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What do we know about the effectiveness of mine health and safety interventions?

Mining is a potentially dangerous occupation with hazards and risks that can lead to injuries, illnesses, and death. To ensure the safety of the miners and the mine sites, the mining industry is regulated by government agencies, including the Mine Safety and Health Administration (MSHA) at the U.S. Department of Labor. These agencies develop safety regulations and conduct inspections to enforce the regulations, administering sanctions and penalties for violations. Workplace safety is also promoted through outreach, education, and training.

CLEAR conducted a systematic evidence review that examined the impacts of interventions on mine worker and mine workplace health and safety.[1] This synthesis brief presents a summary of the evidence from the studies identified in the review that received a high or moderate causal evidence rating. This rating means that we have a good degree of confidence that the impacts reported in these studies are attributable to the interventions examined.[2] It also includes the findings from studies that received a low causal evidence rating as these studies may provide valuable information; however, a low rating means that CLEAR is not confident that the estimated effects are attributable solely to the intervention, and other factors are likely to have contributed.

About the mine workers and mine health and safety topic area

CLEAR's mine workers and mine health and safety topic area focuses on interventions designed to reduce or prevent mine worker injury, illness, disability, exposure to hazards and death, as well as the reduction or prevention of environmental hazards in the mines. It includes interventions implemented in the United States, Australia, Canada, Poland, South Africa, and Sweden.[3] Based on geographical and other criteria described in the review protocol, CLEAR identified 13 reports published from January 2008 to April 2019 that were eligible for review.[4] Within these reports, there were 15 distinct studies, with nine of the studies receiving a high or moderate causal evidence rating.[5]

Additionally, CLEAR created an annotated bibliography that included 17 studies of interventions that were designed to improve overall mine safety and prevent fatalities and illnesses among mine workers, but that could not be evaluated according to CLEAR's Causal Evidence Guidelines due to the study designs.[6] These studies may offer other useful contributions to the evidence base.

Overview

The interventions examined in the studies fell into four categories (Table 1).

[1] For more information on CLEAR, including how CLEAR conducts systematic reviews, see https://clear.dol.gov/.
[2] See the CLEAR Causal Evidence Guidelines for information on the evidence guidelines used to determine the causal evidence ratings (https://clear.dol.gov/about).
[3] The countries were identified in collaboration with MSHA as being similar to the United States in the scope of industry, technological advancements, and safety practices.
[4] See the CLEAR Mine Workers and Mine Health and Safety Review Protocol (https://clear.dol.gov/reference-documents/review-protocol-mine-workers-and-mine-health-and-safety) to learn more about the literature search parameters and the specific criteria used to determine which studies were eligible for inclusion in the systematic review.
[5] The number of studies is not the same as the number of reports because findings from multiple studies may be presented in a single report (for example, one report included three laboratory experiments).
[6] See the Mine Workers and Mine Health and Safety Annotated Bibliography for detailed information about the studies (https://clear.dol.gov/sites/default/files/Mine_Annotated_Bibliography_508%20compliant.pdf).

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Table 1. Types of mine health and safety interventions

Intervention	Features
Engineering controls	Engineering controls are physical manipulations of the sources of the hazard or the manner of exposure to the hazard.[7] Examples include atmospheric monitoring, explosion suppression, fire warning and fire suppression, ground control, hearing protection, proximity detection systems, and respiratory devices.
Safety regulations	Government agencies develop safety regulations to keep workers safe and healthy. Regulations may include directives for mine operations and exposure regulations (e.g., maximum noise levels).
Enforcement activities	Government agencies conduct inspections to enforce the established regulations and administer sanctions and penalties for violations of safety standards.
Training	Workplace safety is promoted through education and training. Training includes both classroom-based and on-the-job training.

As summarized in Table 2, the most frequently evaluated interventions were engineering controls (8 out of 15 studies). The majority of interventions (13 out of 15 studies) found favorable impacts on health and safety outcomes. ***More than half of the studies that found favorable impacts received a high or moderate causal evidence rating.*** These high- or moderate-rated studies provide credible, quality evidence of promising interventions to reduce injury and enhance safety practices.[8]

Table 2. Overview of the evidence base

Intervention	Total number of studies (n=15)	Studies rated high or moderate	Favorable impacts [a]	No Impacts [b]	Mixed Impacts [c]
Engineering controls	**8**	**6**	**7(5)**	**-**	**1(1)**
Safety regulations	**2**	**1**	**1**	**1(1)**	**-**
Enforcement activities	**2**	**2**	**2(2)**	**-**	**-**
Training	**3**	**0**	**3**	**-**	**-**

Key: [a] Indicates the number of studies that found at least one favorable impact in the outcome domain. These studies had at least one statistically significant favorable impact and no statistically significant unfavorable impacts.
[b] Indicates the number of studies that found no statistically significant impacts in the outcome domain.
[c] Indicates the number of studies with mixed impacts in the outcome domain. These studies had some statistically significant favorable and some statistically significant unfavorable impacts.

