UNDERSTANDING MINERS' HAZARD RECOGNITION SKILLS: A PSYCHOLOGICAL PERSPECTIVE

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ABSTRACT

This paper presents selected perceptual concepts found in the literature that may be applicable for research on improving the hazard recognition skills of miners. The literature review includes the areas of psychology, the military literature, especially target detection, and the transportation and safety literature. The goal of this search was to target appropriate concepts, theories and principles to utilize as a basis for improving hazard recognition training and to enhance the perceptual skills of miners. Four specific areas are discussed: 1. Degraded targets 2. Time sharing 3. Search strategies including the nature of expertise and 4. Selected theories of individual differences such as field dependence/field independence, cognitive mapping and risk-taking behavior. The authors include suggestions for applications. These concepts are applicable to all areas of mining, coal and metal/nonmetal, surface and underground where the recognition of hazards is a critical task for workers.

INTRODUCTION

Through the years the Bureau has accessed the various bodies of literature generally referred to as the "hard sciences", specifically chemistry, mathematics and physics. This information has provided a basis for research in fires and explosions, ventilation, ground control, and in better and safer ways for man to mine the earth's minerals. We are in a new time in our industry. Our technology has advanced. Our ability to design and operate safe mines is a credit to the industry, as leaders have responded and made changes based on new information gleaned from research in these "hard sciences".

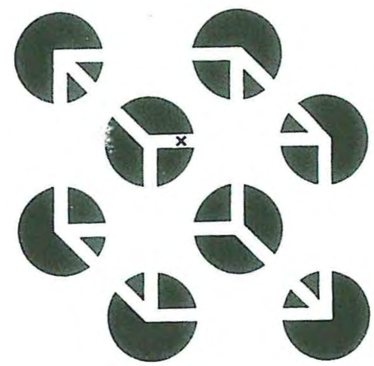
From 50% to 80% of all industrial accidents each year are attributed to human error (*1*). In our industry, the etiology of recent mine injuries and fatalities is increasingly attributed to the human behavior factor (*2*). The application of principles from the behavioral sciences has the potential for making a substantial contribution to health and safety in the mining industry. In the study of individual and group behavior, patterns emerge which can increase our understanding of motivating safe behavior, enhance performance of routine skills, add to our knowledge of successful management/ worker relationships, and augment our comprehension of the general principles of organizational development. Exploring this body of literature offers the promise of new and safer work behaviors for miners, improved ways to educate miners for hazard recognition and safety on the job, and enlightened techniques for balancing the interaction between safety and productivity.

We have advanced to a point in the U.S. mining industry that safety and production are viewed as being intertwined. Recognizing, controlling and eliminating hazards is clearly an integral part of the mineral extraction process. Yet the unremitting query remains: how can we better detect and respond to hazards in the dangerous mining environment? How can we improve the hazard recognition skills of workers?

The Bureau concluded from earlier investigations that the failure of miners to recognize hazardous roof conditions had contributed to many groundfall accidents (*2*). In one of these studies, circumstances leading to roof fall fatalities that are documented in Mine Safety and Health Administration (MSHA) accident investigation reports were reviewed. It was noted in many of these reports that the failure of miners to recognize hazardous conditions was a contributing factor in the accidents. For example, in one report an "undetected" kettlebottom fell from the roof near the face and caused fatal injuries to a worker. In another, an "undetected" horseback formation fell and caused fatal injuries to a miner who was scaling the roof nearby. The direct causes of these accidents, as reported, were the "failure to detect" hazardous conditions. The workers failed to perceive the potential danger.

Thus, it is an appropriate time for the industry to turn its attention to the "soft" sciences, the behavioral sciences such as psychology, for answers. It is fitting to access a body of knowledge relatively new to the mining industry to provide answers to the question, "How can we improve miners' hazard recognition skills?"

