Mine Rescue and Self-Escape Survey: Current Preparedness Perceptions and Availability of Training Modalities

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Abstract

The Mine Rescue and Self-Escape Survey (MRSES) was developed to collect information on perceived preparedness of underground mining professionals in mine rescue and self-escape situations. With the development of new digital training modalities, it is important to investigate the potential usefulness of different training methods, and how the frequency of current training methods and familiarity with evacuation tools and protocols play a role in perceived preparedness. Responses from this survey were used to assess the current state of training for mine rescue and self-escape in emergency situations. This survey found an interest in expanding the frequency of training opportunities and an openness to incorporate more digital training modalities into current training practices.

Keywords Mine rescue · Self-escape · Mine emergency · Safety training · Emergency preparedness · Gamified training

1 Introduction

Underground mining presents a unique set of health and safety risks. Underground mining disasters have claimed numerous lives over the past century, and while fatality rate trends have begun to plateau in the United States, it is still important to investigate the causes and perceptions of miner fatalities [1, 2]. To prepare underground mine workers for disaster and other emergency scenarios, underground mining operations turn to various training modalities. While current research indicates that the adoption of more frequent training exercises and mixed-modality training may yield improved emergency preparedness, this survey aims to investigate current perceptions of rescue and self-escape training, and how these corresponding feelings of preparedness correlate to current training paradigms [2–9].

Digital training modalities are gaining traction for underground rescue and self-escape training at mining operations across the United States [2, 7, 8, 10, 11]. These modalities have the potential to change approaches to emergency preparedness and familiarity with evacuation tools and protocols. However, the readiness of the mining industry to implement new digital training methods that match the increasingly digitalized mining environment must be assessed. Modern digital training modalities pose a transition away from PowerPoint or similar slideshow-based training, with the use of methods like computer-based training simulations, virtual reality, and gamified training [8, 10–13]. This survey was designed to assess the current state of self-escape and rescue training as digital training technologies are becoming more prevalent in the mining industry. The inclusion of modern digital training modalities as a supplement to live training exercises has been shown to improve health and safety outcomes, but current perceptions of the adoptions of such technology are still poorly defined. The Mine Rescue and Self-Escape Survey (MRSES) aims to better understand these perceptions across the mining industry, with additional focus on training frequency, modalities, and perceived preparedness.

2 Methods

The MRSES assessed the responses of professionals who have been employed in underground mining with the intention of collecting pilot data regarding mine rescue and self-escape training. The survey is comprised of two major

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sections: mine rescue and self-escape practices and technologies. In addition, the demographic profile of the respondents was also assessed. The survey recorded responses with most questions using a modified Likert scale, typically ranking sentiments across five categories (strongly agree to strongly disagree). The use of Likert-styled responses was selected during survey design for ease of data analysis and to emulate a more quantitative study environment. The MRSES asked a total of 29 questions. Eleven questions were posed regarding demographic information and mine rescue and 12 were posed regarding self-escape practices and technologies. The remaining six questions focused on personal protective equipment and gear fit. Although these questions were included for the sake of collecting pilot data, personal protective equipment and gear fit fall outside the scope of this paper.

The mine rescue section of the MRSES collected information on respondents' roles within their operation and years of experience, then rescue training frequency, training modalities, perceptions of training frequencies and preparedness, and perceptions of the inclusion of digital training methods for mine rescue teams. The self-escape practices and technologies portion of the survey collected responses to questions of the use of unmanned ground vehicles for aid in self-escape, frequency of self-escape training and perceived preparedness in emergency situations requiring self-escape, and the role of gamified modalities for self-escape training.

This survey was developed in an online format and distributed to 65 individuals employed in the underground mining industry in the United States and across commodities that had previously been identified as having involvement in their operation's health and safety oversight. As shown in Table 1, the 41 respondents indicated the role that most closely matched their day-to-day work at their operation. This allowed some flexibility in responses from respondents who were not necessarily the primary health and safety professional at their operation. Distribution of the survey began in the Fall of 2022. The MRSES was available to participants for a total of 12 months to allow for an adequate number of responses for data analysis. After the 12-month survey

Table 1 Job roles of respondents

Current role	Count
Health/safety professional	23
Supervisor	10
Other	4
Engineering	1
Administration	1
Maintenance	1
Total	41

Table 2 Respondents by years of experience

Years of experience in the mining industry	Count
10+ years of experience	31
5 to 10 years of experience	6
3 to 5 years of experience	1
0 to 3 years of experience	3
Total	41

