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BUREAU OF MINES
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Effects of Environmental Stressors on Vigilance Performance

By J. C. Duchon and S. D. Hudock

UNITED STATES DEPARTMENT OF THE INTERIOR

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The U.S. Bureau of Mines is conducting human factors research for the purpose of reducing accidents and improving the person-machine interface found in surface and underground mining operations. Miners are exposed to a variety of environmental stressors, e.g., extreme heat, noise, vibration, and adverse illumination, throughout the workday. Exposure to these environmental stressors has been noted in the literature to affect performance of vigilance tasks. Since impaired performance of vigilance tasks can lead to industrial accidents, further investigation of the effects of environmental stressors on human performance is warranted. A brief description of the environmental conditions present in the mining workplace is followed by a review of experiments dealing with the effects of environmental stressors on vigilance task performance. The applicability of past research to actual mining operations is considered.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

dB	decibel	in	inch
dBA	decibel, A-scale	kHz	kilohertz
°F	degree Fahrenheit	km	kilometer
ft	foot	lx	lux
ft/min	foot per minute	min	minute
h	hour	pct	percent
h/d	hour per day	s	second
Hz	hertz	yr	year

EFFECTS OF ENVIRONMENTAL STRESSORS ON VIGILANCE PERFORMANCE

By J. C. Duchon[1] and S. D. Hudock[2]

ABSTRACT

The U.S. Bureau of Mines is conducting human factors research for the purpose of reducing accidents and improving the person-machine interface found in surface and underground mining operations. Miners are exposed to a variety of environmental stressors, e.g., extreme heat, noise, vibration, and adverse illumination, throughout the workday. Exposure to these environmental stressors has been noted in the literature to affect performance on vigilance tasks. Since impaired performance at vigilance tasks can lead to industrial accidents, further investigation of the effects of environmental stressors on human performance is warranted. A brief description of the environmental conditions present in the mining workplace is followed by a review of experiments dealing with the effects of environmental stressors on vigilance task performance. The applicability of past research to actual mining operations is considered.

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INTRODUCTION

The fit or misfit of inherent human ability and limitation within the work environment is the primary focus of human factors research. Specifically, this research is concerned with the design of tools, equipment, facilities, and working environments and their effects upon the individual's interactions with such systems and system components. There is concern when the conditions under which an individual must work cause a degradation in the health, safety, and performance of the worker. The primary goal of the U.S. Bureau of Mines human factors research program is to design working environments and machinery that optimize the health, safety, and performance of the mining work force. This report reviews research findings dealing with the effects that environmental stressors have on tasks that require sustained attention, which may directly or indirectly relate to accident causation. This review was undertaken to reveal possible sources of human error that have not been previously examined to provide a foundation for further research in the Bureau's human factors program.

Safety experts agree that human error is involved in over 80 pct of industrial accidents. These accidents range in seriousness from minor slips and falls to nuclear powerplant disasters. Many of these human error accidents can be traced to impaired or lowered levels of alertness, i.e., not paying attention, missing warnings or cues, not watching where one steps, not driving carefully, etc. It is commonly observed that when individuals perform tasks that require sustained attention for extended periods of time, their performance in some situations will eventually begin to decline. This change in arousal or alertness has been referred to as the "vigilance decrement." Environmental stressors, such as extreme heat, noise, vibration, and adverse illumination, found in all mining sites, have been shown in previous research studies to alter the course of or interact with the vigilance decrement.

This report focuses on the identification and characterization of those environmental stressors that have been shown to influence the vigilance decrement. This analysis will emphasize those conditions where sustained vigilance tasks appear to be the primary concomitant of alertness decrements that relate to decreased performance and safety. Environmental stressors are viewed as interacting factors that may effect the vigilance decrement. Lowered alertness or distracted attention can occur in other situations. For example, sleep deprivation or alcohol-drug usage can cause similar reactions. A job task that is too complex, too simple, or too long may, in and of itself, cause lowered alertness. Other factors that may influence alertness include circadian rhythms, work-rest cycles, motivation, mood, morale, individual differences, smoking, illness, amount of exercise or physical labor, incentives, and rewards (*1*).[3]

This report discusses the area of alertness and environmental stressors, but only in context of sustained operations or vigilance, with special attention to mining occupations, for several reasons. First, it is felt that the study of alertness is so encompassing that it would be more efficient to focus on a smaller problem area. The vigilance decrement is a clear, precise, and measurable variable that can be validly and reliably researched in a meaningful way. Second, most previous research on alertness has been done in the area of vigilance and sustained operations. It seemed an obvious step to relate this research to conditions in mining. Third, in a study performed by Hudock and Duchon (*2*), it was found that about one-third of the occupations in the surface mining industry were rated by two independent judges with mining engineering backgrounds to require high to extreme amounts of sustained attention-vigilance. The occupations were rated on the basis that (1) the tasks involved were prolonged and continuous and lasted 30 min or more, (2) the tasks involved were boring and monotonous, and (3) there were few disruptions within the job tasks. The surface mining occupation ratings are shown as follows:[4]

High vigilance
- Auger Operator
- Barge Attendant
- Bobcat Operator
- Bulldozer Operator
- Cleaning Plant Operator
- Dispatcher
- Dragline Operator
- Drill Operator
- Dump Operator
- Fine Coal Plant Operator
- Forklift Operator
- Grader Operator
- Kiln Operator
- Power Shovel Operator
- Rotary BWE Operator
- Scalper Operator
- Scraper Operator
- Truck Operator

Medium vigilance
- Belt Man
- Brakeman
- Cleanup Man
- Dimension Stone Cutter
- Drill Helper
- Laborer
- Oiler, Greaser
- Quarry Worker
- Silo Operator

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[3]Italic numbers in parentheses refer to items in the list of references at the end of this report.

[4]Occupational titles are from U.S. Mine Safety and Health Administration, "Accident Data Analysis: A User's Guide," 1982.

