



An Assessment of Interventions to Improve Underground Coal Miners' Ability to Self-Escape Using Human-Centered Design Methods

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Abstract

The literature lacks analysis of human systems integration approaches for self-escape in mining. This research aimed to gather feedback from miners to identify technological interventions that could support their ability to perform critical self-escape tasks. We solicited feedback on the usefulness of 21 proposed interventions to improve confidence in self-escape knowledge, skills, and abilities (KSAs) and evaluate relationships between the interventions and specific demographic parameters of miners. We also analyzed decisions by miners to shelter in place or escape in an underground coal mine fire emergency in relation to how miners' decisions affect the perceived usefulness of the interventions. This research utilizes a novel scenario-based survey to collect feedback from 116 miners. The results show that the miners ranked interventions related to self-contained self-rescuers (SCSRs) and refuge alternatives (RAs) as the most useful. Surprisingly, the demographic variables we examined did not differentially affect the perceived usefulness of the 21 interventions. Interestingly, participants who reported they would shelter-in-place (~48%) also thought all 21 interventions were more useful, with 11 out of 21 being statistically significantly higher at a 0.05 significance level. Future research will directly apply the results of this study to a series of proof of concept and prototype studies aimed at improving self-escape interventions through human systems integration.

Keywords Mine safety · Human factors · Self-escape · Human systems integration · Human-centered designs · Underground coal mines

1 Introduction

Despite advances in safety training and standards, mine safety remains a critical issue; with thousands of accidents and numerous fatalities occurring, annually [1, 2]. In the United States of America (USA), for example, in 2021, the mining industry exhibited a fatal injury rate of 14.2 per 100,000 full-time equivalent workers, significantly higher than the overall rate of 3.8 per 100,000 full-time equivalent workers observed in private industry [3].

The comparatively lower injury and fatality rate in other industries may be partly attributed to the successful implementation of human systems integration (HSI) approaches

to developing safety systems [2, 4]. HSI is a system design approach that examines the interactions of people, tasks, and technology in achieving specific goals; critically, it centers on human factors considerations and human-centered design principles in system design. Several stakeholders, including several US federal agencies such as the United States (US) Army [5, 6] Nuclear Regulatory Commission [6–8], National Research Council [4], and Federal Aviation Association [6], have called for using HSI approaches to analyze and improve safety systems. Several research initiatives have evaluated the effectiveness of HSI in the mining sector [2, 4].

In 2013, the US National Research Council's (NRC's) *Committee on Mine Safety: Essential Components of Self-Escape* conducted an in-depth analysis of mining safety with emphasis on self-escape [4]. The NRC report defines self-escape as “the ability of an individual or group of miners to remove themselves from the mine using available resources” [4] in the event of an emergency. The committee recommended robust consideration of HSI to improve mining safety systems. Of particular relevance to the work, here is their recommendation that feedback

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mechanisms for miners and mine operators be systematically embedded in the design process to identify challenges and opportunities for safety improvements. In 2015, the US National Institute for Occupational Safety and Health (NIOSH) published a report applying an HSI approach to understanding mining safety technologies. The results suggested that ignoring worker needs within the specific work context can negatively impact the integration of safety technologies [9]. This finding further supports the importance of soliciting direct input and feedback from miners to assess their technological needs for safety improvement.

Any discussion of HSI must include a discussion of human-centered design (HCD). HCD is defined by the International Organization for Standardization (ISO) as “an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques” [10]. HCD methods have been implemented in the mining industry to examine and address several interventions and technology-related issues. For example, Horberry et al. [11] examined mobile mining equipment’s access and egress and found that successful implementation of HCD depended on careful observations, group consensus, design iteration, and involvement of multiple diverse experts and managers. In developing a strategy for predicting successful implementation of new mining equipment Boudreau-Trudel et al. [12] found that two key predictors of increased productivity were that the technology required little skill to operate, and that the operator perceived the technology as highly acceptable. HCD of productivity-related mining technology and safety interventions has received increased attention in the last decade [2], and, no doubt, these efforts will improve mine safety. However, understanding and implementing HCD for self-escape interventions is still fairly nascent.

In 2023, NIOSH published results from research aimed at identifying and describing tasks critical to successful self-escape in an underground coal mine emergency [2]. The research also solicited feedback from miners and other mine personnel to understand their perceptions of their own knowledge, skills, and abilities (KSAs) related to completing each of these critical tasks effectively in the face of an emergency. This comprehensive task analysis provides a foundation to identify opportunities for user-centered and use-inspired interventions. In other words, a significant gap in KSAs for a critical task that is already well covered in training could be amendable with a technological intervention. For example, if miners generally report low confidence in their ability to deploy a refuge alternative (RA) and this topic is already well-covered in training, a simple intervention such as improved signage on the RA might be worth exploring.

While the results of the report can be used to identify critical tasks for self-escape that miners and other mining personnel have lower confidence in, it does not make specific recommendations for interventions or design changes that could improve KSA for these tasks. Building on NIOSH’s work we take the next critical step in HCD, which is to solicit feedback from miners and mining personnel to identify interventions that *they believe* could be useful in supporting their ability to perform some of these critical self-escape tasks. Since human capabilities vary based on numerous factors, we assessed whether the perceived usefulness of the interventions varies based on certain demographic factors. We also analyzed whether there is any relationship between the decisions by miners to shelter in place or escape in an underground coal mine fire emergency and the perceived usefulness of the interventions.

