MODIFYING BEHAVIOR TO IMPROVE MINERS' HAZARD RECOGNITION SKILLS THROUGH TRAINING

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ABSTRACT

This paper discusses the application of psychological principles to the critical problem of hazard recognition by miners. The U.S. Bureau of Mines identified fundamental psychological principles that could be employed to enhance the ability of miners to recognize and respond to threats in their dangerous work environment. The goal of this work was to identify concepts that could potentially lead to interventions to improve miners hazard recognition abilities and to modify their behaviors. An innovative training program, adapted from techniques used to train military observers in the identification of camouflaged targets, was developed by Bureau researchers and used in a hazard recognition study. This study, of the effectiveness of such an intervention, is presented to illustrate the feasibility of applying psychological principles to the task of hazard recognition. As researchers hypothesized, underground miners trained using visually degraded (realistically camouflaged representations of mine hazards) instructional materials, performed better on a follow-up hazard recognition performance measure than did miners trained using traditional materials in which hazards are made visually conspicuous for easy recognition. The authors suggest that this type of instructional material and this method of instruction are generally applicable for hazard recognition training in a variety of work environments.

INTRODUCTION

Training in the "recognition and avoidance of hazards present in the mine" is mandated in 30CFR, Part 48 for new miners, newly employed experienced miners and for all miners' hazard training. Additionally, annual refresher training commonly includes discussions that relate to hazardous conditions found in the mine. Most of this training is conducted in the classroom and consists of looking at "highlighted" visuals of hazards and/or engaging in group discussions about hazards observed in the workplace. Even though these discussions provide important safety information for the worker, they usually occur after a particular incident happens. In far too many cases, that incident may have been prevented if the miner had recognized a hazard and responded to it.

The failure of miners to recognize hazards has been identified as an important contributing factor in many ground control accidents over the years. In one accident, for example, a miner helper was killed by a fall of roof while installing temporary support for setting line brattice inby permanent support. The accident involved a 7-ft by 7-ft by 7-in thick slab of the immediate shale roof. Investigators reported that although the fallen slab was not a true kettlebottom, it was similar in shape. It was nearly circular in plan view and was bounded on one edge by a slickensided surface. It appeared that the rock separated along this slickensided edge. The investigators concluded that the victim, who had 36 years of mining experience, failed to detect the loose rock condition and placed himself in an unsafe position while advancing the line brattice.

The question naturally arises as to whether this victim could have been trained to a level of skill that would have prevented making the error that led to his death. Theoretically, the answer is yes. Bureau researchers theorize that if hazard recognition skills of miners can be significantly improved, then the number of mining accidents may be reduced.

Toward this goal, the Bureau developed a hazard recognition model that incorporates those perceptual skills, cognitive resources and behavioral strategies that miners may need to deal with hazardous conditions in the workplace (see Figure 1). This paper discusses the model and the results and implication of a study conducted to test an intervention for improving miners' ability to recognize hazards.

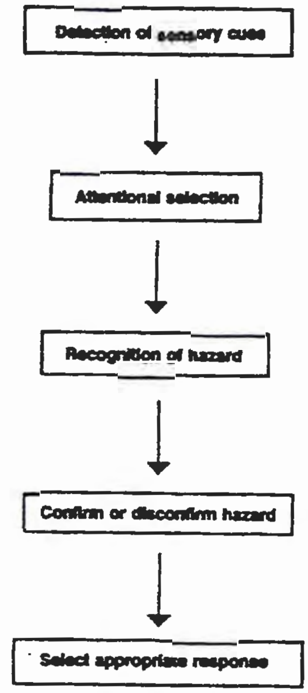

Figure 1. Stages in hazard recognition

MODEL

Hazard recognition is viewed as a complex task with sensory, perceptual and cognitive components. It is a process underlying purposeful identification and the process is applicable in numerous situations including transportation safety, industrial operator vigilance and military target acquisition. Although there are many different ways to conceptualize the hazard recognition process, the authors suggest that in order for an individual to respond to danger from a potential hazard that individual must perform the following:

1) detect the presence of potentially relevant sensory cues or features in the environment; often this takes the form of discriminating "figures" from the other stimuli serving as "ground." In signal detection terms, the hazard "signal" must be discriminated from the extraneous "noise" of mine operations. Factors that may influence the sensory discrimination of hazard features include illumination levels, the apparent color and brightness contrast of the features with their environment, the "embeddedness" of the hazard, and the acuity of the observer.