The psychological literature informs us that recognizing a hazard is a human perceptual task. The ability to perceive the hazard is a precursor to responding to that hazard. Perception is a complex procedure. The Necker Cube shown in Figure 1 serves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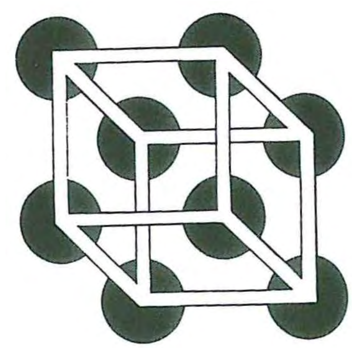
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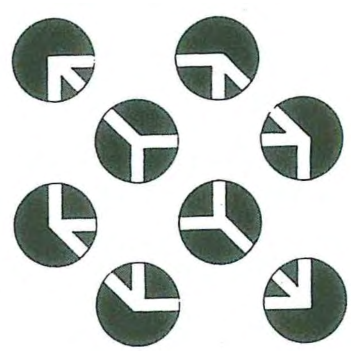
(c)

Figure 1.-The necker cube

as one example of this. With the Necker Cube, the shaded surface can appear as either the front or rear of the transparent cube (a). If you look at the cube for awhile, your perception will alternate between the possibilities (b) or (c). Another example of the complex nature of perception is shown in Figure 2. This is an illustration of how the same sensation (stimuli) can produce different perceptions depending upon your *perceptual set*. Whether you see a young woman or an old woman is dependent upon your knowledge, your experience and the information you are given, ie. your perceptual set. By analogy, a mining hazard serves as a stimulus and a miner's recognition and response reflects his/her perceptual set.

Figure 2.-Perceptual set

Usually when psychologists discuss perception, it is linked with sensation. *Sensation* is defined as the process by which certain stimulus energies are detected and encoded. It is the stimulation of the sense organs. *Perception* is defined as the process of organizing and interpreting sensory information, enabling us to recognize meaningful objects and events. Sensation may be thought of as encoded neural information which is then organized by the brain as a perception that leads us to a response. It is important to note that, in reality, sensation and perception cannot be separated. They exist in tandem, overlapping and interacting.

For our purposes the term perception will serve as a broad characterization of the stages through which a miner must progress in order to respond to cues associated with job hazards. The literature bases in visual search, perceptual skills, aptitude and individual differences, and employee selection issues and personnel testing were examined. In addition, general psychology, military target training, safety, transportation and human factors were explored, as well as operator vigilance in industrial settings. The literature on human information processing and the development of expertise in complex tasks was also investigated.

This paper presents four areas from the research in human perception which appear to have potential for impacting our understanding of a miner's task of hazard recognition and for improving worker skills in this area. The four areas include **Degraded Targets, Time Sharing, Search Strategies** including expertise, and selected theories of **Individual Differences** which concern field dependence/field independence, cognitive mapping, and risk taking behavior. These concepts are applicable to the perception of all hazards at coal and metal/nonmetal, surface or underground mine locations. Some of the concepts will more dramatically impact one area. The initial presentation, Degraded Targets, exemplifies this distinction in that the application to the underground environment is immediately apparent.

DEGRADED TARGETS

In general, an underground mining environment offers the worker who is trying to identify possible hazards a selection of consistently degraded visual and auditory targets. The identifying features of the hazard may be poorly illuminated, minimally distinguished by contour or contrast, masked by coal dust, concealed from direct view, or embedded in an assortment of competing stimuli. An example of this is shown in Figures 3 and 4. What hazards do you see in Figure 3? You may note the water, soft bottom and loose bolts, but do you see the "bad top" in the upper right roof area? That hazard is highlighted in Figure 4; whereas, in Figure 3 it is embedded in an assortment of competing stimuli and is poorly illuminated. Laboratory research suggests that visual degradation of a stimulus hinders its correct identification by slowing both the initial stimulus encoding process and the search for that stimulus in memory. The perceiver finds it more difficult and, consequently, it takes a longer time to construct a "cleaned up" mental representation of the target stimulus and to correctly identify it. In addition, when the mental representation of the stimulus is compared with the contents of memory for identification, each comparison operation takes longer to carry out because of the degradation still present in the mental representation (3).

One aspect of the visual degradation of hazards in mining with implications for the training of miners to recognize hazards is gleaned from the military research on target detection. This research suggests that if the target stimuli to be searched for and identified are under degraded conditions, perceivers should be trained to recognize them using training stimuli that are similarly degraded (4). This means that training stimuli should be similarly masked or embedded in a cluttered background. Refer again to Figures 3 and 4. According to this theory, hazard detection training would be more successful if Figure 3, the degraded target, is used rather than Figure 4, the highlighted target.