We solicited miners’ feedback about self-escape interventions using a scenario-based online survey. Participants read through a mining emergency scenario and responded to two sets of questions at five stopping points. The first set asked participants to consider their confidence in their own knowledge, skills, or abilities to complete critical tasks at each point in the emergency. We tailored the story and question sets to cover critical self-escape KSAs identified by NIOSH [2], emphasizing those that received the lowest mean confidence ratings from rank-and-file miners. The second set of questions at each stopping point asked participants to rate the perceived usefulness of a short set of hypothetical interventions. We selected 21 interventions for their potential to aid in completing critical safety tasks that might be needed at each stopping point. To assess whether perceptions of the 21 interventions varied systematically by user group, we examined several demographic variables known to predict differences in safety behaviors or attitudes, such as work experience and responsibilities. Additionally, we assessed miners’ decisions to shelter in place during an emergency in relation to self-escape interventions.

The novel contribution of this work to literature is that previous research has not examined whether the perception of self-escape interventions varies as a function of user groups within the mine (i.e., seniority, work location, and workgroup). This is important to understand because so much of the decision-making related to whether a particular intervention is used during emergencies is done by rank-and-file miners (although managers and regulators make the decisions on what intervention is developed and deployed in mines), and if miners do not perceive those interventions as useful, there is a risk they may not be used effectively [9, 12]. This work also creates a user-rated list of potential interventions that might help with self-escape tasks. The list is of particular importance because it was generated using a human-centered approach to evaluating self-escape interventions specifically for underground coal miners, which might

be different for metal and non-metal miners. The list can be used for future research and development of self-escape safety interventions.

2 Methods

2.1 Overview

We administered a scenario-based online survey to miners and other mine personnel from the US coal industry. We asked respondents to rate the perceived usefulness of 21 hypothetical self-escape interventions that were aimed at aiding the completion of the critical self-escape tasks in the scenario. We examined this difference across several common user-group demographic indicators to examine whether perception varies as a function of user-group identity.

2.2 Participants

This research was approved by the University of Missouri Institutional Review Board (MU IRB). Miners and other mine personnel were recruited from five coal mines in the USA using a convenience sampling method that incorporated word-of-mouth, emails to mine supervisors, and referrals. As an incentive to complete the study, participants were offered the opportunity to enter a drawing to win one of ten US\$50.00 gift cards to Walmart, Best Buy, Menards, Lowes, or Home Depot. A total of 116 participants completed the survey. Most participants identified as male (96%) with only 3% identifying as female (1% declined to answer). Though distinctly skewed, this nonetheless reflects current gender representation in the US coal industry [13]. All participants were over the age of 18 with 81% falling between the ages of 25 and 54, and 16% were over the age of 55. Majority of participants reported their highest level of education as either a high school degree (57%) or trade certificate (28%), with 3% reporting no high school completion and 13% reporting a bachelor's degree or higher.

2.3 Scenario

Rather than presenting participants with a non-contextualized list of 21 hypothetical self-escape interventions for them to consider, we employed a scenario-based survey design and presented the interventions within the context of a mining emergency. We did this for several reasons. First, research suggests that realistic scenario-based surveys are better for assessing an individual's behaviors in a decision-making context in an emergency [14]. Second, because we were most interested in interventions that would aid in the completion of low-confidence self-escape tasks identified by NIOSH [2], using a scenario-based design afforded the

opportunity to frame the user's mindset around those tasks. This is important because the circumstances in which these self-escape tasks must be completed are relatively rare, as such, low usefulness rating could reflect the participant's inability to think of a rare-event task the intervention might be useful for rather than an assessment of its usefulness for that task. We sought to remove this potential confound by tailoring the scenario in a way that as the emergency unfolds, the low-confidence tasks might reasonably be required. We also asked participants to rate their own confidence in completing the low-confidence task before rating the technologies. Finally, a scenario-based survey design is in-line with human-centered design thinking that promotes the importance of examining the use of interventions within the work context it will be used [15].

The scenario we used was based on existing training material from the US Centers for Disease Control and Prevention-National Institute for Occupational Safety and Health (CDC-NIOSH) called "Harry's Hard Choice" [16]. The original training exercise presents trainees with a detailed hypothetical coal mine emergency and asks them to select appropriate safety protocol responses at various stopping points in the story. To better align the story with the project needs, the emergency scenario and questions were modified by an interdisciplinary research team and industry stakeholders from the mining industry. First, the details of the emergency were adjusted so that the critical safety task needed at each stopping point covered more of the low-confidence KSAs identified by NIOSH [2]. Second, we reframed the question style so that, rather than asking participants to select what safety tasks should be completed at each stopping point, they were instead presented with a set of appropriate tasks and asked to rate the degree to which they felt confident in their own knowledge, skill, or ability to perform each one. Third, after reporting their confidence, participants were asked to rate the usefulness of a subset of hypothetical interventions that could ostensibly aid in completing the safety tasks. The final scenario included an introduction containing brief instructions, a description of the story characters, and a description of the mine (including a map that participants could review at any time). The introduction was followed by five (5) short story segments that built on one another. Table 1 shows an overview of each of the story segments, the type of task competencies being targeted in that story part, and the specific interventions that were assessed.