2) selectively attend to a subset of those features either overtly or in an automatic fashion, favoring them with further processing; the amounts of sensory input that can be attended to will generally be limited by how automatically (subconsciously) the observer is functioning, the ability of the observer to timeshare cognitive resources between tasks, and the mental workload experienced.

3) correctly recognize the pattern of features that identify a particular hazard; experience or training furnishes the information that the cues have been differentially associated with the presence of the hazard in the past and thus are

"diagnostic" of that hazard. In addition, the degree to which the often degraded "real-world" image of the hazard is consistent with the observer's cognitive representation of the hazard will influence the speed and accuracy of recognition.

4) test the initial hypothesis of the recognition or denial of a hazard by searching further for confirming or non-confirming evidence, the search being guided by some mental representation or schema of the nature of the hazard and the general environment of the underground mine. Since people seem generally reluctant to try and disconfirm any tentative hypothesis they hold (Watson, 1968); the efficacy of this stage will be determined by the ability of the observer to avoid a simple "confirmatory bias."

5) consider and select an appropriate response to the identified hazard. To a certain extent this depends upon the subjective evaluation of risk by the observer; simply because a potentially hazardous condition has been identified does not mean that the observer views it as a personal threat that compels avoidance. Objective danger does not always elicit an appropriate response if there is no personal, subjective assessment of danger (Benda & Hoyos, 1983).

An example of the application of this model to mining might be a situation where an underground shuttle car operator, in the process of transporting coal from the mining face to the evacuation point, driving at high speed under varied lighting conditions is required to identify a hazard. The operator at some point may detect a presence in the path of the shuttle, perhaps initially simply as a glimmer of reflected light or the impression of movement ahead. The operator may then focus more attention on the stimulus, either consciously or automatically attempting to discern the nature of the object: What is its shape? Its size? Its speed?

The initially ambiguous sensory impressions (a faint outline, a gleam of light) may be interpreted as the presence of reflective tape or a swaying cap light on a human form, and thus the mental picture emerges of a miner walking across the path of the shuttle car. The operator has then recognized that these cues signal a potentially hazardous event, a collision with a worker. Presumably the operator will continue to attend to the hypothesized "worker" ahead, testing his interpretation by searching for more confirming (non-confirming) details. Once the operator has achieved a necessary amount of confidence in his interpretation of the hazard, he has a variety of responses to consider, depending on the proximity of the miner, the miner's behavior, and the braking capabilities of the shuttle. Of course, all of these "stages" in responding to a hazard are likely to be accomplished swiftly and perhaps with little conscious awareness of discrete steps in the process.

It is important to note here that hazard recognition is a *process* and in reality it is very difficult to divide it into neat stages. The steps in the process are overlapping and occur rapidly. A hazard must be discriminated from many cues. Several factors, as mentioned above, influence the ability to discriminate between many different cues and detect the relevance of those cues. The concept of embeddedness is one of those factors. Previous research (Witkin, Dyk, Faterson, Goodenough, and Karp, 1974) has shown that individuals who are field-independent (as opposed to field-dependent) are better able to isolate and identify relevant stimuli that are embedded in a distracting, irrelevant background. It is interesting to note that this ability has little to do with reaction time. It is only when the target stimulus is embedded or "camouflaged" within a complex visual scene that field-independent perceivers enjoy superior reaction times indicating that their advantage lies in the early *detection* of hazard cues and not in the interpretation or recognition of those cues once they are seen (Mihal and Barrett, 1976). This research suggests that certain individuals can detect hazard cues better than other individuals.