period, the MRSES was closed for responses, and analysis of responses began with a focus on grouping responses into three main categories: training exercises and perceived preparedness (Sect. 3.1), the benefit of digital technology in training (Sect. 3.2), and the use of self-escape tools (Sect. 3.3).
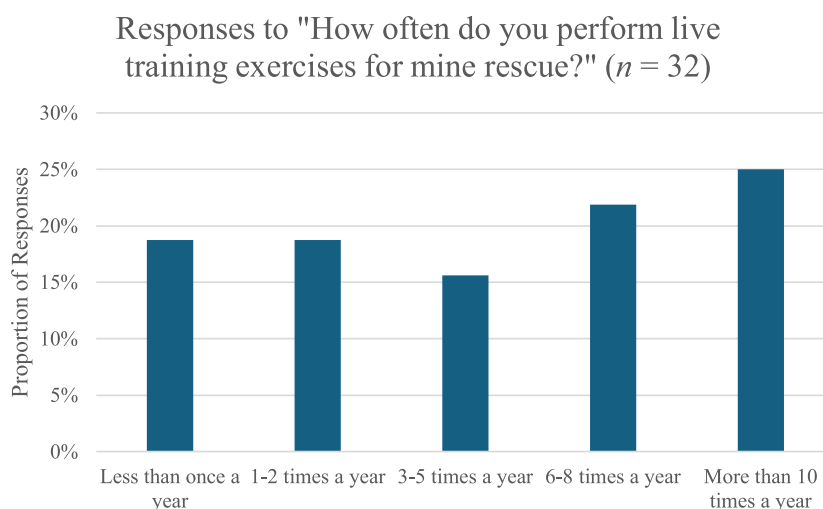
3 Results

Overall, 41 anonymous respondents were a part of this study with 65 surveys distributed, resulting in a 63% response rate. These workers had various career roles and levels of experience. Tables 1 and 2 highlight the occupational groups of survey respondents and years of experience. Health and safety personnel accounted for 56% of the respondents (n=23). Twenty-four percent of the respondents were supervisors (n=10). Additionally, there was one mine rescue team member, an engineer, and one administrator among the respondents. Because respondents were prompted to select the role that most closely matched their day-to-day work, there may exist some disagreement behind how individual respondents define each role or in cases where dual roles apply. This discrepancy may be a cause for the variability seen in job roles, as all individuals invited to participate in the MRSES had previously been identified as working in health and safety-related roles for their operation.

Nearly 75% of the respondents (n=31) had more than 10 years of experience in the mining industry, including experience in surface and underground mining. Respondents with 5 to 10 years of experience represented 14% of the survey population (n=6). The five remaining respondents had between 0 and 5 years of experience ($<$10%).

3.1 Training Exercises and Perceived Preparedness

This survey assessed the frequency of live rescue training at respondents' worksites. Live training exercises included the use of fog machines to reduce visibility and perform search and rescue as well as mapping drills under supplied air from Draeger BG4s. Thirty of the 41 respondents chose to answer questions on the frequency of live rescue training operations.

Fig. 1 Reported frequency of live training exercises

Responses to "How often do you perform live training exercises for mine rescue?" ($n = 32$)
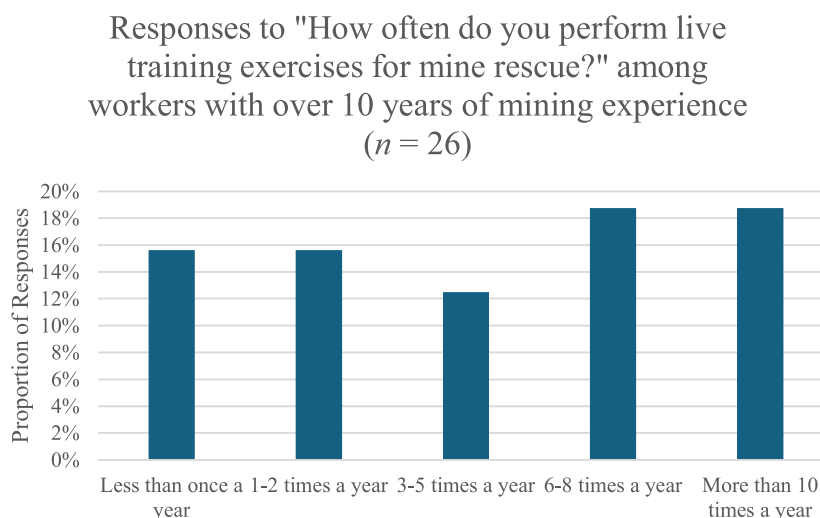
Among that group, 15 respondents had a relatively higher frequency of six or more live rescue training operations per year. Eight of these 15 respondents reported more than ten live training sessions per year (Fig. 1).

Respondents with less experience reported receiving less frequent live rescue training than those with more experience. Among workers with more than 10 years of experience, there is a wide range of training frequency, as displayed in Fig. 2. This highlights the need for a uniform and effective enforcement of well-defined live training sessions, regardless of underground mining experience or supervisory position. Reducing between- and within-group variability may help to elucidate causal factors of emergency preparedness that are currently obscured by high variability in training type and frequency.

This survey also evaluated respondents' sense of preparedness for an actual mine rescue situation. None of the respondents with 1 to 3 years of mining experience reported feeling "very prepared" for the next real mine rescue situation

at their site. Furthermore, despite being the individuals with the most mining experience, the same number of respondents with ten or more years of experience reported feeling "very prepared" as feeling "neutral" and "unprepared." The responses to the question about training frequency indicated that employees with more experience get more frequent rescue training, so the number of "very unprepared" experienced miners led to an exploration of the relationship between training frequency and incident preparedness.