Stone Finishing
Surface Miner
Tipple Operator
Washer Truck Operator
Watchman
Weighman

Low vigilance
Blaster
Boom Operator
Car Dropper
Carpenter
Coal Sampler
Communication Repair
Electrician
Highlift Operator
Machinist
Mason
Mechanic
Supplyman
Welder
Yard Foreman

Those surface mining jobs that were rated as highly vigilant had more than twice the accident severity rate[5] (96 days) as those jobs that were rated as requiring low amounts of vigilance (45 days) for 1986. Two job tasks involving driving mining machinery are worthy of note. For scraper operators, the rate (152 days) was nearly three times the rate for the surface mining industry norm (54 days) for the year 1986. Haulage truck operators had almost twice the rate (100 days) of the industry norm in the same year. In both situations, the operator was driving an easy-to-operate vehicle at low speeds, in light traffic areas, in a high-noise environment, over sparse, uninteresting terrain, with few work breaks; the driver typically worked different shifts throughout the month.

DEFINING VIGILANCE

"Man is a poor monitor" (*3*). This statement was made in an opening of a book titled "Vigilance" to describe people's lack of ability in maintaining "watch" for prolonged periods of time. There have been hundreds of articles and books that attempt to systematically study the conditions that relate to this performance degradation, often referred to as the "vigilance decrement." It is generally accepted that in most instances performance tends to decay over time. Nevertheless, in spite of, and in some cases because of, technological advances, humans are required to perform vigilance tasks under conditions of sustained operations. Therefore, in industrial and military settings, it has been critical to understand the conditions that affect the speed and severity of the vigilance decrement. For instance, in the military, national security is dependent upon human accuracy in early radar detection and signal interpretation. Therefore, since World War II, the military has sponsored a great deal of research on the exploration of the conditions of optimal vigilance and sustained operations.

In industrial settings, production, safety, and quality control are dependent upon tasks that involve sustained attention. In the mining industry in particular, missed cues or brief lapses of attention have been known to result in serious injury of the worker from roof falls, truck rollovers, forward and backing-up vehicle collisions, etc. "Alertness" can be defined as "the ability to maintain optimal sensitivity to external stimuli" (*4*). By definition, the study of vigilance is concerned with the process of maintaining attention and alertness to stimuli over prolonged periods of time. A vigilance task is "one that requires subjects to respond in some way to the occurrence of relatively infrequent and unpredictable (in time, space, or both) stimulus changes over relatively long periods of time" (*5*). These definitions should be considered only as general guidelines. It should be noted that quite different definitions exist (*6*). For instance, McGrath (*7*) proposed that among other criteria, a vigilance task must contain these attributes: (1) The stimulus to be detected must be specified; (2) the ratio of nonsignificant to significant signals should be high; (3) the signals should occur at random intervals; and (4) the response of the observer should have no effect on the probability of signal occurrence. These criteria limit tasks to simplified and controlled laboratory simulations, such as a visual signal detection. In contrast, other researchers have included a variety of tasks in their concept of vigilance, such as vehicle driving, radar operation, air traffic control, industrial inspection, and the performance of anesthesiologists during surgery. A more comprehensive definition of vigilance situations was described by Warm (*4*): (1) The task is prolonged and continuous, usually lasting longer than 30 min; (2) signals to be detected are clearly perceived by the observer when he or she is alerted to them, but may seem weak to most observers because they are not "compelling changes" in the observer's operating environment; (3) the signals to be detected occur infrequently and without forewarning; and (4) the observer's response typically has no effect upon the probability of occurrence of future signals. As the tasks in question become more like real occupational tasks, such as driving, definitions of vigilance and sustained operations must be more encompassing.

[5]Accident severity is represented by the sum of the actual number of days lost plus the number of statutory days charged plus one-half the restricted workdays charged for each accident.

However, there is a price to pay as definitions and tasks become more inclusive. It becomes more difficult to generalize results from one situation to another. For instance, although it may be found that random bursts of noise may improve performance of a visual signal detection task in the laboratory, it may not be the case that a similar noise condition will aid a long-distance truck driver. There are, in fact, many seemingly inconsistent results in some of the literature (see the section "Vigilance Performance Under Noise Conditions"), which complicates drawing specific conclusions from past research. This problem is directly relevant to mining, since tasks of interest in the mining industry are more complex, such as haulage truck operations, mechanical repairs, etc.

Operational definitions of vigilance and corresponding vigilance decrement have been as varied as the research itself. Mackworth (*8*) has been credited with being the first to study sustained operation in a systematic way. During World War II, he was asked to study the problem of missed radar signals on antisubmarine patrol. Mackworth devised a vigilance task called the clock test, which has been used in subsequent research. The clock was a simulated radar screen that showed a black pointer that moved around the otherwise blank clock, jumping 0.3 in each time. The critical signal was a double jump of the pointer, i.e., jumping 0.6 in. An observer would watch the clock for several hours at a time, indicating when the double jump was perceived. From these experiments, Mackworth concluded that accuracy of signal detection decreased most dramatically after about 30 min exposure and then gradually declined. Brief, planned interruptions would improve performance for approximately 30 min, but performance would then revert to previous low levels. The important point here is that the vigilance decrement (lowered level of alertness across time) was operationally measured and defined as a percentage of missed signals.

At least three categories of methods of measurement have been used in vigilance research: (1) psychophysiological measures, i.e., electroencephalograph (EEG), electromyograph, and galvanic skin response; (2) performance measures, such as signal detection (as in the clock test described above), errors of commission (false detections), changes in stimulus thresholds for positive detections, and response latency or response times; and (3) subjective measures of alertness and related mood states. Closer inspection of these measures shows that alertness is multidomained. That is, alertness encompasses not only biological and chemical processes in the body but also corresponds to actual performance and to subjective mood states. Any complete conceptualization of vigilance and alertness, then, should take into account these aspects.

THEORETICAL MODELS AND SPECIFIC EFFECTS OF ENVIRONMENTAL STRESSORS

Several theoretical models have been put forth to account for the effects that environmental stressors have on performance. It should be noted that, while these theories do account for many of the findings, none are fully acceptable. It has been pointed out (*9-11*) that it would be unrealistic at this time to attempt to develop a comprehensive model that explains the seemingly inconsistent findings of research. Briefly described below are the arousal model, attentional model, and control model, which attempt to explain the interaction between the vigilance decrement and environmental stressors. Also discussed are factors related to some of the stressors that help explain their specific effects on vigilance.