Note: The number in parentheses indicates the number of studies that received a high or moderate causal evidence rating.

▶ **Studies receiving a low causal evidence rating provide valuable information about the intervention.** Causal evidence ratings are based on the quality of the study, not the intervention. A low rating does not mean that the intervention was ineffective or had unfavorable outcomes. Low-rated studies often reflect the most rigorous methods authors could use given the circumstances. Six studies received a low causal evidence rating based on their study design, but all found favorable impacts on health and safety outcomes. When interpreting the findings from low-rated studies, we cannot attribute the findings solely to the intervention as other factors are likely to have contributed to the observed outcomes.

Table 3 at the end of this brief summarizes all studies included in the review with information about the intervention, study design, rating and impact(s), with links to profiles that summarize each study on the CLEAR website.

▶ **Engineering controls prevented injuries or improved safety practices that could prevent injuries.** All but one high-rated study examining engineering controls found favorable health and safety outcomes. The studies found that engineering controls increased steering accuracy of underground coal mine shuttle cars (Burgess-Limerick et al., 2013), improved detection speed for continuous mining machine movements (Sammarco et al., 2012), reduced operator errors while using roof-bolting machines

[7] Kowalski-Trakofler, K. M., Vaught, C., McWilliams, L. J., & Reisman, D. R. (2011). Psychological and behavioral aspects of occupational safety and health in the US coal mining industry. In R. J. Burke, S. Clarke, & C. L. Cooper (Eds.), *Occupational health and safety* (pp. 197-214). Gower Publishing, Ltd.
[8] For more details on these studies, please see Table 3 in this synthesis.

(Steiner & Burgess-Limerick, 2013; Steiner et al., 2014), and reduced whole body vibration exposure (Kim et al., 2018).

Two low-rated studies of engineering controls also found improved safety practices that could prevent injuries. One study found that engineering controls prevented injury by reducing noise exposure (Wilson, 2010), while another found they improved error rates over time (Steiner & Burgess-Limerick, 2013). However, these findings should be interpreted with caution.

▶ **Enforcement activities improved health and safety outcomes but the evidence base is small.** The moderate-rated studies found significant reductions in worker injuries due to enforcement activities, with one study showing a significantly lower likelihood of injury with higher penalties per violation (Gernand, 2016) and the other finding reduced citations and worker injuries with mine safety disclosures in financial reports (Christensen et al., 2017). The studies provide a small body of credible, quality evidence of promising interventions to improve health and safety outcomes.

▶ **The only moderate-rated study on safety regulations showed no significant impact on health and safety outcomes.** This study found that exposure regulations were associated with lower mortality rates, but the author did not provide tests of statistical significance that would indicate that the findings were not due to chance (Edwards et al., 2014). However, one low-rated study of a safety regulation found a decrease in injury rates (Monforton & Windsor, 2010). More evidence is needed to draw stronger conclusions on the effectiveness of safety regulations.

▶ **Training interventions may increase knowledge and skills that could improve health and safety outcomes.** The studies found improvements in knowledge and skills that could reduce injuries, such as higher health and safety knowledge scores (Cherniack, 2016) and higher belief in successfully completing a virtual mine rescue (Hoebbel et al., 2015). Only one study looked at the effects of training on actual injury rates, finding a lower lost time injury rate at one mine (Burgess, 2016). This small body of literature shows promise to potentially reduce injuries but the studies received a low causal evidence rating.

Where are the gaps in the research on mine health and safety interventions?