This information purports that when teaching miners to recognize a specific hazard such as loose, hanging roof rock, the visual presentation should be within a realistic environment and not highlighted. The typical format for hazard recognition training used by most mine trainers is to show slides in the classroom. These slides generally highlight specific hazards coupled with a verbal admonition, "if you see this, avoid it." The mining industry may benefit from designing training programs according to the theory behind military target training and the recognition of degraded stimuli: train with materials that are degraded, like the hazard the miner must identify.

TIME SHARING

In understanding how humans process information, an important consideration is the issue of attention. In most information-processing models of accident causation, selective attention to environmental cues is a primary explanation for accidents. In studies completed in South Africa on hazard perception, a reoccurring theme was the miner's *failure to perceive* the signals leading to an accident (5, 6). Many models of attention propose that an observer's perceptual selectivity is enforced by limited cognitive resources; the assumption is that a "bottleneck" of information processing develops. The observer cannot attend to all stimuli simultaneously. It follows that if the observer's ability to attend is limited, then attention must be divided or shared. The stimuli compete for priority. This is not to say that humans can only perform one task at a time in serial fashion; people seem to

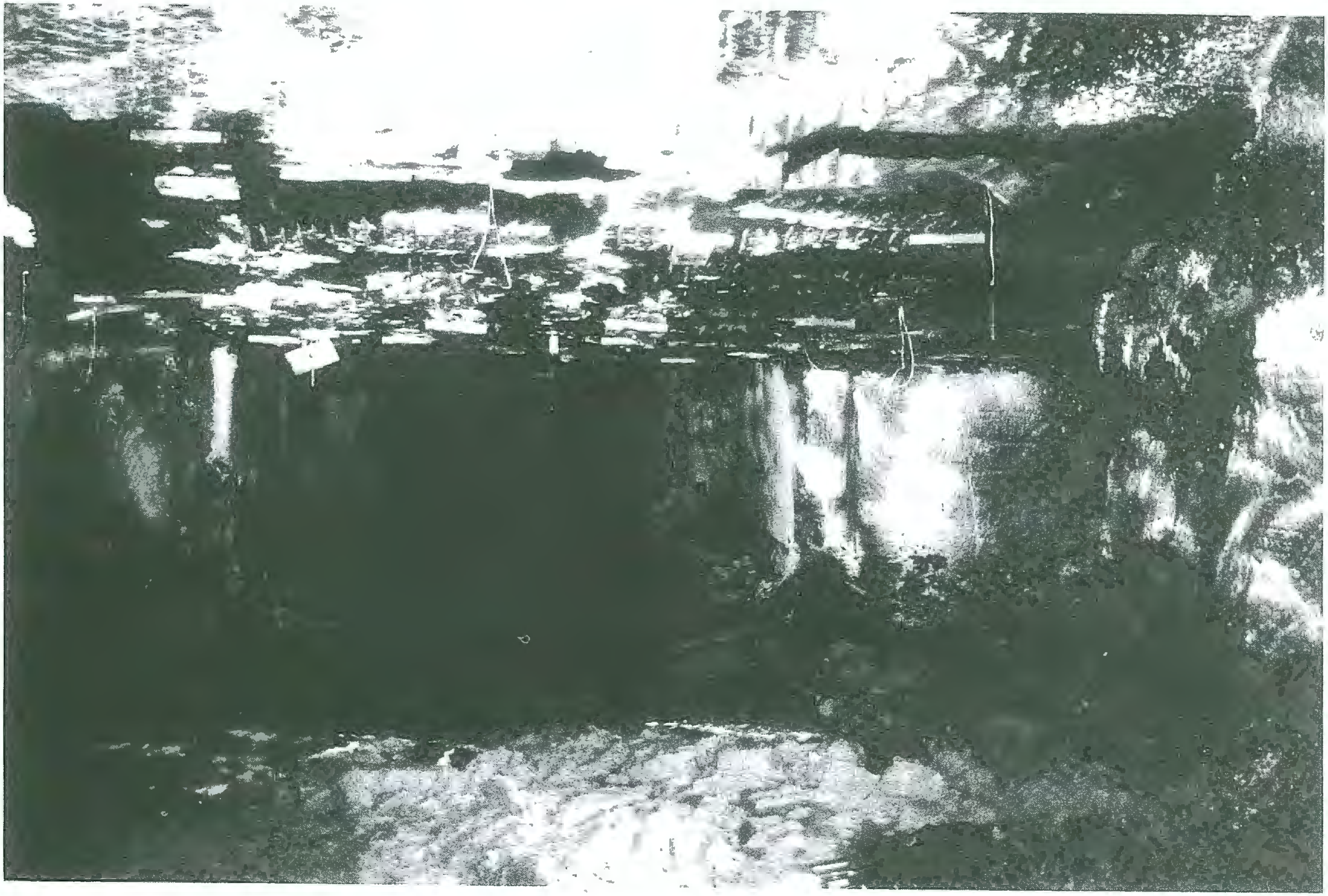

Figure 3.-Mine scene showing embedded hazard

Figure 4.-Mine scene showing highlighted hazard

process information in parallel fashion on certain tasks and can "time-share" between tasks, if they are not too difficult or if the tasks are familiar.

While there are a few exceptions, hazard recognition is a task that is time-shared with production; thus, the workload of the miner is likely, at least partially, to determine his or her ability to respond to hazards. If hazard identification must be accomplished concurrently with actual production-related tasks, like the operation of mining equipment, or becomes relegated to the status of a secondary task, then the available data seems to suggest that the competition for attention resources will decrease the efficiency with which hazard cues will be detected (7, 8). The research on the perception of hazards by automobile drivers finds that one of the most consistent correlates of risk is high "mental load" on the driver; traffic situations determined to be the most hazardous are those that present the operator with the greatest number of stimuli (9, 10). The concept of time sharing, when applied to the task of hazard recognition, could have implications for how we train miners to identify hazards. The mental load of different jobs underground and the experience of the miner in that job would impact the "share" of attention that hazard recognition would command. Experience and practice in a specific job or training in hazard recognition raises the next relevant concept, Search Strategies.