In the final story segment (Part 5), we describe a situation in which an injured story character who was forced to stay behind in a refuge alternative (RA) with another injured miner, begins to feel better and tries unsuccessfully to contact their command center. Participants were then asked what they would do if they were in this situation; would they choose to stay in the RA with the injured miner or would

Table 1 Overview of the scenario plot and targeted task competencies for each story part, and the corresponding list of interventions description presented to participants after each story segment. The shortened codes used in the analyses are included for reference

Summary of story part	Tasks competencies being targeted	Interventions presented	Code used in analyses
Part 1—(Emergency onset. Alarms sound, area becomes smokey	Gathering information about emergency from environment and command, relaying info to others, don SCSR	CO monitors with audible voice notification that verbally communicate the exact CO levels in the immediate vicinity and the current threat levels Reference card with simplified step-by-step instructions from ERP on how to respond in a fire situation and emergency radio channels that you can refer to at any time	CO_Monitor_1 ERP
Part 2—Air quality worsens, crew begins moving out by, one miner is injured	SCSR protocols and usage, communicating during an emergency	Reference card listing which info to gather and report to the surface when you contact them (e.g., card with checklist such as location, headcount, names, physical condition, and needs) A hand-held interactive device (interactive maps) with location of SCSRs displayed on them A hand-held interactive device that miners can use to access real-time CO measurements from any CO monitor throughout the mine Handheld CO monitors that are easier to read and interpret than currently available options	Communication_1 SCSR_1 CO_Monitor_2 CO_Monitor_3
Part 3—Escape progress slow, visibility is low, there is an SCSR's cache up ahead	Using tether/tagline, switching over SCSR's	Reference card with information on when to don SCSR An SCSR that is easier to don than current technology An SCSR that allows you to talk while wearing Flexible length taglines that reduce the need to untether for reasonable distances Tether/taglines that allow one miner to disconnect and reconnect easily without breaking entire connection Lifeline with voice commands explaining each symbol as you touch/squeeze them Improved SCSRs that allow miners to switchover without breathing contaminated air	SCSR_2 SCSR_3 SCSR_4 tether_1 tether_2
Part 4—Some miners can't continue, a refuge alternative (RA) is nearby	Knowing when to use a RA, activating RA	Hand-held guidance system that provides ongoing audio and text updates about current safe evacuation route including when refuge alternative is the best option Refuge alternative with fewer required steps for entering Clearly labelled instructions inside shelter with step-by-step instructions for activating an in-place refuge alternative	SCSR_5 RA_1 RA_2 RA_3

Table 1 (continued)

Summary of story part	Tasks competencies being targeted	Interventions presented	Code used in analyses
Part 5—An injured miner in the RA is feeling well enough to leave, communication between the RA and the surface is lost	Escape option—Route planning, map reading Stay option—RA maintenance, re-establishing communication	Robot that can be deployed from refuge alternative to troubleshoot and re-establish communications Improved and simplified way of purging bad air and setting up scrubbers Display in the refuge alternative that shows the current location of other miners, and gas and temperature monitoring data directly outside the RA Interactive mine maps with highly reflective signage under low-lighting conditions Active voice/text turn-by-turn guidance based on the safest route at the moment through the mine similar to “vehicle GPS”	Communication_2 RA_4 Communication_3 Map_1 Map_2

they try to self-escape? Based on their answer, they were asked about tasks and interventions related to their choice. Once they responded to this set of questions, they were also asked to consider the tasks and interventions associated with the alternative. We did this because, on the one hand, several low-confidence tasks from the NIOSH report were related to the effective and appropriate operation of RAs, so it was important to create a context in which we could assess the usefulness of interventions related to those tasks. However, on the other hand, feedback from coal mining stakeholders during the development stage of the scenario suggested that many coal miners have such strongly negative feelings about using an RA. They may view using an RA as a hopeless resort. If that were the case, when asked about interventions aimed at improving the operation of an RA, participants who hold this view might rate these technologies as useless merely because they believe entering an RA is generally useless. A choice option allowed us to analyze perceptions of the usefulness of interventions related to RA interventions separately for those who opted to stay and those who opted to leave.

2.4 Measures

The primary variables of interest in the study included the ratings of usefulness for each of the 21 interventions, the decision to leave or stay in a refuge alternative, and self-reported demographic data.

The 21 interventions were hypothetical or conceptual ideas that could directly or indirectly aid in completion of critical self-escape task identified in NIOSH’s information circular [2]. The complete list of interventions can be found in Table 1. The list was generated by comprehensively investigating safety approaches used by other (non-mining) industries for similar tasks, or by mining industries outside the US. This list was refined through conversations with subject matter experts (SMEs) from mining technology development companies, coal mining companies, and NIOSH’s Escape, Rescue, and Training Team (Pittsburg Mining Research Division). We solicited feedback from more than a dozen SMEs and used their feedback to further refine our list of interventions.

Several demographic variables were captured in order to examine differences across user groups with respect to the perceived usefulness of the 21 technologies. A foundational principle in human-centered design is that people have unique needs and characteristics that influence how they interact with systems [17, 18]. It is not always practical to examine every user’s unique needs, but it can be helpful to examine user groups. User can be grouped by numerous characteristics such as experience, work role, level of education, physical or cognitive attributes, and so on depending on the design goals [18].

In this study, we look at several potential user group variables that might reasonably be expected to differentially affect perceptions about the use of self-escape interventions (see Table 2 for breakdown of responses across each variable). We asked participants to report their years of work experience in mining because this has previously been shown to predict safety decisions of miners [19–21]. However, other research suggests that experience is not the only factor that predicts safety-related behavior. For example, Bahn [22] found that miners identified safety hazards and mitigation strategies differently based on role rather than experience. As with many organizations, roles within a mining context can overlap.