To determine if a statistically significant relationship existed between the two responses, a Kruskal-Wallis test was performed relating respondents' frequency of live mine rescue training exercises and their sense of preparedness for an actual mine rescue situation. With a threshold of $p = 0.05$, there is no evidence from this survey that the frequency of training meaningfully impacts perceived emergency preparedness ($p = 0.677$). Similarly, a Kruskal-Wallis test was performed to compare the duration of respondents' mining experience. With $p = 0.579$, there does not exist substantial

Fig. 2 Training frequency for respondents with more than 10 years of experience in the mining industry

Responses to "How often do you perform live training exercises for mine rescue?" among workers with over 10 years of mining experience ($n = 26$)

evidence to claim that mining experience has a meaningful impact on perceived emergency preparedness within the findings of this study.

Moving away from rescue preparedness in the event of an emergency, respondents were likewise asked about their perceived preparedness in self-escape scenarios. Once again, with a Kruskal-Wallis test comparing training frequency and self-escape preparedness, a value of $p = 0.388$ indicates that the frequency of self-escape training has no significant impact on the perception of preparedness for an emergency requiring self-escape. This may be indicative of a need to re-evaluate current training modalities and methodologies, rather than increasing the frequency of live training exercises for mine rescue and self-escape. Analyzing the factors behind the variability in training frequencies and perception of preparedness lies outside the scope of this survey. Investigations that include information on commodity and different mining techniques may help to identify trends of preparedness and frequency not seen in the MRSES responses.

The lack of evidence for improved preparedness with increased frequency of training is unsurprising. Training frequency alone does not suffice for perfect preparation in any situation. Blended training methods have been shown to increase intrinsic motivation in learners while improving learning outcomes [14]. This also corresponds to a noticeable increase in learner engagement and satisfaction. Flexible teaching modalities, like those that include a range of live training, digital learning, and dedicated review, have likewise been shown to lead to improved long-term learning outcomes [15]. The impact of increasing training frequency alone on learning outcomes is still generally unclear, with results differing between cohorts, and the current thought that there may exist a ceiling limit at which increasing training frequency does not provide a meaningful improvement in learning outcomes [16, 17].

Through this survey, we also assessed the confidence that respondents had in their sites' mine rescue teams. Thirteen respondents strongly agreed that they had confidence in their team, while 11 somewhat agreed. Seven respondents answered as neither agreeing nor disagreeing, one respondent responded as somewhat disagreeing, and one respondent answered as disagreeing. When considering health and safety personnel exclusively, the plurality of respondents felt highly confident in the capabilities and preparedness of their sites' mine rescue team. Among respondents in supervisory roles, the plurality of respondents reported that they felt somewhat confident in the capabilities of their mine rescue team (Figs. 3, 4, 5, 6, and 7).
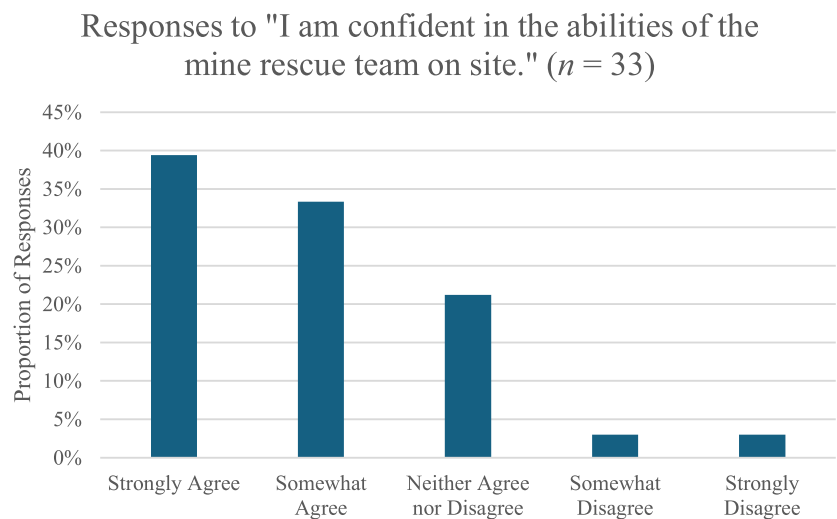
In all, 20 respondents reported that they felt it important to have more frequent live mine rescue training sessions. Ten responded that it was somewhat important, and less than five respondents reported that they neither agreed nor disagreed with the idea of increasing the frequency of live training exercises. Of the 20 respondents who felt it important to increase the frequency of live training exercises, 15 had over 10 years of experience in the mining industry. Similar held true when asked about increasing the frequency of self-escape training exercises.

No respondents felt it explicitly unnecessary to increase the frequency of self-escape training. Twenty respondents either agreed or somewhat agreed to an increase in self-escape training frequency, and seven neither agreed nor disagreed to an increase in training frequency.