THEORETICAL MODELS

The most commonly cited model is the view that environmental stressors affect vigilance performance by activating internal arousal mechanisms (*12*). According to the arousal or activation theory, performance rises with increases in physiological mechanisms within organisms, as measured by increased levels in heart rate, blood pressure, muscle potentials, skin conductance, and high-frequency, low-amplitude EEG activity (*13*). After a certain point of increasing activation, any further increase causes a drop in

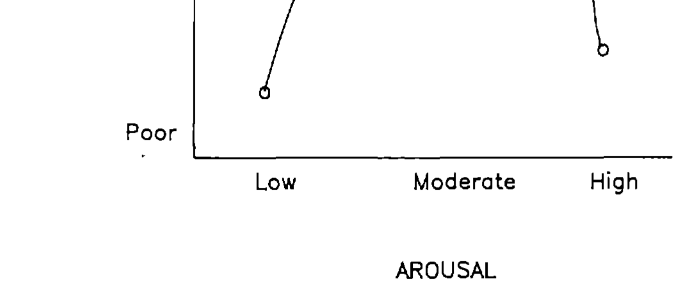

Figure 1.–Physiological arousal in inverted-U model.

performance. One basic tenet is that there is some optimal level of activation where performance is at its best. Less or more arousal creates an understimulation or overstimulation, which causes performance decrements. Figure 1 shows this inverted-U relationship. The introduction of moderate levels of noise, for example, may improve performance by arousing the individual, but large amounts of noise for extended periods of time would hyperarouse or greatly fatigue a worker, causing decreases in performance. Poulton (*12*) discussed this model in great detail in relation to heat, noise, vibration, and isolation. The inverted-U model accounts for many vigilance research findings, but there is much that this model does not account for.

Hancock and Pierce (*14*) posited an attentional homeostatic model to explain thermal effects on vigilance. They maintain that, as dynamic increases of body temperature occur, attentional resources are competed for, thereby draining attentional resources needed to maintain performance standards. This model better accounts for findings (as mentioned in the section "Vigilance Performance Under Extreme Heat Conditions") that indicate that automatic or highly skilled behaviors are less affected by stressors, since less attention is needed to perform the task. This theory would also apply to any other stressor, such as noise, that would tend to perturb attention.

A less popular, but nonetheless reasonable, model to account for some of the effects of environmental stressors is the control or learned helplessness model. This model emphasizes the role of perception of personal control or lack of control and predictability over environmental events, such as noise or vibration. A perception of lack of control and of the unpredictability of noxious or unwanted stimuli will interfere with immediate and subsequent behavior. A classic series of studies by Glass and Singer (*15*) demonstrated that the detrimental effects of intermittent noise peaking at 108 dB were attenuated when individuals were given the opportunity to switch off the noise, even though they did not choose to do so, or when the noise was more predictable. These studies show that the perception of the stressors is important and should be considered when dealing with performance. Most studies that have demonstrated these effects have been in controlled laboratory settings. These results need to be verified in real-world settings.

SPECIFIC EFFECTS

Besides noise acting as an environmental stressor in a generic sense, as in the above models, noise can create performance decrements in subtle ways. Noise can mask auditory feedback that individuals use to signal certain responses. For instance, the click of typewriter keys, the sound of gears shifting, or the sound of high revolutions per minute in truck engines represent sensory feedback signals that workers often use for information about their performance. In intermittent and continuous noise, these indicators may not be heard. Also, acute partial hearing loss often occurs with exposure to noise, which would contribute to this problem.

Related to the masking of auditory feedback is the masking of inner speech caused by external noise (*16*). An example of inner speech is the quiet rehearsal of a telephone number so as not to forget it. Tasks that involve short-term memory are particularly vulnerable to this. Several studies have shown that rehearsal of information is degraded because of noise (*17*).

Finally, an often overlooked effect of noise is the annoyance (*16*). Poulton (*12*) suggested that intermittent noise is more annoying than continuous noise and that unlocalized noise is more annoying than localized noise. Although difficult to measure and to objectively define, the detrimental effects of annoyance on performance, experienced over time, should not be underestimated.

Vibration, especially at 5 and 7 Hz, has been shown to have activating effects on the central nervous system, similar to other stressors (*18-19*). Therefore, vibration could fall into the realm of activation theory for effects on performance. Vibration has, however, specific effects important in the consideration of performance at vigilance tasks. For instance, vibration has direct effects on visual perception (*18*). Visual blurring has been documented in the 5- to 90-Hz range and seems to be related to specific frequencies (*20*). The loss of visual acuity correlates to the amplitude of vibration and peaks at 10 to 25 Hz (*18*).

Whole-body vibration has been associated with a loss of a sense of limb position (*21*). In a manual-tracking experiment, a loss of isotonic control was demonstrated, owing to a decrease in the effectiveness of feedback information concerning limb motion and position.

Finally, studies have shown that occupational vibration causes a diminution in grip force and fingertip sensation and tactile sensitivity (*22*). Each of the above effects of vibration could have important implications for performance of vigilance tasks.

Many studies of the effects of extreme heat or cold on vigilance performance assume a cognitive deterioration at the vigilance task, as predicted by activation or attentional resource theories. However, temperature-related decreases in performance over time may have other causes. Cooling of the hand or fingers produces stiffness of the joints. A loss of dexterity occurs when the forearm is cooled, owing to an increase in muscle viscosity of the long flexors and extensors of the fingers (*23*). In general, studies have shown that local cooling of the arm causes a significant decrement in manual dexterity, whether or not general body temperature is low.

ENVIRONMENTAL STRESSORS

The remainder of this report will discuss the ways in which four environmental stressors–extreme heat, noise, vibration, and adverse lighting–affect alertness in the context of sustained operations. How stressors affect alertness is of obvious significance in mining environments. Surface and underground miners are exposed to extreme environmental conditions such as dust, heat, cold, fumes and whole-body vibration. How and why these stressors affect vigilant performance is unclear. There are several theories that attempt to answer these questions, but as will be demonstrated in the following material, too many inconsistences still exist for a clear-cut unified theory.