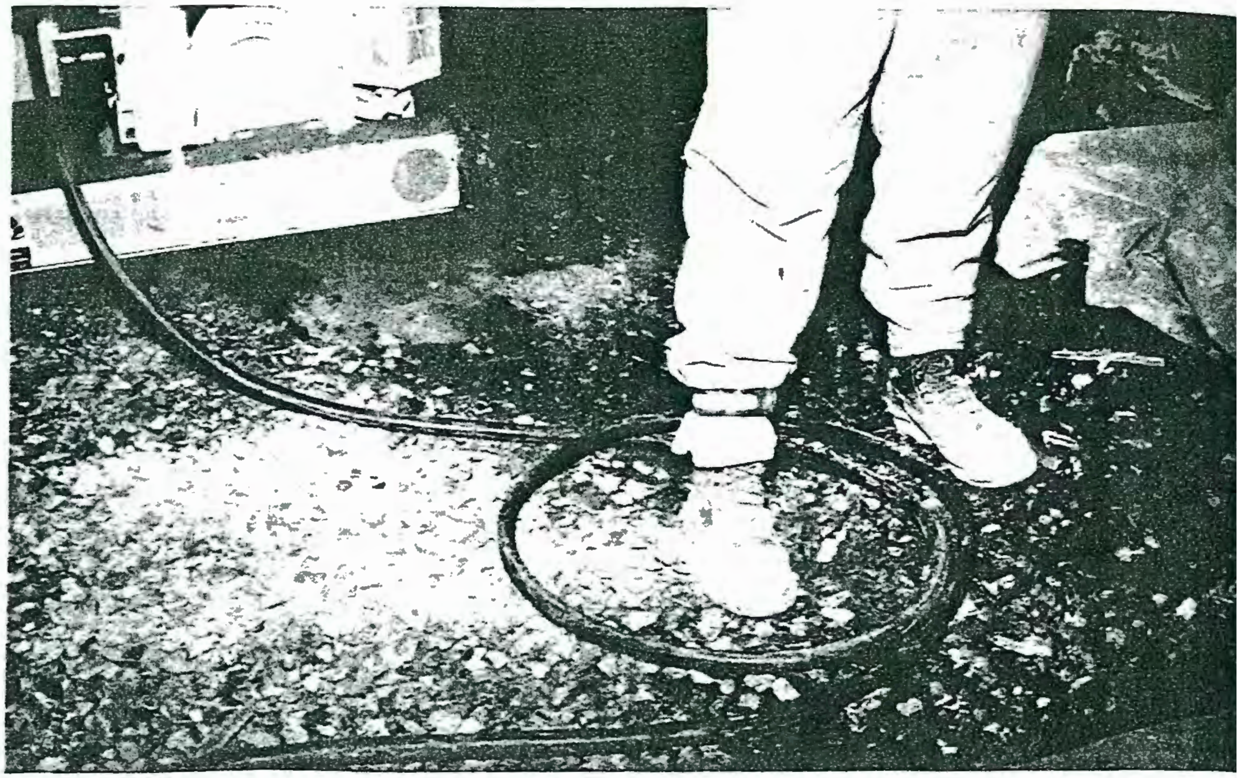

Figure 2. Highlighted Scene

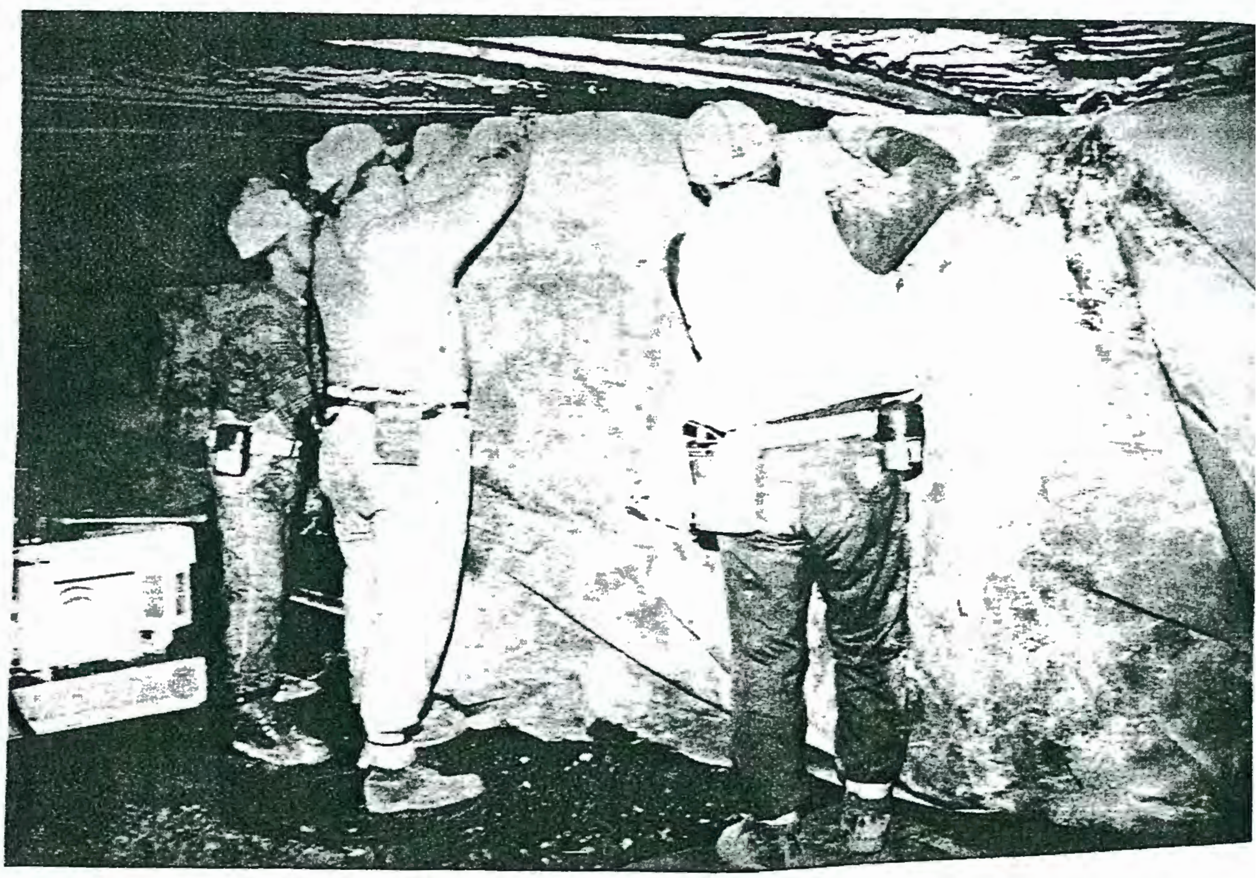

Figure 3. Degraded Scene

Cockrell (1979) conducted an experiment and confirmed that observers attempting to recognize targets in naturalistic settings must get accustomed to seeing these targets under less than optimal (degraded) condition such as the target being partially hidden from view, observed from an eccentric angle, viewed through haze or dust, or inadequately illuminated. In his experiment, observers were asked to correctly identify slides of model cars that had been "degraded" to some extent by obscuring significant portions of the cars; observers who had also been trained using degraded views produced the most consistently accurate identifications. Observers trained using clear, complete photographs of the cars suffered a reduced ability in their identification performance when confronted with the partially obscured stimuli in testing. Thus the author concluded that training with camouflaged or "degraded" stimuli proved to be advantageous in accuracy of later identification.

Another explanation for the advantage of training with "degraded" targets may be attributed to the variability of the training stimuli. To facilitate information processing, individuals often store mental representations of typical targets or situations, often referred to as "prototypes." These mental prototypes are often arrived at by abstracting the defining or most typical features of the targets (Franks and Bransford, 1971; Posner and Keele, 1968). In a way, the observer has a variety of related experiences he somehow "averages" into a prototypical experience, or what may be thought of as the best example of those experiences. Training for hazard recognition using visually degraded stimuli will present him with a more representative sample of the natural variation in appearance he is likely to observe in the actual environment. The observer will tend to abstract or construct a more useful representative prototype that can be