3.2 Benefit of Digital Technology in Rescue and Incident Training

This survey also asked respondents to select which rescue teaching tools have been used in their regular training from a list of common modalities. Figure 8 displays a
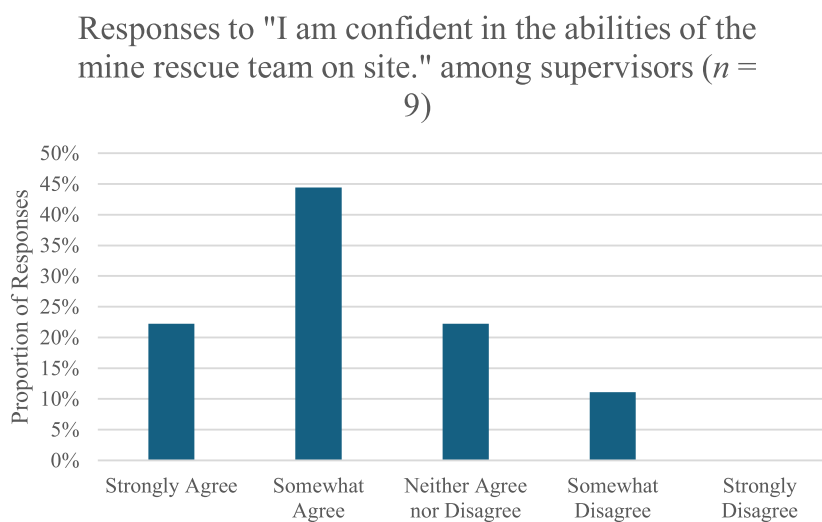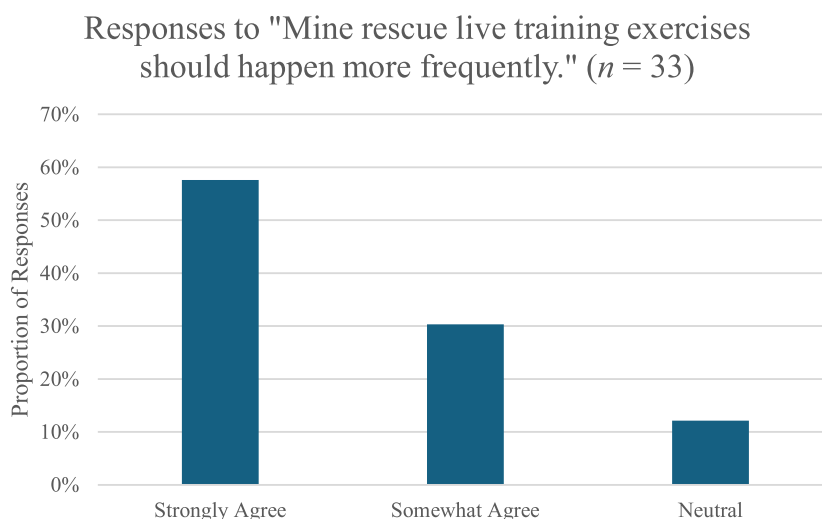
Fig. 3 Reported confidence in mine rescue teams

Responses to "I am confident in the abilities of the mine rescue team on site." ($n = 33$)

Fig. 4 Confidence in mine rescue teams for respondents who identified themselves as health and safety professionals

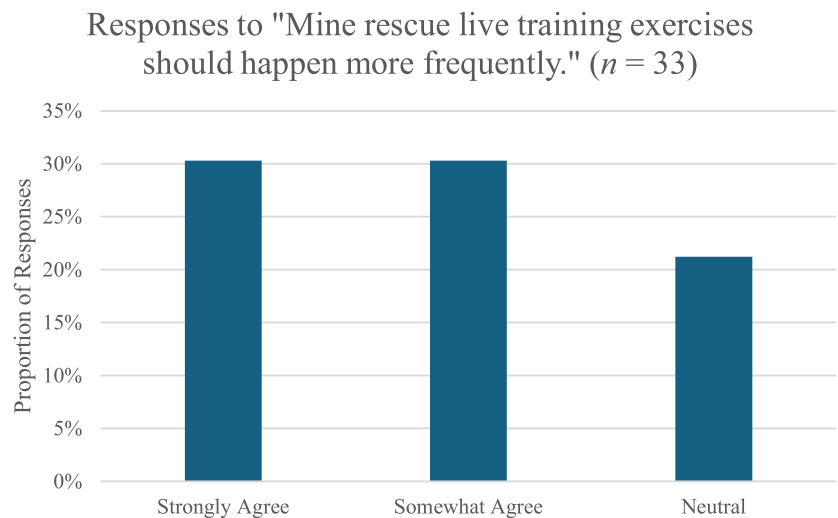Responses to "I am confident in the abilities of the mine rescue team on site." among Health and Safety professionals ($n = 18$)

Fig. 5 Confidence in mine rescue teams for respondents who identified themselves as supervisors

Responses to "I am confident in the abilities of the mine rescue team on site." among supervisors ($n = 9$)

Fig. 6 Recorded responses for an increased frequency in live training exercises

Responses to "Mine rescue live training exercises should happen more frequently." ($n = 33$)