VIGILANCE PERFORMANCE UNDER EXTREME HEAT CONDITIONS

Working in industrial settings where elevated temperatures are involved, such as close proximity to metallurgical furnaces, or exposure to extreme climatic temperatures, is the status quo in many job situations and is not easily altered for optimum human safety and performance. This section gives some background information on the thermal conditions present in the U.S. mining industry and then summarizes studies concerned with the effects on human sustained attention capabilities during exposure to elevated temperatures.

Ambient temperature is a major environmental concern in many mining operations. Temperatures can range from 115° F in the Southwest open pit copper mines to -45° F in the surface taconite mines of Minnesota. Mining operations usually continue despite these climatic extremes. Underground operations do not have as wide a range of temperatures as surface operations. Underground ambient temperatures are usually in the range of 59° to 95° F, with relatively high humidity, depending on the depth of the mine and the type of deposit being worked.

In addition to climatic conditions, certain geologic and operational variables contribute to the heat load in underground mines (*24*). The temperature of the wall rock may be elevated because of the radioactivity of the rock minerals, proximity to igneous activity, oxidation of sulphide ore, or hot ground water. In addition to the native rock temperature, operational factors, such as blasting, oxidation of support timbers, heat produced by powered equipment, mine water and compressed air lines, and the adiabatic compression of ventilation air, contribute to the underground heat load.

Job tasks also affect the thermal load of miners. Haulage truck drivers and heavy equipment operators usually sit in enclosed cabs, which are often not temperature controlled. The tasks involved in mining, such as lifting, shoveling, and pushing, are strenuous operations that inevitably raise body temperature, even when climatic conditions are normal. Metallurgical furnace attendants must work in close proximity to extremely high temperatures. Underground workers may work in ambient temperatures that are over 90° F with extremely high humidities. Other underground workers may work in conditions of relatively mild temperatures with strong airflow creating cool conditions.

These are the basic thermal conditions to which workers in the U.S. mining industry are exposed. Conditions can change from day to day at surface operations because of climatic factors. Underground conditions are fairly constant from day to day but can change seasonally and within the different levels of a mine. How these thermal conditions affect the performance or safety of the miners on a daily basis is a matter of concern. A review follows on the effects of environmental temperature on vigilance performance.

Mackworth (*25*) explored the effects of environmental temperature on the watchkeeping ability of subjects. The visual vigilance task used by Mackworth was mentioned in the "Defining Vigilance" section of this report. Subjects were given a single 2-h practice session with the clock test prior to performance at one of four elevated temperatures. In all conditions of the experiment, performance efficiency, as measured by missed signals or false alarms (reporting a signal when none occurrred), was reduced during the second hour of the task. Further, this vigilance decrement was magnified by the imposition of increased ambient heat. The study demonstrated the superiority of performance at 79° F when compared with one lower and two higher effective temperature (ET)[6] conditions, 70°, 88°, and 97° F. The study concluded that vigilance performance was better in warm environments, as compared with cool and hot environments.

Bell, Provins, and Hiorns (*27*) investigated the effects of temperature on visual and auditory vigilance tasks during exposure to hot and humid conditions. In this study, the subjects were asked to monitor the movement of 20 separate dials in 5 different climatic conditions. Dry bulb (and wet bulb) temperature conditions, controlled in an environmental chamber, were 85° (76°), 109° (95°), 124° (99°), 124° (109°), and 145° F (117° F), with an air velocity of 50 ft/min. Each subject stayed within the environmental chamber as long as he or she was physically capable, for a maximum of 4 h. The mean exposure times for the temperature conditions stated above were 4 h, 187.5 min, 67.8 min, 28.4 min, and 19.3 min, respectively. When the performance of the subjects was examined with respect to the proportion of signals missed to the signals given, no evidence was found of a change in vigilance under varying climatic conditions. However, it was found that body temperature was inversely related to performance, where the higher the body temperature, the worse the performance. That is, according to Bell, performance is a function of body temperature, not environmental temperature. A

[6]The ET scale is an index of perceived warmth considering measures of dry- and wet-bulb temperatures and air velocity developed by Houghten and Yagloglou (*26*).

major problem in interpreting these results is that the exposure time decreased as the environmental temperature increased, because the subjects left the chamber at the higher temperatures.

Colquhoun (*28*) found a similar result in a study designed for analyzing the effects of differing frequencies of signal presentation and temperature on a vigilance task. Subjects responded to a light signal that was 30 pct brighter than the standard signal. Although there was a performance decrement across the length of the experiment, the three climate conditions, cool, warm, and hot, did not have a significant effect. This unexpected finding was conjectured to be due in part to the low frequency of signal presentation used. However, when subjects' oral temperature was analyzed, it was found that oral temperature correlated with performance decrements ($r = 0.71$) for the cool environments but not for the warm and hot environments.

Wilkinson, Fox, Goldsmith, Hampton, and Lewis (*29*) studied the direct effects of body temperature on vigilance tasks under different body temperatures while holding room temperature constant. The four body temperatures at which subjects were tested were 98.6° (normal body temperature), 99°, 100°, and 101° F. Body temperature was readily elevated by exposing the subjects to a hot, humid climate of 109.4° F and 100 pct relative humidity. Once the desired body temperature was reached, subjects were removed from the hot, humid climate and dressed in a vapor barrier suit. The performance tests were conducted in a room maintained at 98.6° F with a relative humidity of 20 pct. The subjects listened to a series of tones (1 kHz, 0.65 s) and signaled the occurrence of randomly placed longer tones (0.90 s). Performance at the vigilance task decreased as body temperature increased from normal body temperature to 99° F. An improvement in vigilance performance was manifested at 100° and 101° F, the two higher body temperatures. This improvement was attributed to the arousing effects of heat. It was concluded from this study that performance on vigilance tasks is directly related to body temperature rather than environmental temperature.