used to facilitate the identification of new stimuli. It could be expected that in training miners to recognize hazards and dangerous situations in their highly variable and often visually "degraded" environment, it would be desirable to give them experience with equally variable representations of these hazards in the training presentations. Practice with a series of normally distributed variations on common hazards should stimulate trainees to actively generate their own prototypical mental models of these hazards. This tends to be useful as their expertise develops and they become proficient at matching these mental models to new conditions in the mine. On the other hand, exposing trainees to a limited set of professional well-lighted photographs or slides of hazards taken at close range will unlikely provide them with a sense of the variation they are likely to see on the job, limit their ability to abstract a usefully complete prototype of the hazard and deprive them of the realistic contextual and background features that facilitate real-world hazard identification. Bureau researchers tested the hypothesis that miners trained using degraded training materials (slides) would be more proficient at identifying hazards than miners trained using more traditional or highlighted training materials. Examples of a highlighted slide and a degraded slide are shown in Figures 2 (highlighted) & 3 (degraded).

Figure 2 shows a miner's foot positioned within a trailing cable loop on the mine floor. This type of highlighted scene is traditionally used by trainers to explain the potential dangers of tripping or the sudden take-up cable on a reel. Figure 3 is a degraded scene showing several hazards. The most obvious one (highlighted in Figure 2) is the miner's foot in the cable loop. More subtle, but equally important, potential hazards in Figure 3 include working in a confined area between equipment and rib, working without gloves and safety glasses and placing tools on equipment where they could be knocked off and injure a worker.