Fig. 7 Recorded responses for an increased frequency in self-escape training

Responses to "Mine rescue live training exercises should happen more frequently." (*n* = 33)
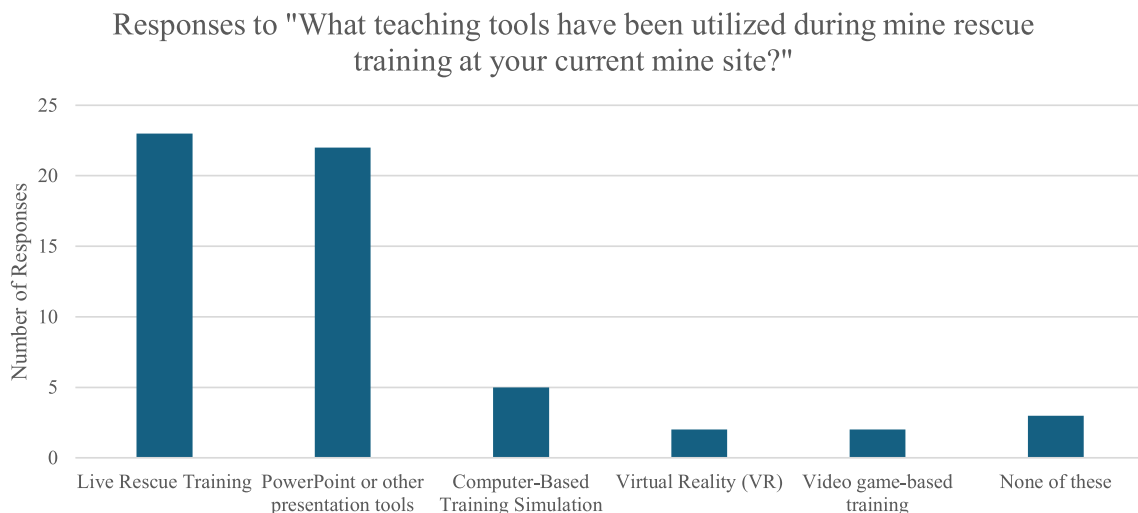
histogram of responses. The dominant teaching methods for rescue training are live training and PowerPoint or similar slideshow presentations. Multiple training modalities are often implemented concurrently to increase comprehension and preparedness. Respondents selected multiple responses to the question to reflect all of the methods through which they are trained. The common pairings stand out as displayed in Fig. 9, in which the total responses have been cataloged into the most common groups. Over half of the responses to questions regarding teaching tools used a combination of live rescue training and PowerPoint instruction. More individuals receive solely live rescue training than solely slideshow presentations.

The same teaching tools question was asked about the tools used at the respondents' current sites to teach self-escape. The results in Fig. 10 indicate that live training is the predominant meth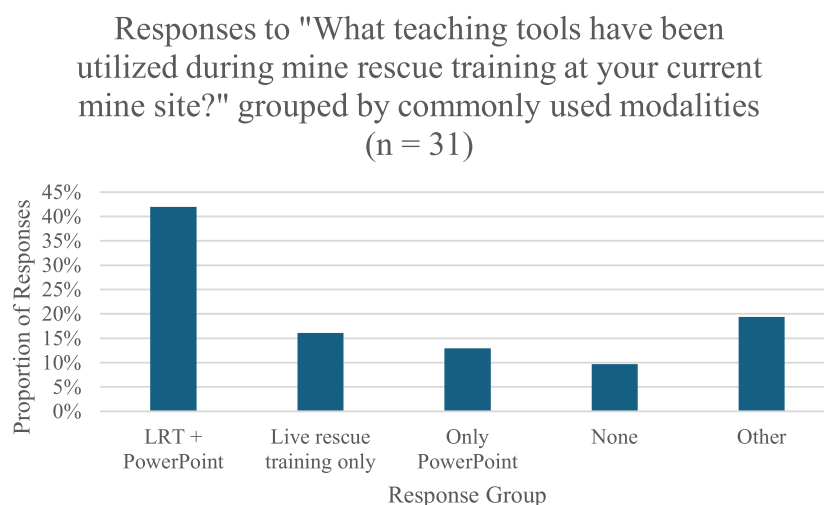od for self-escape training. The majority of respondents train for self-rescue with live evacuation practice sessions. Like with rescue training, PowerPoint or similar presentations are the second most common training tool, with 23% of responding individuals using presentations as their main self-escape teaching method. The diminished presence of PowerPoint presentations in comparison to live scenarios reflects the growing awareness of a classroom presentation's limited capacity for information retention and for relaying the complex practical understanding of a mine that is necessary for safe self-escape and rescue operations [10]. The shift away from PowerPoint-based training is further underscored by evidence that slideshow presentations offer no meaningful improvement in learning outcomes when compared to other teaching methods [18].

Workers were prompted for their opinion of how helpful digital rescue training can be for mine rescue preparedness. Digital rescue training was explicitly described

Responses to "What teaching tools have been utilized during mine rescue training at your current mine site?"