Benor and Shvartz (*30*) attempted to study the effects of cooling the surface-body temperature while core-body temperature remained constant. For this experiment, subjects were exposed to ambient temperatures that ranged from 86° to 122° F for periods up to 2 h. The subjects walked on a treadmill wearing impermeable suits. The impermeable suit did not allow the evaporation of perspiration or the dissipation of body heat, which resulted in a rapid elevation of core-body temperature. The test was replicated with the subjects wearing the impermeable suits that were equipped with built-in cooling systems, thereby keeping surface-body temperature, skin temperature, and heart rate constant. All of the experiments with the subjects wearing noncooling suits showed the same performance pattern in detecting an auditory signal: an initial improvement for about 10 min, a leveling-off period, and subsequent deterioration. When the subjects wore the cooled impermeable suit, performance improved significantly; the detection rate leveled off after the initial adjustment period. The conclusions of this experiment were that detection rate is related to environmental temperature, not core-body temperature, and that detection rate is determined by heat stress as reflected by skin temperature and sweat rate, not heat strain as expressed by internal body temperature and heart rate.

Loeb and Jeantheau (*31*) found that vigilance with respect to several different signal sources was unaffected by high environmental temperatures, except when high temperatures were combined with noise and vibration. However, the comparison of vigilance at the elevated temperature condition and the lower control temperature condition was confounded by possible differences in day versus night performance. Evidence suggests that signal reaction times are appreciably longer at night than during the day (*32*). Therefore, it was concluded that the effects of the elevated temperature condition may be masked by diurnal (daily) variations in the level of alertness.

Bursill (*33*) investigated subjects' responses to light signals presented on the peripheral visual field while the subjects were also performing a centrally presented task under varying environmental temperatures. Performance on the two simultaneous tasks during 2 h exposure to temperatures of 65° and 95° F was compared. While attending to a psychomotor tracking task in the center of the visual field, each subject reacted to brief light signals occurring on the periphery of the visual field at irregular intervals. In the high-temperature condition, the peripheral signal was missed more often than in the low-temperature condition. Signals on the lateral sides of the visual field were missed more often than those at the center of the field. These effects were found only when the centrally presented psychomotor tracking task placed heavy attentional demands on the subjects. The findings led Bursill to propose an explanation of heat effects on human performance in terms of "funneling of attention." Peripherally placed signals may be missed at a higher rate when an individual is performing on a difficult central task compared with an easier central task. Bursill concluded that this condition of funneling of attention was intensified by exposure to heat.

Another experiment was conducted by Colquhoun and Goldman (*34*) on the effects of elevated temperature on performance of a vigilance task. In this instance, body temperature was elevated by having the subjects walk on an inclined treadmill in hot and humid conditions (103° F dry bulb, 93° F wet bulb) for periods of 0, 10, 20, or 30 min. The signal to be detected was a light signal that was approximately 30 pct brighter than the standard event signal. Subjects responded to the occurrence of the signal at three levels of confidence–"maybe," "fairly sure," and "certain." The results showed that the detection rate was unaffected by changes in body temperature induced by various amounts of treadmill work immediately prior to the vigilance task. However, it was found that the percentage of being certain of a signal detected was significantly greater following the 30-min treadmill task than following no treadmill work. The false report rate also increased with the lengthening of prior treadmill work.

The combination of these two findings suggests that there was a decrease in the degree of caution exercised by the subjects in making a response. That is, the decision of the subjects to report a signal was presumably based on less adequate sensory evidence of signal occurrence as the subject's body temperature rose. It therefore appears that subjects exhibited strategy changes, as opposed to physical deficits, with regard to their performance. It was also found that for highly trained subjects, the rise in body temperature was considerable before any deterioration in performance occurred. This conclusion by Colquhoun and Goldman (*34*) is in line with that of Provins (*35*), who suggests that the effect of increased body temperature is an overall increase in the arousal of the subject. When the level of arousal exceeds a point that is optimal for performance of the task, then the increase in body temperature causes a deterioration in the performance of the task.

Mackworth (*25*) found that the effect of increased temperature differed depending upon the prior experience the subject had with watchkeeping tasks. One group of subjects gained watchkeeping experience while performing naval lookout duty. This experience is analogous to the monitoring required in the experiment. The second group of subjects did not have previous watchkeeping experience. At temperatures of 70° and 79° F, there were no differences between the experienced and inexperienced groups. However, at 88° F ET, those subjects with prior watchkeeping experience demonstrated superior performance over the inexperienced subjects' performance. It was concluded, therefore, that extreme temperatures have more effects when subjects are inexperienced.

Hancock (*36*) reviewed the effect of skill on performance under environmental stress. He concluded that skillful performers or those performing less complex tasks are less vulnerable to adverse environmental conditions than are less skilled subjects, owing to the more automated nature of performance of the task by more skillful operators. It was suggested that familiarity with the stressor may reduce the physiological impact on individual subjects while familiarity with the task reduces the behavioral impact of the stress.

Hancock and Dirkin (*37*) investigated the effects of elevated head temperature upon performance of tasks, as opposed to raised whole-body temperature. In a study of central and peripheral visual choice reaction time under conditions of elevated head temperatures, slower but more accurate responses under the heat condition were found. In an experiment on the effects of elevated head temperature upon the performance of simple mental addition (*38*), significantly more additions were accomplished under the heat condition. No significant effect on error rate was seen due to the heat condition. This study suggests that the processing rate in a behavioral task, such as mental addition, may be further abetted by a localized increase in head temperature. The differences between the results of the two studies may be due to the two types of tasks used, how the tasks were presented, and the difference in head temperature and temperature location.