Table 2 Responses for each user group variable. (Employment Type, Work Group, Work Experience, Employment Type, Work Schedule, and Work Location)

User group variable	Number	Percent
Employment type		
Salaried	36	31.3
Hourly	75	65.22
Contractor	1*	0.87
Prefer not to say	3*	2.61
Total	115	100.00
Work group		
Production	62	53.45
Maintenance	22	18.97
Safety	23	19.83
Engineering	3*	2.59
Other	6*	5.17
Total	116	100.00
Work experience		
Less than 1 year	0*	0
1–5 years	20	17.24
6–10 years	25	21.55
11–15 years	31	26.72
16–20 years	11	9.48
More than 20 years	29	25.00
Total	116	100.00
Work schedule		
Set schedule	60	51.72
Rotates/shift	56	48.28
Total	116	100.00
Work location		
Working face	61	52.59
Outby	25	21.55
Surface	10	8.62
Other	20	17.24
Total	116	100.00

*Not included in analyses

To capture roles in the context of a mining emergency, we asked participants to report their work group and typical work location within the mine. Where participants work in the mining operation and what their assigned job duties are could affect their role in a mining emergency and, in turn, how they think about self-escape. For example, with respect to work location coal miners who work primarily at the “working face” are more likely to be trapped in a mining emergency than those who work at the surface. Individuals trapped underground during a mine emergency assume a role of self-escaping or sheltering in place, whereas those who are not trapped, may assume roles related to aiding others to the surface or getting resources to those who are trapped. This could ultimately mean that the usefulness of some interventions would be perceived differently by these two groups [22]. With respect to work group, training and responsibilities also vary, which could affect the types of safety tasks each would perform as well as the KSA each possesses for performing these tasks. For example, miners in the safety work group have specialized training in safety that is likely to differentially influence their beliefs about how and why a safety intervention could be useful.

Two other group variables we considered were work schedule and employment type. The impact of hours of work or work schedules on accident and incident rates has been researched extensively in both the general and mining industry [23–25]. Results from the past research have established some relations between work schedules and incident and accident rate [24, 25]. Similarly, studies have shown statistically significant differences in incidents and fatal mining injuries based on employment types such as salaried, hourly, or contractor [25]. Because risk *experiences* differ by work schedule and employment types, it is possible that there could be corresponding differences in perceptions about technologies that would help mitigate risk.

2.5 Procedure

The online survey was created using QualtricsXM and participants were provided a weblink to access the study. Upon arriving on the website, participants were asked to read a study cover letter informing them of their rights and protections. Participants who chose to proceed were then presented with an overview of the study procedure, an introduction to the mining scenario and story characters, and a map of the hypothetical mine.

Participants then moved through the story scenario at their own pace. Segmented into five story parts with stopping points for questions at each one, participants could re-read previous story segments and review the mine map at any time. After each story segment, participants answered two sets of questions.

The first presented a set of 3–5 critical self-escape tasks relevant at that point in the emergency and participants were asked to rate how confident they were in their own knowledge, skill, or ability to complete each one. Participants provided their responses using a slider bar with a scale of “0” to “10,” with “0” being “No Confidence” and “10” being “Extremely Confident.” These ratings were included to focus participants’ attention on specific tasks related to the story segment. Next, participants were presented with a list of 3–5 interventions (see Table 1) and were asked to consider, if they were in the situation represented in the story, how useful they believed each of the interventions would be. Responses were provided using a slider bar with a scale of “0” to “4,” with “0” being “Not at All Useful” and “4” being “Extremely Useful.”

At the end of story segment 5, before presenting the critical self-escape tasks or interventions, participants were first asked to consider whether, if they were in the situation presented in the story, they would opt to shelter in place or try to self-escape. If a participant selected shelter in place, they were presented with three tasks and three interventions related to sheltering in place. Once complete, they were then asked to imagine that they selected the alternative (i.e., self-escape in this example) and were then presented with three tasks and three interventions related to self-escape. If a participant selected self-escape first, the order of presentation was correspondingly reversed. In other words, participants always first responded to tasks and interventions related to supporting their first choice and the alternative, second.

Upon completing the scenario-based questions, participants were asked to provide demographic information and were given an opportunity to provide open-text feedback about the study or other interventions they felt might be helpful in mining self-escape.

2.6 Statistical Analysis Overview

We examined usefulness ratings of the 21 interventions in two ways. First, we conducted a series of analysis of variance (ANOVA) and *t*-tests using the JMP® software to compare differences in perceived usefulness as a function of user group as well as age and education. Second, we conducted a series of *t*-tests using the JMP® software to compare differences in perceived usefulness as a function of participants’ stay/escape decision.

3 Results

3.1 User Group Variables

The user group variables analyzed were employment type, work group, work experience, work schedule, and work

location (see Table 2). Some user group variables were excluded from the analysis due to small sample sizes. The variables which were excluded are noted by an asterisk (*) in Table 2. ANOVA was used to analyze work group, work experience, and work location variables. The *t*-tests were conducted on employment type and work schedule. No analyses were conducted based on gender because of the highly unequal sample sizes.

To examine differences in usefulness ratings as a function of a user group, we conducted a series of ANOVA and *t*-tests comparing usefulness ratings for each intervention across each of the user group variables. The user group variables included were employment type, work group, work experience, work schedule, and work location. In total, we conducted 105 tests. Homogeneity of variance, which is an underlying assumption of ANOVA and *t*-tests, was tested using Levene’s test. Tests with significant Levene’s results ($p < 0.05$) were rerun using the Wilcoxon/Kruskal–Wallis test. The Wilcoxon/Kruskal–Wallis test was run to check for type I errors, which are usually associated with ANOVA with unequal variance.