Fig. 8 Histogram of teaching tools used for rescue training (multiple selections permitted)

Responses to "What teaching tools have been utilized during mine rescue training at your current mine site?" grouped by commonly used modalities (n = 31)

within the MRSES as self-contained computer-based training resources including VR and computer simulation, but excluding slideshow presentations or the presentation of videos. The results are compiled in Fig. 11. One respondent considered the incorporation of digital resources as "not useful," while 16 respondents felt that digital resources "may be useful," and 11 respondents felt that digital training modalities and resources were "useful." Of respondents with 0 to 5 years of experience, all reported that the inclusion of digital training modalities and resources might be useful. While two respondents with 5 to 10 years of experience were likely to find digital training resources useful, one respondent from this category shared that the inclusion of digital training resources was not useful, and the other felt that the inclusion might be useful. Among respondents with over 10 years of mining experience, all reported that digital training modalities and resources are useful or might be useful. Twelve respondents indicated that the inclusion might be useful, and the remaining nine indicated that the inclusion is useful.
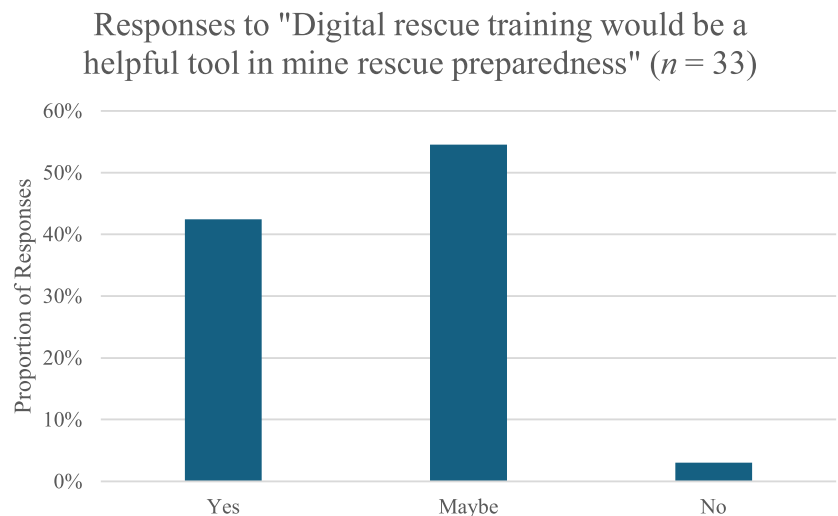
The uncertainty surrounding the adoption of digital training modalities is not directly clear through responses obtained from survey participants. A potential answer may lie in the double immature burden. The double immature burden suggests that the technology underpinning digital training platforms is not yet well-established and widely accepted and that operations are not logistically prepared to adopt new training modalities. The combination of these two factors can lead to additional hesitation from mining operations to adopt new technologies, training, or otherwise [19]. Adoption of digital training modalities outside of slideshow presentations is low for rescue and self-escape training, as indicated in Figs. 8 and 10. Despite this, there is still a sizeable volume of ongoing and prior research on the development of digital training tools [6, 10–13]. The double immature burden may begin to explain the results obtained from the survey, but studies across a wider portion of the mining industry are warranted to better capture perceptions among those not in health and safety, training, or supervisory roles.

Responses to "What teaching tools have been utilized during self-escape training at your current mine site?"

Fig. 11 Perceptions of the usefulness of digital training modalities for mine rescue

Responses to "Digital rescue training would be a helpful tool in mine rescue preparedness" ($n = 33$)