SEARCH STRATEGIES

It has been observed that the amount of attention necessary to complete a task will vary depending upon how familiar that task is. With increasing practice, a task requires less and less focused attention, and with a great deal of practice, the task may appear to demand almost no conscious attention at all. Activities that can be completed with little or no conscious attention are often referred to as *automatic processes*, as opposed to *controlled processes* which require the active attention and intervention of the observer (11, 12).

Controlled information processing is:
* relatively slow
* serial (sequential, step by step mental operations)
* effortful
* consciously monitored
* limited by the cognitive workload of the task

Automatic information processing, on the other hand, is:
* comparatively fast
* parallel (simultaneous operations may be performed)
* mostly effortless
* executed below conscious awareness
* less affected by cognitive workload
* the product of considerable practice and experience with the task.

Hazard recognition may be viewed as one of the many perceptual-cognitive tasks that the miner must learn to perform consistently, while meeting productivity requirements of the job at the same time (time sharing). If job-related behaviors and mental operation tend to become automatic with consistent practice, the reduction in the workload will allow greater attention to be directed to a systematic search for potential hazards in the mine environment. The automatization of work behavior results in a dividend - more time for the task of hazard recognition.

Expertise

Viewing hazard detection as a skill and acknowledging that skills can be learned, the question of expertise arises. What differentiates an expert from a novice? How might this distinction relate to the task of hazard recognition or to improved training? Psychologists have attempted to determine the essential attributes that define "expert" judgment and problem solving. A person possessing expertise in some domain is usually thought of as making rapid, confident decisions even under pressure, and as being, in general, more accurate in their judgments than an inexperienced "novice" (13). Expert performance, regardless of the domain, appears to be qualitatively distinct from the performance of a novice in several ways:

1. Experts have acquired a greater knowledge base and skill set in their field as a function of greater experience.
2. Experts have organized their knowledge into well-developed mental models or representations of their field that serve to guide thinking.
3. Experts display superior pattern recognition; they perceive large, meaningful patterns in their field.
4. Experts process information in their field more automatically; they process faster and with less conscious effort.
5. Experts attempt to understand problems in terms of underlying principles rather than their superficial aspects.
6. Experts are good self-monitors; they are alert for their own errors and failures.