The vast majority of these comparisons were non-significant at 95% confidence level. There were only scant few individual technologies where the usefulness ratings were significantly different across the user group variables. For example, the mean usefulness rating for “CO monitor 1 (CO monitors with audible voice notification that verbally communicate the exact CO levels in the immediate vicinity and the current threat levels.)” differed as a function of employment type, and “Lifeline 1 (lifeline with voice commands explaining each symbol as you touch/squeeze them)” differed as a function of work schedule. However, it is critical to note that of the 105 tests performed, only two (2) were significant at the 0.05 significance level; looking at the data more holistically, this suggests that the variables we examined did not predict the perceived usefulness of the safety interventions. A complete list of ANOVA results can be found in the supplemental material.

3.2 Education Level and Age Variables

This section examines whether the reported usefulness ratings for the 21 interventions correlate with age and education level variables. In this study age and education were treated as ordinal variables because there is an order associated with the levels. Example age is unevenly spaced and arranged from youngest to oldest. So, to run an ordinal to continuous variable comparison we employed Kendall’s tau-b correlation test to examine the relationship between usefulness ratings and age as well as education level among 115 participants. There was a significant weak (0.10 to 0.19) to moderate (0.20 to 0.29) positive correlation between age and RA_1 ($\tau_b = 0.163$, $p = 0.036$), age and

Communication_2 ($\tau_b=0.186, p=0.016$) and age and RA_4 ($\tau_b=0.202, p=0.011$), that is a “hand-held guidance system that provides ongoing audio and text updates about current safe evacuation route including when refuge alternative is the best option”, “a robot that can be deployed from refuge

alternative to troubleshoot and re-establish communications” and an “improved and simplified way of purging bad air and setting up scrubbers”, respectively. However, for education, we found weak (0.10 to 0.19) or moderate (0.20 to 0.29) correlations for 8 of the 21 technologies (Table 3). All were negative, that is as education level increased, usefulness decreased.

Table 3 Significant Kendall’s tau-b correlations result for 8 out of the 21 interventions based on education level and usefulness ratings

	Correlation coefficient (τ_b)	p (2-tailed)
tether_1	-0.208*	0.010
CO_Monitor_1	-0.218**	0.008
CO_Monitor_3	-0.201*	0.013
tether_2	-0.172*	0.034
lifeline_1	-0.240**	0.003
RA_1	-0.201*	0.013
RA_3	-0.171*	0.041
RA_4	-0.161*	0.050

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Very weak: <0.10|

Weak: 0.10 to 0.19|

Moderate: 0.20 to 0.29|

Strong: ≥ 0.30 |

3.3 Stay/Escape Decision Variables

After reading the final segment of the scenario (Part 5), participants were asked whether they would stay in a refuge alternative with an injured miner (stay) or leave the refuge alternative in order to attempt self-escape on their own (Escape). Approximately 48% of the participants responded that they would stay in the refuge alternative and 52% responded they would attempt self-escape. We conducted a series of correlation analyses to examine the relationship between the decision to stay in the refuge chamber or leave, and the measured demographic parameters (employment type, work group, work experience, work schedule, and work location). Interestingly, none of these variables accounted for the differences in the decisions to stay in the refuge chamber or to escape. Figure 1 shows the mean usefulness ratings of the 21 interventions for the stay and escape groups. Table 1