STUDY

Control (highlighted hazards) and experimental (degraded hazards) training modules were developed for use in Part 48 annual refresher training class. Slides were selected for the modules based upon whether the targeted hazard was conspicuous (highlighted or easily seen) or whether it was visually degraded in some way (partially obscured, competing with other stimuli, or in a peripheral location). Eighty-two mine workers were recruited from 10 separate annual refresher training classes in cooperation with mining companies in three states: Pennsylvania, West Virginia, and Alabama. Four of the classes consisted of miners working in track (haulage) mines in Pennsylvania, another four classes from belt mines in Alabama and the remaining two classes of miners from various belt mines across West Virginia. Participants were requested to report their age, the number of years of experience they had in mining and their current job classification. The first column in Table 1 presents a breakdown of the overall group of subjects with regard to their distribution across the three states, the type of mine in which they work, their job classifications, the reported ages of the miners, and their years of experience in mining. The two remaining columns in Table 1 summarize this same information for miners assigned to the control group and the experimental group, respectively.

The number of miners recruited from each class varied from a minimum of five persons to a maximum of 12 persons. Although the classroom instruction was considered part of their annual refresher training and all attendees received this instruction, participation in the post-instructional test phase of the study was voluntary and several miners declined participation. Assignment of subjects to either the control (highlighted) group or the experimental (degraded) group was accomplished by alternately designating an entire class of subjects at each site to receive instruction using either the traditional slides of "highlighted" hazards (control group) or the degraded hazard views (experimental group). In both conditions, eleven instructional slides (depicting a combined total of 35 hazards) were displayed to the class for five seconds per slide, after which a Mining Industry Specialist reviewed the slides and discussed the multiple hazards depicted in each. The procedure for the training phase was similar for both control and experimental groups, except for the manner in which hazards were pictured in the training slides.

After the training phase, participants in both control and experimental groups were tested individually on an assessment task which presented them with a sequence of 10 slides illustrating a total of 36 known hazards; subjects examined each test slide for five seconds and then reported any hazards identified to the experimenter. Scores were computed by tallying the number of correctly identified unsafe conditions. The highest possible score a participant could receive by identifying each hazard as well as recognizing the one slide depicting no hazardous condition was a 37. Subsequent to the study, an item review, conducted as part of the overall analysis revealed a possible bias on the assessment task with regard to three items all of which depicted a miner not wearing safety glasses. As part of the degraded training, the experimental group had observed two instances of miners not wearing safety glasses while the control group observed no such hazard as part of the highlighted instruction. This difference may have given the experimental group an unfair advantage in performing the tasks and consequently these three items were deleted from the assessment task, reducing the highest possible score to 34.

RESULTS

The results indicate that scores on the assessment task for the experimental group were statistically significantly higher than scores for the control group. Means and standard deviations were computed on the scores for the experimental (degraded) and control (highlighted) groups. Differences between the means were analyzed using the independent sample's t test. Since the

Table 1. Frequencies and Descriptive Statistics of Demographic Information for Overall Sample, Control Group and Experimental Group

Description	Overall Sample	Control Group	Experimental Group
State of Mine Location:			
PA Track mines	32(39%)	16(38%)	16(40%)
WV Belt mines	21(26%)	9(21%)	12(30%)
AL Belt mines	29(35%)	17(41%)	12(30%)
Total	82(100%)	42(100%)	40(100%)
Job Classification:			
Production:			
Longwall	6(7%)	3(7%)	3(7.5%)
Continuous Miner	20(25%)	14(33%)	6(15%)
Management	3(4%)	0	3(7.5%)
Subtotal	29(36%)	17(40%)	12(30%)
Support:			
Maintenance	14(17%)	7(17%)	7(17.5%)
General	34(41%)	16(38%)	18(45%)
Management	5(6%)	2(5%)	3(7.5%)
Subtotal	53(64%)	25(60%)	28(70%)
Total	82(100%)	42(100%)	40(100%)
Age of Workers:			
Mean	40.6	40.2	41.1
Std. Dev	6.94	7.35	6.56
Years Mining Experience:			
Mean	16.4	15.8	17.1
Std. Dev	5.10	5.61	4.46

Table 2. Means, standard deviations(SD), and results of *t* test for examining differences in performance scores between the control and experimental groups.

Group	Instructional Method	Number of miners	Mean score	SD	*t*-value
Control	Highlighted	42	11.8	4.0	
					2.57*
Experimental	Degraded	40	14.0	3.8	

$^{*}p < .01$.