Some studies have attempted to study the effects of heat on vigilance performance in real-world situations. It should be cautioned that, while these studies may have more applicability to industrial settings, they lose a certain amount of control over some potentially important variables. Romansky, Plummer, and Neumann (*39*) investigated the effects of environmental stressors on performance of a simulated sustained driving task. The researchers evaluated the relative effects of a moderate, not extreme, level of heat and noise (90° F, 78 dBA) on human stress and fatigue using performance and physiological measures. The control condition was exposure to 76° F and 55 dBA. Fatigue was defined as a group of phenomena associated with the impairment, or loss, of efficiency and skill, and the development of anxiety, frustration, or boredom. The higher environmental stress condition resulted in significant differences in heart rate, heart rate variability, and reaction time to a visual display. It was postulated that during sustained operation of driving a vehicle on a roadway, driver performance can be negatively affected by moderate levels of environmental heat and noise stress. Elevated temperatures and noise levels create a stressful condition that consequently leads to subject fatigue and a deterioration in task performance.

Mackie and O'Hanlon (*40*) investigated the combined effects of extended driving and heat stress upon arousal and driving performance. The subjects drove automobiles a total of 360 miles (580 km) over a 9-h period with a break of about 45 min at the halfway mark. Each of the subjects made the trip twice, once under self-selected "comfortable" conditions (approximately 67° F Wet-bulb globe temperature (WBGT)) and once at an elevated heat stress condition of 90° F WBGT. Physiological and performance measurements were obtained for each subject as were subjective ratings of alertness and fatigue. The performance measures included steering precision, vehicle speed control, driver errors, and performance on a secondary vigilance task. One conclusion of the study was that exposure to the hot environment produced physiological signs of heat stress (such as increased sweat rate, increased oral temperature, overall elevation in systolic blood pressure, and greater heart rate variability) and signs of lowered central nervous system arousal (as reflected by the lower average level of the EEG power ratio of alpha and beta waves) across time. After exposure to the heat for a period of about 5 h, the drivers reported more fatigue and decreased alertness than when in a comfortable environment. During the heat condition, drivers had decreased steering control, increased lane shifting, and committed more technical driving errors than when driving at the comfortable condition. However, performance on the secondary vigilance task was inversely related to driving performance under hot conditions. This point raises a question regarding the applicability of secondary task performance measures in comparison with those for the primary task. Also, using a secondary task may change the entire nature of the primary task.

Ramsey, Burford, and Beshir (*41*) studied the effects of heat on safe work behavior. Unsafe behavior rate as measured in this study is a function of the number of unsafe acts and the total number of observations made by impartial observers at two industrial plants. Among the conclusions of this study was that ambient temperature had a statistically significant effect on unsafe work behavior rate. The relationship between unsafe work behavior rate and ambient temperature follows a U-shaped curve. The minimum unsafe behavior rate was shown to occur between 63° to 73° F WBGT. An increase in unsafe behavior rate occurs when the ambient temperature increases or decreases outside of this range.

Nearly all studies on the effects of heat on vigilance performance have found either no effect or a decrease in performance measures. Results that indicate an improvement in performance as a function of heat, suggesting an arousal mechanism, are rare. As will be shown in the next section, this is not necessarily the case for studies that have looked at noise as an environmental stressor.

The question of whether it is environmental heat or inner-core temperature that relates to the performance decrement is still unanswered. However, the study by Benor and Shvartz (*30*), which found that by cooling the body's surface temperature the vigilance decrement was eliminated, should be further explored as an important research direction.

Past research has also indicated that the task itself is an important determinant of the vigilance decrement under conditions of heat stress, e.g., event rates and task difficulty. Similarly, the skill level of the individual seems to have an effect. Finally, the idea that performance decrements are due to strategic changes of the individual has also been shown.

VIGILANCE PERFORMANCE UNDER NOISE CONDITIONS

In many work and nonwork environments, humans are exposed to sounds or noises, ranging from mild background conversation to the 110-dB roar of a jet aircraft at 1,000 ft. Noise pollution is prevalent in the mining industry where the use of common types of machinery guarantees that workers will be exposed to high levels of noise and vibration. The more severe of these conditions have been regulated against, allowing a maximum exposure time to different levels of noise. Table 1 presents maximum allowable exposure times for differing levels of noise in surface and underground mines, as regulated by the U.S. Mine Safety and Health Administration (MSHA) (and identical to U.S. Occupational Safety and Health Administration standards) (*42*). The table also shows that the American Conference of Governmental Industrial Hygienists (ACGIH) suggests more stringent noise levels than MSHA levels. However, it is probable that miners are still being exposed to levels beyond these standards, as indicated in a 1981 MSHA study (*43*) (table 2). This section will suggest that noise, even at lower levels than what is considered physically harmful, may contribute to vigilance decrements.

Table 1.–Maximum allowable noise exposure times

Decibel level, dBA	MSHA PDNE, h/d	ACGIH TLV, h/d	Examples
65	–	–	Normal conversation.
70 to 80	–	–	Roof signals.
80	–	16	([1]).
85	–	8	([1]).
90	8	4	Trucks.
92	6	–	Rotary drill.
95	4	2	Some mining machines.
97	3	–	([1]).
98	2 -3	–	Shuttle car (load).
100	2	1	([1]).
102	1.5	–	Dozers.
104	1 - 1.5	–	Wood planer.
105	1	.5	([1]).
107	.75	–	Continuous miner.
108	.5 - .75	–	Loading machine.
110	.5	.25	([1]).
115	≤.25	.125	([1]).
More than 115	NEP	NEP	([1]).
118	NEP	NEP	Drill, roof bolter.
126	NEP	NEP	Large jet motor.
130	NEP	NEP	Pneumatic hammer.
140	([2])	NEP	([1]).

NEP No exposure permissible.
PDNE Permissible daily noise exposure.
TLV Threshold limit value.
[1]No example given.
[2]Maximum decibel, A-scale, that impact and impulsive noises reach (metal and nonmetal only).

NOTE.–Dashes indicate no standard cited at this decibel level.