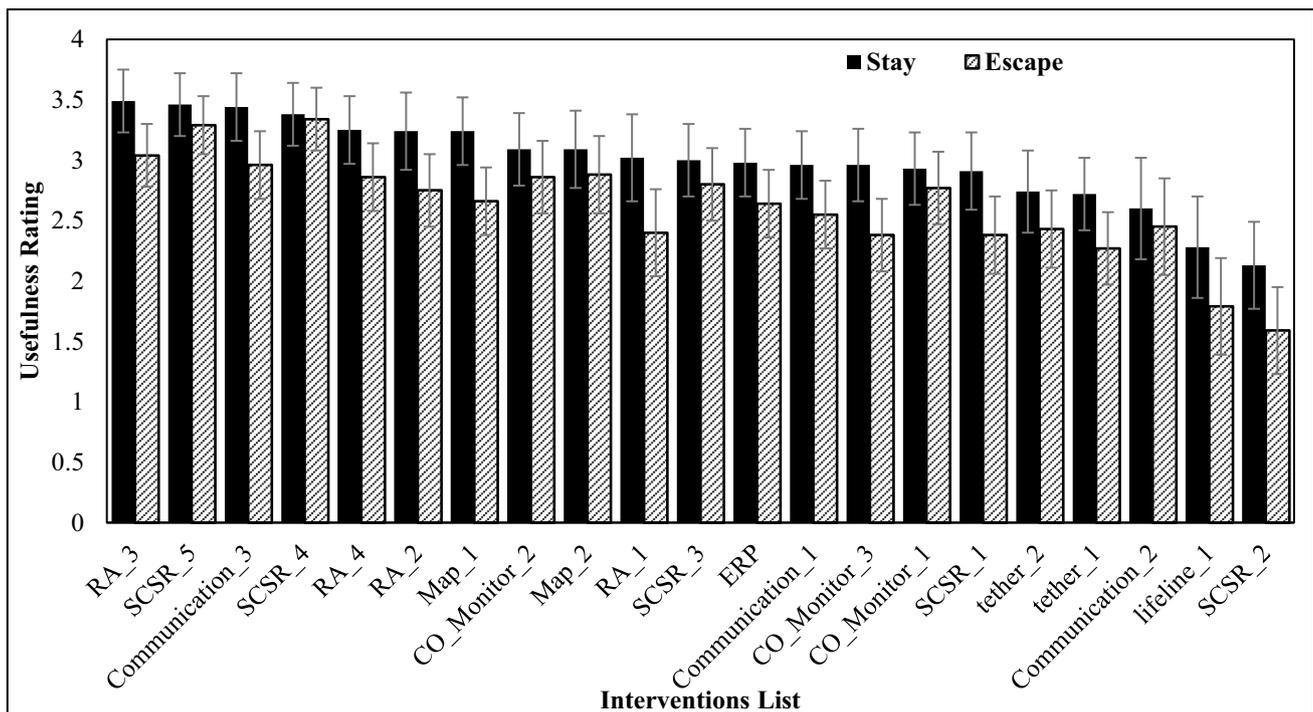


Fig. 1 Mean usefulness ratings of each intervention; arranged in descending order for “Stay” and “Escape” groups. “Stay” represents participants who selected the option to shelter-in-place in a refuge

alternative and “Escape” represents participants who selected the self-escape option when asked whether they will stay with the injured miner or escape. Error bars represent 2 times the standard error

shows the codes and descriptions for the list of interventions used in Figs. 1 and 2.

Miners who opted to stay reported consistently higher usefulness ratings than miners who opted to escape. To determine if these differences were statistically significant ($p < 0.05$), we conducted a series of *t*-tests for each technology. Table 4 shows statistically significant differences in the mean usefulness ratings between the two groups for 11 out of the 21 interventions.

The only variable that showed differences in usefulness was the stay/escape variable. However, even then the ranked order is not different between those two groups. Figure 2 shows the usefulness ratings of the entire group together. The usefulness rating for all the 21 interventions ranges from approximately 1.88 to 3.38; that is, from slight to moderately useful to very useful.

4 Discussions

Prior research conducted by NIOSH and the NRC revealed certain limitations associated with approaches and interventions used by miners to self-escape a mine in an emergency. For example, NRC research identified limitations surrounding verbal communication, positive pressure, device weight, and size associated with the functionality of SCSRs required for self-escape. However, these studies to assess shortcomings in self-escape approaches were assessments made by

upper management and external governing bodies with little regard to rank-and-file miners. In this study, we used a novel scenario-based survey methodology to collect feedback from rank-and-file miners on the usefulness of certain 21 interventions required for self-escape.

We found that interventions related to SCSRs, and refuge alternatives (RAs) dominated the first five interventions that miners perceived as most useful. Improved SCSRs that allow miners to switchover without breathing contaminated air and an SCSR that allows you to talk while wearing were the two most highly rated interventions related to SCSRs followed by the three interventions related to RAs such as clearly labeled instructions inside the shelter with step-by-step instructions for activating an in-place refuge alternative, display in the refuge alternative that shows the current location of other miners, and gas and temperature monitoring data directly outside the RA and improved and simplified way of purging bad air and setting up scrubbers in the RA. These findings extend those of the NRC and other researchers, confirming that there is a need for some improvements related to functionality and ergonomics in the current SCSRs used in the mining industry [4, 26, 27].

The results from miners' decision to stay or escape were split nearly down the middle, with 52% of miners responding they would attempt self-escape and 48% responding that they would wait in the refuge alternative. This issue is an important one in mining because the general perception is that miners are unwilling to use refuge alternatives