3.3 Tools for Safe Evacuation

Respondents were asked to evaluate their perception of the value of unmanned ground vehicles (UGVs) for use in mine rescue operations. All but two of the respondents were either unsure of their value or felt that they served a benefit to rescue operations. This indicates a general sense of openness to the adoption of such technologies in the industry. However, the unsure respondents made up a significant portion ($n=8$) of the response. This could be attributed to the history of UGV failures in highly publicized mine rescue efforts, including at the Crandall Canyon Coal Mine and the Midas Gold Mine in 2007, in Utah and Nevada, respectively, where robots were unable to navigate the extreme terrain and were essentially unhelpful to the rescue efforts [20] (Fig. 12).
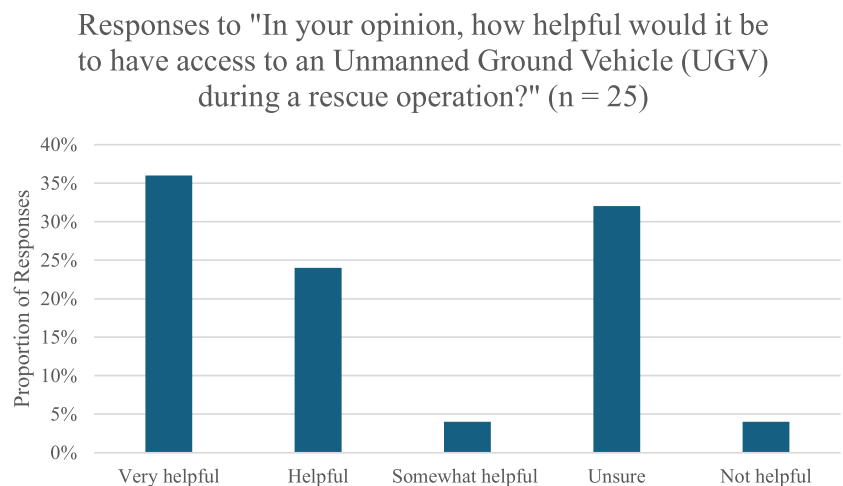
A study conducted by NIOSH in the aftermath of the above-mentioned mining disasters highlights that in addition to technical knowledge, mine-specific knowledge, and conceptual knowledge are core competencies for successful self-escape in emergency situations [1]. The mine-specific knowledge includes information about the mine maps, the escapeways, the ventilation system, the location of self-contained self-rescuer (SCSR) caches, and the mine's emergency response plan. In this survey, around 90% of the respondents felt that mine mapping was extremely important, as outlined in Fig. 13.
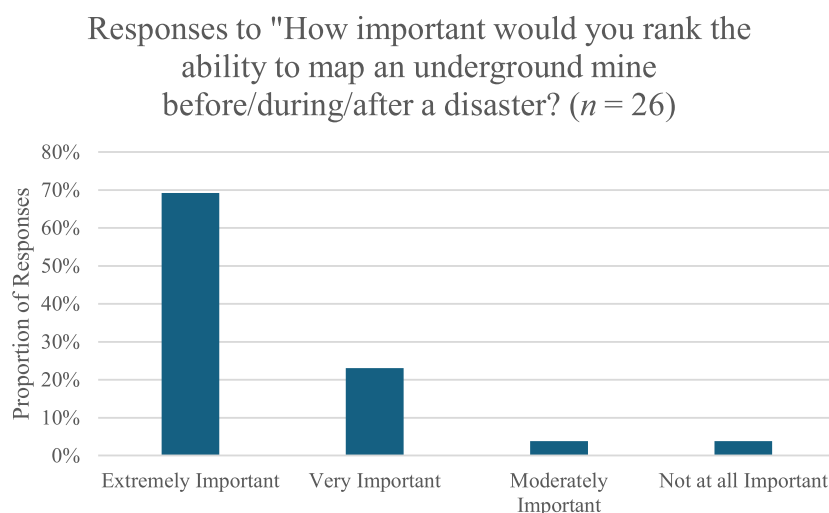
Respondents were asked to share their level of comfort with their current tools and equipment for self-escape and with digital training modalities for self-escape preparation. The respondents were largely comfortable with both, but slightly more so with current tools and equipment. On the whole, respondents were either extremely or somewhat comfortable with tools and equipment and digital training (Fig. 14).

Emergencies always happen unexpectedly and present unique sets of challenges, but providing miners with more opportunities to practice making decisions in environments that replicate the environment in which escape will occur

Fig. 12 Respondents' perception of the use of UGVs

Responses to "In your opinion, how helpful would it be to have access to an Unmanned Ground Vehicle (UGV) during a rescue operation?" (n = 25)

Fig. 13 Perceived importance of mine mapping

Responses to "How important would you rank the ability to map an underground mine before/during/after a disaster? ($n = 26$)

has been found to increase their odds of successful self-escape [3]. The overwhelming majority of respondents had confidence in their abilities to navigate the mine during a self-escape situation, as outlined in Fig. 15. Among 23 respondents with over 10 years of experience, 19 were confident (either strongly agree or somewhat agree) in their abilities to navigate the mine during a self-escape situation, and one felt somewhat lacking confidence.
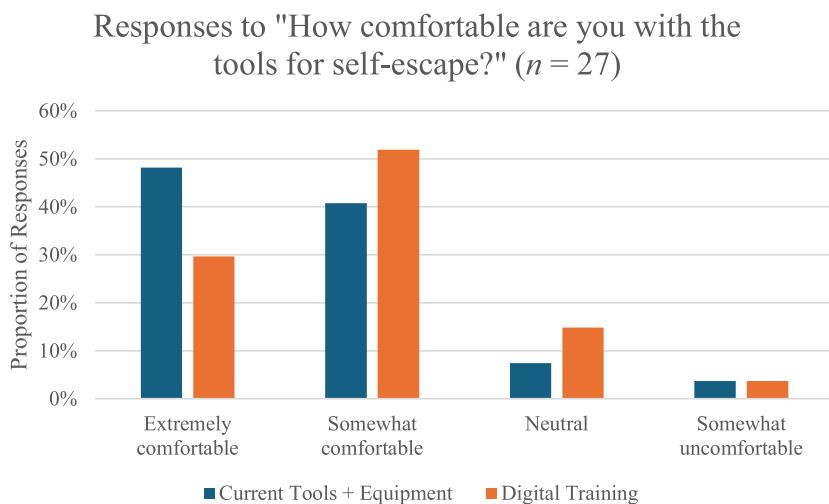
4 Discussion