- ***Little higher-rated evidence exists on the effectiveness of training interventions to increase health and safety outcomes.*** The systematic review found three studies that tested the impacts of training interventions on health and safety outcomes. All three studies found favorable impacts on health and safety. However, none of the studies received a high or moderate causal evidence rating due to methodological issues with the studies. More rigorous, credible research would enable us to draw stronger conclusions about the effectiveness of training interventions.
- ***Exploring the context of the safety violations would further explain the effects of enforcement activities on health and safety outcomes.*** One study of enforcement activities in the review examined the effect of the amount of the penalty on future rates of injuries or illnesses. However, the study did not identify if the violations for receipt of the penalty were obvious nor did it look at a reduction of fatality rates which are the most important measure regarding mine safety. More research about the violation types and subsequent sanctions due to the violations as well as characteristics of the mines would provide more contextual information about the effectiveness of specific penalties for different types of mines and levels of violation.
- ***More research is required to determine the effects of engineering controls on rates of injuries and illnesses.*** The systematic review included outcomes that prevent injury or illness and enhance safety practices (e.g., increased reaction time or reduction of respirable dust). While all but one study of the impact of engineering controls found favorable health and safety outcomes, the findings did not directly pertain to rates of injuries or illnesses. Also, 17 studies of engineering controls were identified during the systematic search process but could not be reviewed using the CLEAR Causal Evidence Guidelines. CLEAR reviews studies that use specific research methodologies that are found in the behavioral sciences, such as randomized controlled trials and comparison group designs that compare those who participated in an intervention to those who did not, and interrupted time series designs that examine trends before and after an intervention. However, many studies of engineering controls used scientific experimental designs that did not include a comparison group or examine trends over time. Alternate research methods could provide stronger evidence on the effects of engineering controls on rates of injuries and illnesses.
- ***Additional research is needed to determine the effects of safety regulations on health and safety outcomes.*** Only two of the 15 studies examined the impact of safety regulations on outcomes. Also, the studies look at aggregate changes in rates of injuries/illnesses before and after the implementation of the regulation. More research could explore the implementation of the safety regulation at the individual mine level to further identify challenges and solutions to implementation in the mines, providing context for the changes in health and safety outcomes.

Table 3. Summary of studies found in the systematic review

Publication	Intervention	Study Methodology	Causal Evidence Rating	Outcome Effectiveness	Profile
Engineering controls					
Burgess-Limerick et al. (2013)	First-order and second-order joystick controls	RCT	High	Favorable impacts	https://clear.dol.gov/study/effect-control-order-steering-simulated-underground-coal-shuttle-car-burgess-limerick-zupanc
Kim et al. (2018)	Seat suspension systems	RCT	High	Mixed impacts	https://clear.dol.gov/study/evaluation-commercially-available-seat-suspensions-reduce-whole-body-vibration-exposures
Sammarco et al. (2012)	Visual warning systems	RCT	High	Favorable impacts	https://clear.dol.gov/study/visual-warning-system-reduce-struck-or-pinning-accidents-involving-mobile-mining-equipment
Steiner & Burgess-Limerick (2013): Experiment 1	Shape-coding and length-coding of roof-bolting machine levers	RCT	High	Favorable impacts	https://clear.dol.gov/study/shape-coding-and-length-coding-measure-reduce-probability-selection-errors-during-control
Steiner & Burgess-Limerick (2013): Experiment 2	Shape-coding and length-coding of roof-bolting machine levers (order reversed)	RCT	High	Favorable impacts	https://clear.dol.gov/study/shape-coding-and-length-coding-measure-reduce-probability-selection-errors-during-control
Steiner & Burgess-Limerick (2013): Experiment 3	Shape-coding of roof-bolting machine levers	RCT	Low	Favorable impacts	https://clear.dol.gov/study/shape-coding-and-length-coding-measure-reduce-probability-selection-errors-during-control
Steiner et al. (2014)	Directional control-response relationships of roof-bolting machine levers	RCT	High	Favorable impacts	https://clear.dol.gov/study/directional-control-response-compatibility-relationships-assessed-physical-simulation
Wilson (2015)	Automated bagging system	Pre-Post	Low	Favorable impacts	https://clear.dol.gov/study/evaluation-automated-vs-manual-bagger-exposures-related-ergonomics-dust-and-noise-sand-mine
Enforcement activities					
Christensen et al. (2017)	Mine safety disclosures	Difference-in-differences	Moderate	Favorable impacts	https://clear.dol.gov/study/real-effects-mandated-information-social-responsibility-financial-reports-evidence-mine-safety
Gernand (2016)	Mine Safety and Health Administration (MSHA) inspection violations	Statistical modeling	Moderate	Favorable impacts	https://clear.dol.gov/study/evaluating-effectiveness-mine-safety-enforcement-actions-forecasting-lost-days-rate-specific