Table 2.–Actual mining noise exposure (*43*)

	dBA	h per 8-h shift
Shakeout	118	3
Underground drill	116	2
Crusher	107	8
Mucker	107	6
Surface drill	107	6
Vibrating screen	103	8
Bulldozer	102	8
Front-end loader	101	8
Load haul dump	101	6
Chute	100	8
Rod and ball mill	100	8
Scraper and grader	100	8
Continuous miner	100	3
Longwall cutting machine	98	4
Dragline and shovel	94	8
Truck	93	8
Shuttle car	93	3
Kiln	90	8

Among the most immediate reactions to loud noise are feelings of annoyance and discomfort (*44*). Studies have shown that increases in noise levels in industrial settings directly correlate with reports of annoyance and discomfort (*45*). It has been found that workers who have been chronically exposed to industrial noise complain of feelings of tiredness and fatigue and other disturbances, such as headaches, anxiety, disruption of sleep, irritability, and work and social conflicts (*44*).

In a study of a film processing laboratory, noise was experimentally reduced from 99 to 89 dB in one room and was kept constant at 99 dB in another room. Comparing the results of this study, it was found film breakages were reduced in the quieter room (*46*).

A few nonexperimental studies have clearly shown that, in some industrial settings, there is a direct correlation between noise levels and accidents. A study by Kerr (*47*), for example, investigated the accidents of over 12,000 employees at 1 site. Of the 40 factors considered in the study, average noise level was one of the most highly associated factors. Noise level was positively correlated with accident frequency ($r = 0.42$) but not with accident severity. Cohen (*48*) evaluated two plants for noise levels and accidents as well as other health-related variables. Five hundred workers situated in noisy work areas, defined as 95 dBA or higher, were compared with 500 workers in quieter areas, 80 dBA or less, over a 5-yr period. Cohen's data show that workers in noisy conditions had significantly more accidents than those in quieter conditions.

Although these studies show that industrial settings may have noise conditions that could cause performance decrements, there are some studies that show performance improvements or no change in performance under noise conditions. It is, in fact, still uncertain as to what situations produce positive or negative effects. It is also uncertain as to how the effects of noise interact with vigilance job tasks to produce these effects.

Several reviews on the effects of noise on performance have been published in the past few years (*11-12, 49-50*). These reviews generally conclude that few generalizations can be made from previous studies because of inconsistent results. Consequently, it appears that it is impossible to predict the effects that particular types and levels of noise will have on specific tasks. However, several interesting models, such as the one presented in figure 2, have attempted to put some order into the seemingly conflicting results. This model suggests that, for example, when noise level is high and invariant (white noise) and processing demands are high, then performance will be degraded. However, it has been pointed out that this relationship is not so simple (*50*). Koelega and Brinkman (*11*) state that inconsistent results can be attributed to the complex interaction of many factors. These factors include (1) the type of experimental design employed, (2) the intensity of noise used, (3) the comparison between different noise levels, (4) the frequency composition of the noise, (5) the type of noise (e.g., white noise, conversation, music, etc.), and (6) the scheduling of the noise stimuli (i.e., number of noise stimuli per time unit, time interval between noise stimuli and signal occurrence, and variability of interval between various noise stimuli). These factors coupled with the variety of tasks available (i.e., reaction time, cognition, discrimination, physical labor, driving, etc.), set up an almost infinite number of possible combinations. Gulian (*51*) states that, because of these factors, not only are results totally unpredictable but also that one can only compare results from different studies in a general manner.

In an effort to find generalizations regarding the effects of variable or intermittent noise on vigilance, Koelega and Brinkman (*11*) analyzed all studies from major journals since 1960 that had similar task characteristics–namely, simple sensory monitoring. Their hypothesis was that if task type is controlled for, consistent results may be found. Of the studies cited, 14 reported incremental and/or decremental effects of noise, while 15 of the studies showed no effects of noise. No pattern emerged from the analysis. The authors concluded, therefore, that "we know nothing about variable or intermittent noise in vigilance experiments."

In spite of all the confusion regarding the effects of noise on vigilant behavior, most authors would agree that vigilant situations are particularly sensitive to noise (*52*). Therefore, rather than make another attempt to draw generalizations and conclusions from existing laboratory and field studies that would be applied to the mining environment, the remainder of this section will discuss those variables that have theoretical implications with predictive applications in these respects. The primary purpose is to delineate those factors that relate to and have *potential* effects on real working conditions.

The largest body of vigilance research stems from an area referred to as the "Signal Detection Theory" (SDT). While most of the work has been done in controlled laboratory situations, many of the principles gained from this research may be applied to real job tasks. In most vigilance tasks, subjects are asked to detect and then respond to auditory or visual signals for certain lengths of time. The clock test mentioned earlier is a popular example of a vigilance task. These laboratory tasks are designed to systematically measure people's ability to monitor or remain vigilant at watchkeeping jobs. It could be argued that any physical task can be broken down into signal detection of some sort. Wiener (*53*), for instance, compares looking out of the windshield of a car with watching the gages of a control panel typical in vigilance tasks.

According to SDT, there are two primary reasons why performance shows a decrement over time (*54*). If an individual experiences a decrement in his or her sensitivity to a stimuli, then the percentage of correct detections and/or reaction time will suffer. It has been found, however, that the most consistent reason for a performance decrement is a change in an individual's criterion or strategy for responding (*54-55*). When individuals adopt a risky strategy, they will manifest a high percentage of false alarms (indicating a signal is present, when in fact there was none), which is usually accompanied by higher percentages of correct "hits." When, on the other hand, subjects adopt a conservative approach, they will manifest a low rate of false alarms, which normally is accompanied by lower percentages of correct hits.