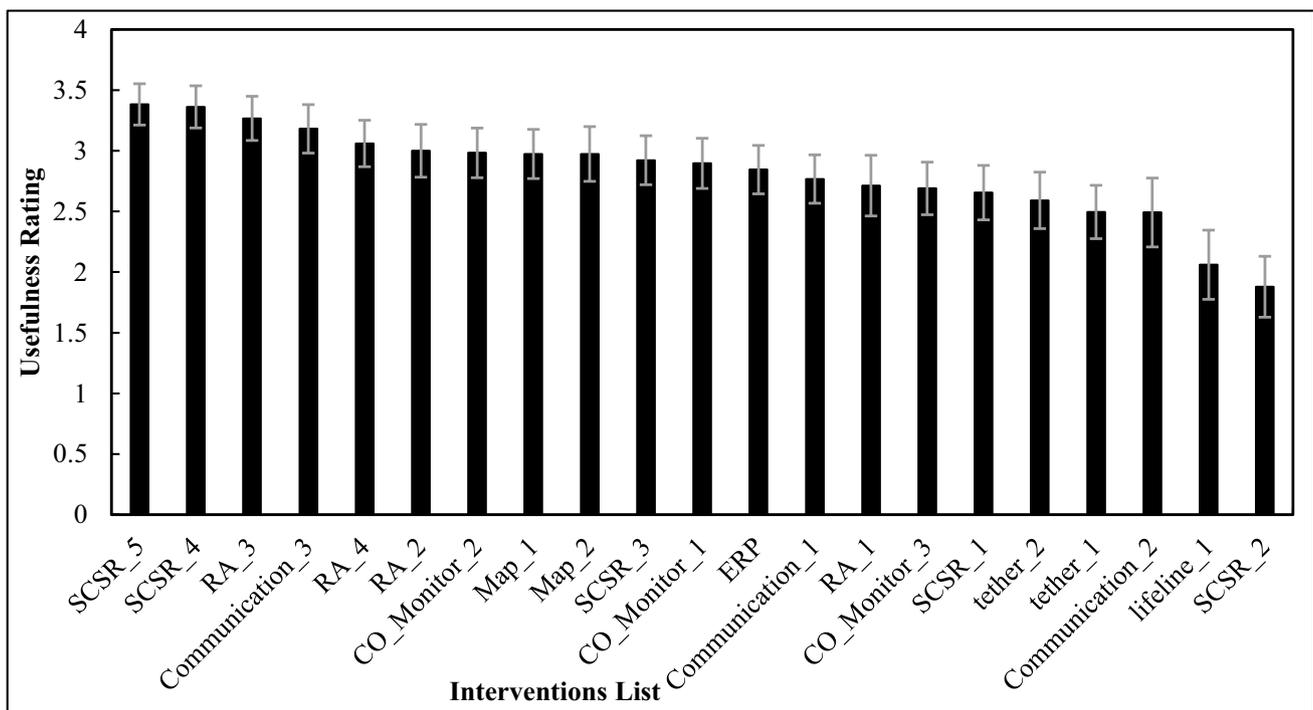


Fig. 2 Mean usefulness rating of all 21 interventions, arranged in decreasing order. (N=116). Error bars represent two times the standard error

Table 4 Independent *t*-tests (one-sided) comparing usefulness ratings for each intervention between participants who selected stay and those who selected escape

	Stay		Escape		df	<i>t</i>	<i>p</i>	Cohen's <i>d</i>
	M	SD	M	SD				
RA_3 ^a	3.49	0.13	3.04	0.13	110.4	2.342	0.010**	0.431
SCSR_5	3.46	0.13	3.29	0.12	113.0	0.807	0.211	0.151
Communication_3	3.44	0.14	2.96	0.14	114.0	2.444	0.008**	0.454
SCSR_4	3.38	0.13	3.34	0.13	114.0	0.143	0.443	0.027
RA_4	3.25	0.14	2.86	0.14	114.0	1.934	0.028*	0.359
Map_1	3.24	0.14	2.66	0.14	113.0	2.535	0.006**	0.473
RA_2 ^a	3.24	0.16	2.75	0.15	107.5	2.114	0.018*	0.388
CO_Monitor_2	3.09	0.15	2.86	0.15	114.0	1.005	0.159	0.187
Map_2	3.09	0.16	2.88	0.16	113.0	0.993	0.162	0.185
RA_1 ^a	3.02	0.18	2.4	0.18	112.1	2.282	0.012*	0.424
SCSR_3	3	0.15	2.8	0.15	114.0	0.569	0.285	0.106
ERP ^a	2.98	0.14	2.64	0.14	113.8	1.161	0.124	0.215
CO_Monitor_3	2.96	0.15	2.38	0.15	114.0	2.502	0.007**	0.465
Communication_1	2.96	0.14	2.55	0.14	114.0	1.751	0.041*	0.325
CO_Monitor_1	2.93	0.15	2.77	0.15	114.0	0.464	0.322	0.086
SCSR_1	2.91	0.16	2.38	0.16	114.0	2.074	0.020*	0.385
tether_2	2.74	0.17	2.43	0.16	113.0	1.119	0.133	0.209
tether_1	2.72	0.15	2.27	0.15	113.0	1.713	0.045*	0.320
Communication_2	2.6	0.21	2.45	0.2	114.0	0.786	0.217	0.146
lifeline_1	2.28	0.21	1.79	0.2	113.0	1.554	0.061	0.290
SCSR_2	2.13	0.18	1.59	0.18	114.0	1.912	0.029*	0.355

^aSignificant Levene's test; the result reported is for equal variances not assumed

* $p < 0.05$; ** $p < 0.01$

to shelter-in-place [19] and are also trained to use it as a last resort when escape is impossible [16]. However, previous work on miner perceptions tends to evaluate the decision as an individual decision a miner makes regarding their own safety without any regard to the team dynamics that will likely exist in most mining emergencies [19]. By using a scenario about a group of miners, our study could elicit a more realistic response from miners regarding their decision to self-escape or shelter in place.

Interestingly, our analyses revealed that none of the measured demographic variables were significantly associated with the decision to stay or escape. This indicates that the decision-making process was not affected by factors such as age, gender, education level, employment type, work group, work experience, employment type, work schedule, and work location.

Previous work has documented the relationship between miners' demographic variables such as mining experience, marital status, age, gender, and income on their evacuation decision during an emergency [19]. Furthermore, past research has also shown that safety performance of miners is significantly correlated to their time in the mining industry and time at their current mine [20, 22]. To expand on this research, in this study, we assessed miners' feedback on interventions that could increase confidence in performing

critical self-escape KSAs and compared these responses across numerous demographic variables. Although we found a few statistically significant differences in some of the interventions, the majority of the results suggested perceptions of the usefulness of the 21 self-escape interventions did not vary consistently by work location, work schedule, work experience, and work group.

There is a good body of knowledge in the literature that documents the relationship between age and technology use and adaption [28–32]. Their results show that younger people tend to adapt and use technologies faster than older people. However, we did not find any work in the literature that assesses how different age groups perceive usefulness of certain interventions at the workplace. Results from our study show a positive correlation among 3 out of the 21 interventions rated by the miners. This shows that older mine workers find improvements in certain self-escape interventions to be more useful than younger mine workers.

The results from Kendall's tau-b correlation test to examine the relationship between usefulness ratings and education level among participants of this survey suggest education might impact the perceived usefulness of self-escape interventions. Past research mainly focused on the role of education in technology use and adoption of new technologies at the workplace [32–34]. These past researchers found

a positive correlation between education level and technology use and adaptation; that is, workers with higher education levels tend to adopt new technologies faster than less educated workers [32–34]. In contrast to our study, we evaluated the perceived usefulness of certain 21 interventions by mine workers. Our results show a negative correlation between 8 out of 21 interventions and education level. Although none of the demographic variables evaluated in this study readily explains these results and to the best of our knowledge no research in the current literature has data to support these findings.