Publication	Intervention	Study Methodology	Causal Evidence Rating	Outcome Effectiveness	Profile
Safety regulations					
Edwards et al. (2014)	U.S. radon exposure standards	Statistical modeling	Moderate	No impacts	https://clear.dol.gov/study/occupational-radon-exposure-and-lung-cancer-mortality-estimating-intervention-effects-using
Monforton & Windsor (2010)	Mine Safety and Health Administration (MSHA) Part 46	ITS	Low	Favorable impacts	https://clear.dol.gov/study/impact-evaluation-federal-mine-safety-training-regulation-injury-rates-among-us-stone-sand-and
Training					
Burgess (2016)	Risk management programs	Matched comparison group	Low	Favorable impacts	https://clear.dol.gov/study/implementation-risk-management-programs-identification-best-practices-reduce-injuries-and
Cherniack (2016)	Mining Healthy Worksite Program (MHWP)	Comparison group	Low	Favorable impacts	https://clear.dol.gov/study/mining-healthy-worksite-program-cherniack-2016
Hoebbel et al. (2015)	Virtual mine rescue training	Pre-post	Low	Favorable impacts	https://clear.dol.gov/study/assessing-effects-virtual-emergency-training-mine-rescue-team-efficacy-hoebbel-et-al-2015

Note: RCT is a randomized controlled trial; ITS is an interrupted time series.

Publications included in the review

Burgess, J. L. (2016). *Implementation of risk management programs: Identification of best practices to reduce injuries and maximize economic benefits*. (Report No. AFC113-07). Tucson, Arizona: University of Arizona.

Burgess-Limerick, R., Zupanc, C., & Wallis, G. (2013). Effect of control order on steering a simulated underground coal shuttle car. *Applied Ergonomics, 44*(2), 225-229.

Cherniack, M. (2016). *The Mining Healthy Worksite Program*. (Grant No. AFC113-9). Philadelphia, PA: Alpha Foundation for the Improvement of Mine Safety and Health, Inc.

Christensen, H. B., Floyd, E., Liu, L. Y., & Maffett, M. (2017). The real effects of mandated information on social responsibility in financial reports: Evidence from mine-safety records. *Journal of Accounting and Economics, 64*(2-3), 284-304.

Edwards, J. K., McGrath, L. J., Buckley, J. P., Schubauer-Berigan, M. K., Cole, S. R., & Richardson, D. B. (2014). Occupational radon exposure and lung cancer mortality: Estimating intervention effects using the parametric G formula. *Epidemiology, 25*(6), 829-834.

Gernand, J. M. (2016). Evaluating the effectiveness of mine safety enforcement actions in forecasting the lost-days rate at specific worksites. *Journal of Risk and Uncertainty in Engineering Systems, 2*(4).

Hoebbel, C., Bauerle, T., Macdonald, B., & Mallett, L. (2015). *Assessing the effects of virtual emergency training on mine rescue team efficacy*. Paper presented at the meeting of the National Institute for Occupational Safety and Health, Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) in Pittsburgh, PA.

Kim, J. H., Marin, L. S., & Dennerlein, J. T. (2018). Evaluation of commercially available seat suspensions to reduce whole body vibration exposures in mining heavy equipment vehicle operators. *Applied Ergonomics, 71*, 78-86.

Monforton, C., & Windsor, R. (2010). An impact evaluation of a federal mine safety training regulation on injury rates among US stone, sand, and gravel mine workers: An interrupted time-series analysis. *American Journal of Public Health, 100*(7), 1334-1340.

Sammarco, J., Gallagher, S., Mayton, A., & Srednicki, J. (2012). A visual warning system to reduce struck-by or pinning accidents involving mobile mining equipment. *Applied Ergonomics, 43*(6), 1058-1065.

Steiner, L. J., & Burgess-Limerick, R. (2013). Shape-coding and length-coding as a measure to reduce the probability of selection errors during the control of industrial equipment. *IIE Transactions on Occupational Ergonomics and Human Factors, 1*(4), 224-234.

Steiner, L., Burgess-Limerick, R., & Porter, W. (2014). Directional control-response compatibility relationships assessed by physical simulation of an underground bolting machine. *Human Factors, 56*(2), 384-391.

Wilson, L. A. (2015). *Evaluation of automated vs. manual bagger exposures related to ergonomics, dust, and noise at a sand mine processing plant* (Unpublished master's thesis). Montana Tech of the University of Montana, Butte, MT.