Table 3. Score means and standard deviations (in parentheses) by Demographic Groupings of the Overall Sample, Control Group and Experimental Group

Description	Overall Sample	Control Group	Experimental Group
State of Mine Location:			
PA Track mines	14.9 (3.5)	13.3 (3.0)	16.5 (3.3)
WV Belt mines	10.8 (3.7)	9.7 (4.1)	11.7 (3.4)
AL Belt mines	12.2 (3.9)	11.5 (4.3)	13.1 (3.2)
Job Classification:			
Production	12.6 (4.9)	12.1 (4.7)	13.2 (5.3)
Longwall	12.7 (3.9)	14.3 (5.1)	11.0 (1.7)
Continuous Miner	11.6 (4.8)	11.6 (4.7)	11.5 (5.4)
Management	18.7 (4.0)	-	18.7 (4.0)
Support	13.1 (3.3)	11.6 (3.5)	14.4 (3.1)
Maintenance	13.7 (3.7)	12.0 (2.7)	14.3 (3.7)
General	12.8 (3.6)	11.2 (3.4)	14.3 (3.1)
Management	14.6 (4.2)	13.5 (7.8)	15.3 (1.5)

expectation was that the experimental group would obtain a higher score than the control group, a one-tailed *t* test was performed. The computed statistics are reported in Table 2.

A summary of the average scores obtained on the task by demographic subgroupings of miners within the overall sample is provided in Table 3. These subgroupings represent a breakdown of the overall sample relative to the state in which the miner works and their job classification as listed previously in Table 1. The first column of Table 3 lists the mean scores for the subgroups within the overall sample while the remaining two columns list mean scores for the control and experimental groups, respectively. Comparing the means between the two groups, the average scores for the experimental group exceed those obtained by the control group in all but two of the subgroupings.

Note that a comparison for the production managers could not be made since there were no production managers assigned to the control group. However, for miners classified by job under Longwall Production and under Continuous Miner Production, the average scores were higher in the control group than in the experimental group, suggesting that the effectiveness of the degraded training varies across job categories. Although the study was not designed to examine differences across job categories, a closer scrutiny of the data offers some explanation for the observed discrepancies in the outcome. In the case of the Longwall production miners, given the small number of persons (n=3) within each of the groups, a meaningful interpretation of any computed difference in the means is not realistic. Additionally, an examination of the standardized residuals (predicted scores minus obtained scores) identified two outliers (unusually high or low scores) within the overall sample. One of these outliers, an unusually high score, was obtained by one of the Longwall miners in the control group and its effect on the mean is reflected in the relatively high standard deviation (5.1) computed for that group. The second outlier, an unusually low score, occurred among the scores within the Continuous Miner Production category for the experimental group. If this outlying score were eliminated, the resultant mean (13.0) computed for the five remaining miners would now exceed that obtained by the 14 miners in the corresponding control group (11.6). Both of these examples illustrate the effect of extreme scores (high or low) on the mean when small sample sizes are involved.

The intent of providing the information listed in Table 3 is to address the concern that the experimental group was predisposed to performing better than the control group by initial differences between the groups in their ability to recognize hazards rather than being due to differences in the type of instruction provided. Although time constraints prevented researchers from pretesting participants on their hazard recognition abilities, the demographic information obtained is useful in determining whether miners were more or less evenly distributed across the two groups on relevant demographic variables. As mentioned previously, there were no production managers in the control group, and as can be seen in Table 3, the three production managers assigned to the experimental group had the highest average score (20.3) of all the subgroupings. However, when the overall sample was reduced by eliminating these three managers, the resultant *t*-value (2.14) remained statistically significant (df = 77, $p < .05$). Additionally, eliminating management from the sample also eliminated any advantage the experimental group may have had in terms of the previously observed differences in age and years of mining experience. Any other differences in the distribution of miners with regard to state (and type of mine haulage) or job classification appear to be negligible or favor the Control group. The conclusion is therefore that miners instructed using the degraded hazard approach were able to identify more hazards on a hazard recognition task than miners instructed by the traditional highlighted approach as a result of the type of instruction they received.

IMPLICATIONS

The authors suggest that since the miners in this study who were subjected to degraded training showed improvement in their ability to recognize mining hazards, the use of degraded scenes might be helpful in improving the overall ability of miners to recognize and consequently avoid hazards in the dangerous mining environment. The development of site specific degraded slides and programs is a low cost way to target specific health and safety issues. The major cost of developing such a program is in the staging, taking of the slides, evaluating and validating the degraded materials. It is suggested that this concept could readily be applied to other mining situations such as metal/nonmetal, surface mining operations, and/or preparation facilities. Bureau researchers are actively working with several mining companies to develop hazard recognition training based on the degraded training concept.

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