Two types of expertise may be relevant to the consideration of mining safety: expertise concerning the performance in the assigned mining job itself, and expertise in the identification of hazards. The development of expert-level competence in performing mining work suggests that the routine mechanics of the work are automatic, leaving additional processing capacity for the task of detecting risky stimuli or situations. In studies of the eye movements of expert drivers, researchers have found that because experienced drivers have routinized the operation of the vehicle, they did not have to check their position relative to the curb or their speed as frequently as did novices (14). Expert drivers did, however, allocate more attention as measured in frequency of eye fixations to rear-view mirror and side-mirror monitoring. Expert drivers also appeared to visually scan a much larger area of their visual field, with the average fixation point relatively distant in advance of the vehicle. Novice drivers, on the other hand, rarely sampled the rear-view or side mirrors and visually sampled a smaller proportion of the visual area in front of them; novices preferred to glance more often at the speedometer and to monitor their distance to the curb more closely. For inexperienced drivers then, the lack of expertise means that more attention must be allocated to the task of controlling the vehicle, with fewer resources remaining to track the presence of other traffic in the vehicle's mirrors. By analogy, the miner with a high degree of job related expertise should be able to spare more visual scanning time for the purpose of detecting potential hazards.

In studies of expert chess players, the principle advantage they have is the superior ability to recognize familiar patterns of the game pieces as they appear on the board. When expert and novice chess-players were allowed 5 seconds to study slides of chessboards as they might appear in a game, and then asked later to reconstruct the positions of the pieces on the board, the expert chess players correctly positioned more than 20 pieces while the novice players could place only 4 or 5. Later, when the experiment was repeated with the pieces in a random configuration, unlikely to be observed in a real game, the recall performance of the expert players dropped to that of the novice (15). Thus, it appears that the expert has stored configurations of possibilities, memorized patterns or mental schemata from which to draw in problem solving.

Studies in expert visual search support this notion. Experimental measurement of eye-movements shows that experts seem to scan for patterns as opposed to "inch by inch" searches. The eye movements of experienced radiologists indicate that their eye movements, as they search the x-ray film, are indicative of a "top-down" processing - an information processing directed toward some goal by knowledge of patterns or specific structure or schemata. Expert radiologists do not appear to exhaustively or systemically scan the entire film area, but instead in the first few seconds attempt to match the overall pattern of the x-ray to a pertinent anatomical schema in their memory; the evoked schema then is used as a kind of "map" to guide subsequent search of the film (16, 17). After a brief, orienting scan in which the overall pattern of the film is recognized, expert radiologists shift their gaze rapidly to those regions that are most informative and diagnostic within the pattern they have determined.

In an analogous fashion, the cognitive representations developed by miners as they achieve expertise in mine operations will influence their perception of hazards. Experienced miners, as with experienced chess players and experienced radiologists, may generate schemata of patterns, circumstances and risk sequences that represent potentially hazardous situations. Expertise in hazard detection may develop as a consequence of learning to respond to a series of "automatically" recognized hazardous situations.

INDIVIDUAL DIFFERENCES

There are many ways to look at the problem of hazards in the workplace. Personnel may be trained in the necessary skills or persuaded to adopt the type of attitudes that would enhance safe behavior; the workplace might be redesigned or the job redefined (as with Job Safety Analysis); or employees may be selected on the basis of their presumed pre-existing ability to avoid hazards on the job. This last approach assumes that workers are measurably different in personal traits or habitual behaviors that relate to the likelihood of having an accident in the workplace; this paradigm depends on the assessment of individual differences that can be demonstrated to predict "accident proneness." Insurance companies predict accident probabilities using demographic variables; for example, unmarried males under 25 years old have been found, as a group, to have relatively more traffic accidents than the rest of the population and their insurance premiums, in most states, are adjusted accordingly. (Note: in some states unisex laws have equalized the premiums for male and female even though males, as a group, have more traffic accidents.)

Individual accident prediction is more problematic than group prediction; relatively few of the many individual differences investigated have proven to be useful in predicting the likelihood of a worker being involved in an accident (18). The most reliable predictors of the ability to avoid work-related accidents appear to be perceptual aptitudes such as visual acuity. The most common test of recognition acuity since 1862 has been the familiar Snellen eye chart, seen in many doctors' offices. If the perception of potential hazards in mining is principally a function of detection and correct recognition of visual cues, then individual differences in the visual acuity of mine workers may be related to their ability to avoid accidents. Visual acuity is related to accident rates; injury free groups of employees tend to have superior visual skills (19). With respect to other individual differences with potential relevance to hazard recognition in mining we are going to focus on three specific areas: field dependence/field independence, cognitive mapping, and risk taking behavior.

