods are below 30% (Dale, 1969).

Improved vehicle driver training in the fire service was associated with 50% and 19% reductions in emergency services vehicle crashes in Sacramento and Seattle, respectively (Bui et al, 2018). Lift truck operators who received multi-modal safety training and performance feedback reduced their error rates by 23%, compared with 18% for the training-only and 6% for the control groups (Cohen and Jensen, 1984). The training group at an auto manufacturer in Alabama received safety training, feedback and goal setting and observed a significant 18% increase in safety performance (Ray, Bishop and Wang, 1995). Student nurses in an experimental training group that received supplementary training with lectures and demonstration scored significantly better in both knowledge and behavior and experienced significantly fewer needle sticks (OR 0.29; 95% CI 0.11, 0.74) four months after the training, compared to the control group (Wang et al, 2003).

The training products selected and developed by our partners include active learning methods, serious games, and a warm-up exercise program. Injury reductions observed in our study are consistent with the improvements in knowledge acquisition and safety performance found in other research using active learning methods (Caparaz et al., 1990; Cohen and Colligan, 1998; Prince, 2004). Undergraduate students in an introductory biology course were assigned to an experimental group and instructed using a redesigned program that included, among other things, active learning and group problem solving exercises (Armbruster et al., 2009). These students' scores were significantly higher, on identical exams, than those of the control group (*Ibid*). One meta-analysis of 95 studies, representing a sample of 20,991 data points, observed that those safety training programs that were highly engaging (behavioral modeling, simulation, and hands-on training) were approximately three times more effective at promoting knowledge and skill acquisition than the least (lectures, films, and video-based training) engaging (Burke et al., 2006).

Serious games have been shown to engage and motivate learners in a way that is difficult or impossible for passive learning methods to duplicate (Gee, 2004). They also allow trainers to evaluate competency with built-in achievements, and measure performance at higher levels of Bloom's Taxonomy (Bloom, 1956). A competency can be a specific skill, trait, or attribute; a competency-based approach to training facilitates goal setting, feedback that reinforces learning, and its transfer to the job site. In addition to supporting reductions in work-related injury and illness (Okun et al., 2016), competency-based training can drive changes to organizational practice and help cultural administrative changes (Cohen & Colligan, 1998).

Tabletop card games have demonstrated their versatility, flexibility, and efficacy in improving knowledge retention and conceptual competency, including topics such as medicine (Steinman and Blastos, 2002). In one study, undergraduate students were assigned to an experimental and control group, where the experimental group received traditional biology instruction and played a related card game, while the control group simply received the traditional instruction (Gutierrez, 2014). The pre- to post-test improvement of the experimental group was significantly (37.3%) better than that of the control group (*Ibid)*. In another example, one hundred and seventy-one high school students were divided into experimental and control groups, with the experimental group using a combat card game to learn about immunology and the control group received traditional methods (Su, Cheng and Lin; 2014). The experimental group significantly outperformed the control group based on an qualitative assessment of knowledge (*Ibid*).

Although calisthenics has been a staple of occupational health programs for many years (Black, Freeman, Stevens, 2002), their use as a health and safety intervention has provided mixed results (Bazett-Jones, Gibson, McBride, 2008; Herbert & Gabriel, 2002; LaRoche, Lussier, & Roy, 2008; Pope et al, 2000; Shrier, 1999; Thacker et al., 2004; Witvrouw et al., 2004). A combination of warm-up exercises and stretching prior to exercise, similar to our partner's program, have shown promise for improved outcomes (Ce, et al., 2008; Woods, Bishop, Jones, 2007). Da Costa and Vieira suggest that a number of limitations have hampered previous studies, including a lack of control group, carryover effects, and confounding factors, among others (2008). In one NIOSH study, a "flex-and-stretch" program implemented at an underground coal mine in Illinois, with no other changes to the current safety program, was associated with a 27.1% decrease in lost-time injury rate (Kowalski-Trakofler and Barrett, 2003). This study, however, was also limited by the lack of control group, or controlling for intra-site confounders.

Strengths: This study utilized the Pretest-Posttest-Control (PPC) study design, which can still provide useful estimates of training efficacy even when randomization is not feasible (Cook & Campbell, 1979). The PPC study design combined with a randomized controlled trial (RCT) allows the research to control for pre-existing conditions between groups (Cook & Campbell, 1979; Morris & DeShon, 2002). When repeated measures are taken it allows the groups to serve as their own controls, increasing statistical power and precision (Hunter & Schmidt, 2004). By applying the PPC-RCT study design within the same organization, investigators can also control for confounding factors that are unrelated to the training intervention (Morris, 2008). These advantages make the study design an excellent tool for evaluating occupational safety and health programs (Goldstein & Ford, 2002; Quinones and Tonidandel, 2003; Robson et al., 2001). Future research will utilize the PPC-RCT study design and assess both leading and lagging indicators of safety and health to determine whether and to what extend our training resources and programs are effective.

Limitations: The present study did not randomly assign sites, departments, or crews to training or comparison groups, making it quasi-experimental at best. Likewise, we did not compare intra-mine intervention and control groups, limiting our ability to control for other training, non-training and other confounding factors that likely influenced safety. In only one instance did our partner's pre-intervention metric begin within 10% of the parent company's sites or other mines of similar type, based on the defined pre- and post-interventions periods. Also, in only one instance was a partner's pre-intervention metric greater than that of mines of similar type. The data used represent lagging indicators of safety only and are of low granularity, limiting the study's sample sizes. Low data granularity also hampered our ability to limit Partner B's training program comparison to tankhouse workers only. The effect of some Company B sites adopting Partner B's warm-up program at differing times during the post-intervention period was not controlled.

Conclusion: All three of our partners experienced reductions in injury and days lost rate during the study period that substantially exceeded industry averages in four of six cases. For each partner, their site experienced greater declines in days lost and injury rates compared to other sites in same company, in all six comparisons. Average reductions in days lost exceeded 60% across all operators using our training programs – a favorable outcome versus the sector-wide trend, which showed only a marginal reduction of 3.6% over the same period. The large reductions in days lost suggest a decline in serious injuries, which are the types addressed by our training resources.

We believe that improvements to both people (i.e., training, among other things) and systems will be necessary to achieve zero harm, particularly as the mining industry nears that objective. A continuum of competency-based training that employs a variety of active-learning techniques is an important catalyst for continuously improving culture change.

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