Emergency evacuation and decision-making in underground coal mine fire emergencies have been found to be a group activity [35, 36] partly due to the social solidarity that exist among underground coal miners [35–37]. During a major underground coal mine fire, Vaught [35] suggested that a new type of “escape group” is formed, which consist of exclusively different members from normal work crew or work group.

In our study, participants completed the study individually. In a group setting, there is an opportunity for individual members to express ideas and experiences that other members may not have immediately thought of on their own, this can affect decision-making and attitude formation for all members in the group [35, 36]. The outcome of our study might be different if participants were allowed to complete the research in groups and usefulness ratings of our 21 interventions might vary as a function of the work groups.

Interestingly, we did find that participants who reported they would shelter in-place also rated all 21 interventions as being more useful, with 11 out of 21 being statistically significantly higher at 0.05 significance level. This suggests that differences in attitudes toward self-escape interventions, including decision to shelter-in-place or self-escape, may be related to other variables beyond traditional demographics that have been studied in the past.

Future research should explore potential psychological factors that might explain these differences. For example, personality theory argues that stable psychological traits can help explain certain attitudes and behaviors [38–47]. Indeed, this lens has been used to understand decision-making in other industries. For example, in one study participants who scored low on the personality traits of openness to experience, and neuroticism were less likely to shelter in place in the absence of strict government measures [47, 48].

Because participants who opted to shelter in place also rated all the interventions as being more useful, this suggests that perceptions about the usefulness of self-escape interventions might also be related to a person’s attitudes toward self-escape interventions in general. Future research should also examine whether factors such as self-efficacy (the belief that one has the ability to effectively learn and use interventions/tools) as well as trust in safety interventions could also affect

attitudes and decision related to self-escape. Additional factors that were not examined in this study but could also help explain this difference about the usefulness and confidence in using self-escape interventions could include training and institutional culture.

This research is particularly important because it is a pioneering effort in understanding self-escape and individual decision-making by mostly rank-and-file miners in an underground mine fire emergency. Also, this study provides a prioritized list of interventions and ranked mostly by rank-and-file miners that will aid in performing certain critical self-escape tasks. Past research has suggested that demographic variables such as work experience and education level can explain differences in safety attitudes and decisions. However, our study, which included rank-and-file miners, shows that this might not be the case. This seems important since previous research would suggest it might be important to tailor training techniques based on these demographics (i.e., training rank and file differently), but our results suggest this might not be effective if something else, such as technological/safety self-efficacy or personality traits, better explains safety attitudes and decisions.

5 Conclusion

This work assessed miners’ feedback on interventions that could increase confidence in performing critical self-escape KSAs and compared their responses across numerous demographic variables. It also examines the decision by miners to shelter in place or escape in an underground coal mine fire emergency in relation to the perceived usefulness of the interventions.

We accomplished this by administering a scenario-based online survey to miners and other mine personnel from the US underground coal industry. We asked respondents to rate the perceived usefulness of 21 hypothetical interventions that were aimed at aiding with completion of the critical self-escape tasks in the scenario. We examined differences across several common user-group demographic indicators to evaluate whether perceptions vary as a function of user-group identity.

In general, the usefulness rating for all the 21 interventions ranges approximately from slight to moderately useful to very useful. We found that improvements related to self-contained self-rescuers (SCSRs), and refuge alternatives (RAs) dominated the first 5 interventions that miners perceived as most useful. The first five most useful interventions, in order of decreasing usefulness, are:

1. Improved SCSR that allow miners to switchover without breathing contaminated air
2. An SCSR that allows you to talk while wearing

3. Clearly labelled instructions inside shelter with step-by-step instructions for activating an in-place refuge alternative
4. Display in the refuge alternative that shows the current location of other miners, and gas and temperature monitoring data directly outside of the RA
5. Improved and simplified way of purging bad air and setting up scrubbers in the RA.

The demographic variables we examined did not differentially affect the perceived usefulness of the 21 interventions. Approximately 48% of the participants responded that they would stay in the refuge alternative and 52% responded they would attempt self-escape when asked whether they would stay in a refuge alternative with an injured miner or leave the refuge alternative in order to attempt self-escape on their own. We found that none of the measured demographic variables explained differences in decisions about whether to shelter-in-place in the refuge alternative or self-escape. This suggests that differences in attitudes toward self-escape interventions may be related to other variables beyond traditional demographics that have been studied in the past. Future research should explore potential psychological factors that might explain this difference. Participants who reported they would shelter in place also rated all 21 interventions as being more useful, with 11 out of 21 being statistically significantly higher at a 0.05 significance level.

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Author Contribution Eugene Adubofour Gyawu: writing—original draft, formal analysis, investigation, data curation, visualization, project administration.

Denise A. Baker: conceptualization, methodology, validation, writing—review and editing, supervision, funding acquisition.

Kwame Awuah-Offei: conceptualization, methodology, resources, writing—review and editing, supervision, funding acquisition.

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Data Availability The data that support the findings of this study are openly available at https://nam02.safelinks.protection.outlook.com/?url=http%3A%2F%2Fmining-sustainability.com%2Fwp-content%2Fuploads%2F2024%2F08%2F116_Data_Interventions_and_Demographics.xlsx&data=05%7C02%7Ceagvnh%40mst.edu%7Cc9371db4a3c14e564fcc08dcc3884a51%7Ce3f.

Declarations

Competing Interests The authors declare no competing interests.

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