Field Dependence/Field Independence

A perceptual-cognitive style which has been investigated extensively with regard to its influence on the detection of hazards is the dimension of field dependence vs. field independence. Although most of these studies have had to do with driving, generalizations may be made to the tasks of hazard recognition that are applicable to a variety of settings. Persons who tend towards a field-independent type of perception are more able to isolate and identify important, relevant stimuli that are embedded in distracting, irrelevant background. Field-dependent observers have more difficulty in separating objects from the context or background in which they are perceived (20). There are methods of locating an individual on the field dependence vs. field independence dimension including paper-and-pencil-tests that require the person to identify a simple shape that is embedded within a more complex geometric design. This concept has been studied extensively in relation to auto safety, with the findings indicating that field independent drivers are less likely to be involved in actual auto accidents and are more infrequently cited for traffic violations. Thus field independent people appear to have a safety advantage. The most commonly cited explanation for this is that they are more sensitive to the sensory cues that serve as early warning signals of potential hazards. Field independence does not correlate with simple reaction time; it is only when the target stimulus is embedded or camouflaged within a complex visual scene that field-independence perceivers enjoy superior reaction time.

Cognitive Mapping

Cognitive maps are suggested to be the schematic mental images that summarize and allow us to manipulate information about our spatial environment. A cognitive map may be a very detailed and useful representation of our surroundings, or it may bear little resemblance to reality. In the case of miners, presumably a reasonably accurate "map" of the working area would include representations of known or anticipated geologic hazards, location of machinery, and areas of high risk. Increasing experience with an environment creates more accurate cognitive maps in the perceiver's memory, although some individuals are better at cognitive mapping than others because of differential spatial abilities (21). Some researchers have speculated that a person's "sense of direction" is related to an aptitude for constructing accurate cognitive maps of their surroundings. This concept may have interesting applications for underground miners, most particularly in the event of an emergency escape where individuals who are superior in creating accurate cognitive maps may assume leadership roles.

Risk Taking Behavior

In the past ten years there have been some interesting theories proposed concerning the level of risk that will be tolerated by an individual. Simply, these theories propose that people have a target level of risk that they will accept and even prefer in their activities; at any given time a person will compare this preferred target level of risk with their current level and will attempt to reduce any discrepancy. This individual will behave more safely when the level of risk they are experiencing is perceived to be too far above the preferred level. It would also arguably compel the person to increase their perceived level of risk if it fell below that same standard. Does this suggest that some individuals will respond to attempts to make their environment safer by actually behaving in a more dangerous way? Could it happen that miners who are aware of an increased number of safety interventions in the mine setting such as more extensive inspections, newly legislated safety procedures or more sensitive monitoring equipment may actually compensate for their diminished feelings of risk on the job by becoming less attentive to the hazard cues?

Most research indicates that moderate levels of arousal are adaptive. Either too much or too little stimulation is uncomfortable for the individual. Most people seek a moderate level of arousal by controlling the level of external stimulation: too much stimulation and they retreat to a quiet place, too little and they seek greater activity. One psychologist (22) has applied the term "Type T" personality (for thrill-seeking) to those individuals who seem to need constant stimulation and risk-taking. The researchers state that these sensation or thrill seekers are not neurotic but have a distinctly different brain chemistry. Some people have brains that keep pace with stimulation intensities; the stronger the stimulus, the more the brain responds. Other persons have some kind of inhibition that actually diminishes their response at high intensities. High-sensation seekers tend to be the former. They may need the excess stimulation to reach the level that "feels" best, their optimal level of arousal or where they perform most efficiently. Once having adapted to that level they may again need a higher degree of stimulation (23). Mining is a dangerous occupation. Does it attract the Type T personality? Or because it is such a perilous environment, does mining attract safety conscious individuals? The concept of the risk taker or thrill-seeker as applied to miners is intriguing.

CONCLUSION

The authors have presented specific concepts gleaned from the psychological literature that appear to have application to the task of hazard recognition in mining. Degraded Targets, Time Sharing, Search Strategies and Individual Differences have been discussed. Based on the questions raised, the next stage of inquiry is the development of empirical data, based upon these ideas, as they apply to miners. The Bureau is in the first phase of designing experiments to compare miners trained to recognize degraded hazards with those trained more traditionally. This inquiry could lead to a reevaluation of how we teach miners to recognize hazards in the workplace and ultimately result in a safer work environment for miners.

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