On the whole, respondents felt that training exercises for mine rescue and self-escape should be more frequent, despite an indication that higher frequencies of training do not have an impact on perceptions of preparedness. Respondents were overwhelmingly confident in the abilities of their mine rescue teams, but this confidence did not necessarily translate to 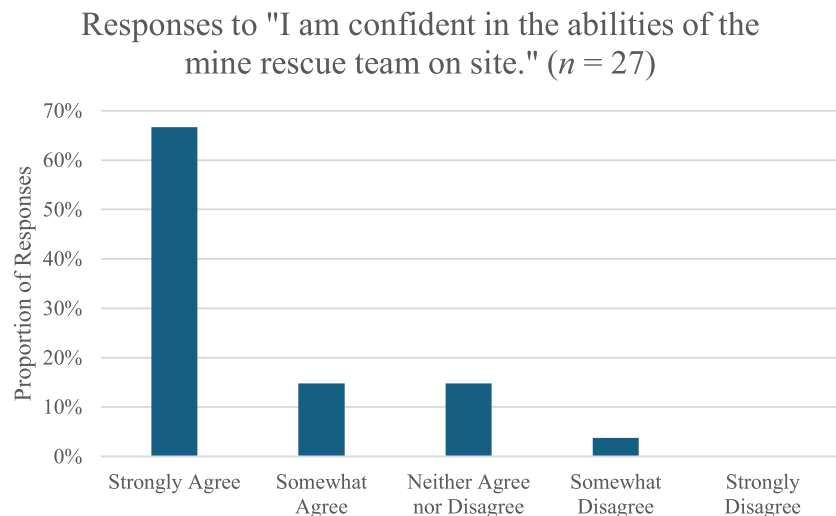confidence in their own abilities during emergency situations. For the purpose of rescue training, live exercises and slideshow presentations remain the preferred modalities, but the use of computer-based training simulations, virtual reality, and video game-based training is beginning to be adopted as supplements to traditional training methods. Perceptions of the use of digital modalities for training are largely viewed with indifference or positively, most likely based on a lack of widespread adoption.

Respondents felt largely comfortable with currently used self-escape tools and acknowledged the importance of up-to-date mine mapping in the case of an emergency. Of respondents incorporating digital training in self-escape preparation, the majority felt more comfortable with their inclusion.

The set of respondents clearly skews towards those with more experience and towards those in health and safety or supervisory roles. This is a natural consequence of inviting individuals previously identified as having involvement in their operation's health and safety oversight. Future work

Fig. 14 Reported comfort with current self-escape tools and digital training for self-escape

Responses to "How comfortable are you with the tools for self-escape?" ($n = 27$)

■ Current Tools + Equipment ■ Digital Training

Fig. 15 Perceived confidence in self-escape scenarios

Responses to "I am confident in the abilities of the mine rescue team on site." ($n = 27$)

should focus on collecting responses from a more diverse set of underground mining professionals. Because the MRSES was delivered in an online-only format, it may be beneficial to conduct further investigations in person at underground mining operations. This may help to reduce barriers to providing responses, as well as allow for future investigators to assess current states of training methods and self-escape preparedness. In-person visits to mining operations will allow for future surveys to collect data from a larger number of miners and will better represent the role-based demographics of the mining industry. It should reasonably be expected that workers not involved in health and safety oversight may have different feelings of preparedness in emergency situations. Likewise, they may not have the same perceptions of the inclusion of digital training modalities or feel it appropriate to increase training frequencies for rescue and self-escape. Follow-up work in this manner will provide a stronger basis to better guide the development of additional training technologies.

While some demographic information was collected in the mine rescue section of the MRSES, this survey did not ask about respondent's gender, height, or weight. Analysis of perceptions across various demographic groups may yield an important insight into motivating social factors underlying operational health and safety culture. Likewise, the inclusion of other types of mining operations (surface mining in addition to underground mining) alongside various commodities (coal, metal, non-metal) can provide a more holistic understanding of existing gaps in training and operational safety culture. With a small sample size to serve as an entry point for further investigation, findings between gender, type of mining operation, and commodity would likely have required non-parametric testing with low statistical power. As a result, further studies will consider these aspects across

a much larger sample size collected across several in-person site visits.

5 Conclusion

The MRSES was designed to compile a snapshot of current perceptions of preparedness across the mining industry, with a focus on mine rescue and self-escape. Sixty-five individuals were invited to participate in this survey, all of whom had been identified as working in roles related to health and safety oversight for their operations. This survey collected responses from 41 individuals over a 12-month period for a response rate of 63%. Questions in the MRSES were grouped into three major categories covering mine rescue, self-escape, and personal protective equipment. The analysis of responses where then grouped into three major themes: training exercises, digital technology in training, and tools for self-escape.

In all, the MRSES provided an initial insight into the current state of mine rescue and self-escape, focusing on perceived preparedness in emergency situations with respect to training modalities and training frequency. While more work is indicated to expand the findings across a more diverse sample set, the MRSES shows an indication that the inclusion of digital training modalities is desired, but there still exists some uncertainty of their usefulness or implementation. Respondents feel relatively prepared to operate safety-critical self-escape equipment, but still somewhat lack confidence in self-escape and mine rescue situations. Critically, an increase in training frequency does not necessarily correlate to increased perceived preparedness. Instead, future work should most likely focus on the design and implementation of novel digital training modalities to assess their impact of perceived preparedness as the industry looks to better equip underground miners for emergency situations.

Data Availability Data presented in this work are available upon reasonable request to the corresponding author.

Declarations

Conflict of Interest The authors declare no competing interests.

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