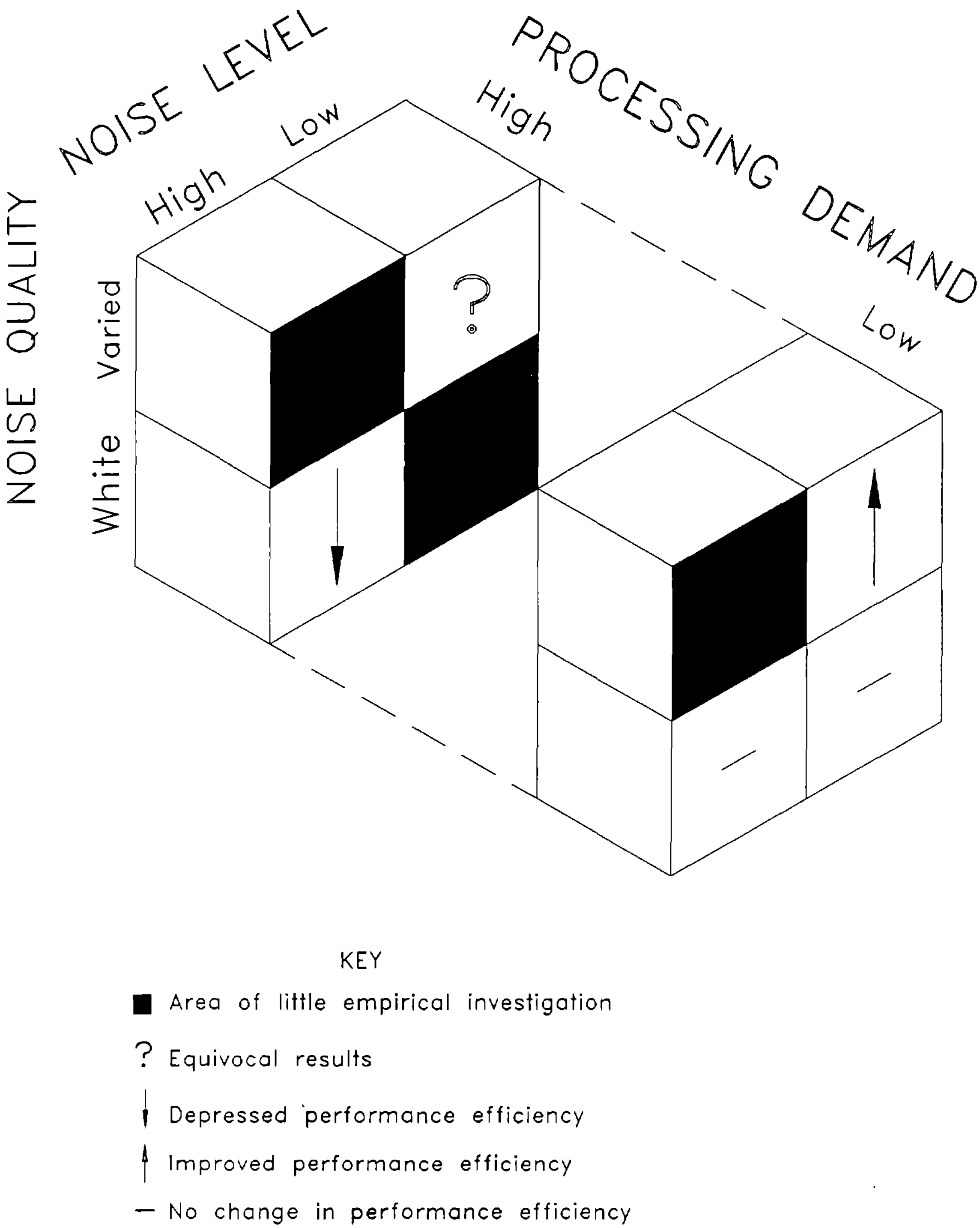

Figure 2.–Three-factor taxonomic approach to describe continuous noise effects on vigilance performance. (Adapted from Lysaght in reference *50*.)

When a driver of a haulage truck detects a need to depress the brake or turn the steering wheel, he or she has adopted a criterion for performing. According to the above definitions, therefore, a risky strategy would mean that a driver makes many adjustments in response to environmental stimuli, even though it may not be at all necessary (high false alarm rate). A conservative approach would mean that the driver will make fewer adjustments but also will not react to potentially important cues. This is what SDT would predict after sustained periods of driving. The most consistent finding is that performance decreases across a vigil owing to the adoption of a conservative strategy for responding, as opposed to a decrease in sensitivity to stimuli. There are, however, some studies that have found performance decrements associated with a decline in perceptual sensitivity (*56*). Warm and Jerison (*57*) conclude that a sensitivity decrement appears to be related to tasks that involve a high rate of observing.

A study by Hockey (*58*) shows the effects of vigilance and noise on a signal detection task and typifies much of the research in this area. Subjects were asked to watch the condition of three light sources by checking or sampling each light source one at a time by pressing one of a set of three corresponding buttons. The amplified valve noise was at 70 dBA in the quiet condition and 100 dBA in the noise condition. The task lasted approximately 30 min. A hit was defined as sampling a light source and immediately correcting the fault before taking another sample. A vigilance decrement was apparent in both the noise and quiet conditions, as evidenced by a drop in the percentage of hits in the second half of the vigil. The important point in the study was the assessment of the unsure hits defined as the correction of a fault in a light source after a second consecutive sampling. Here, the subject "may be regarded as requiring further information before coming to a decision" (*58*). In the quiet condition, the number of unsure hits was three times that of the noise condition. There seemed to be a reduction of repeat responses in the noise condition. It was concluded, therefore, that in the noise condition, the tendency to make more definitive decisions (hits or misses) was increased.

Similar results were obtained by Broadbent (*52*) and others. These studies indicate that performance decrements in quiet conditions have elements of uncertainty, in that performers tend to be unsure or uncertain of their mistakes, while in noise conditions, they may make as many mistakes but are more certain that they have *not* made a mistake. Noise tends to increase the confidence levels of their responses, in spite of their error rates (*59-60*). The important point is that, in quiet conditions, this level of uncertainty translates into behaviors that tend to offset a certain percentage of misses or mistakes.

Another area that has been shown to affect vigilance performance in the presence of noise is priority of responding. A 1954 vigilance study by Broadbent (*52*) showed that in a noise condition, subjects treated distinct parts of the experimental display differentially. Hockey (*61*) attempted to explore this phenomenon in more detail in a task designed to have features similar to driving a car. A tracking task was explained to subjects as having high priority in the overall task, as in steering an automobile. The tracking task was coupled with a task consisting of detecting lights arranged in a semicircle in front of, and equidistant from, the subject, as in detection of hazards or warning signals in a driving situation. Subjects were exposed to these tasks in either 70 or 100 dB white noise for 40 min. In the loud noise condition, the detection of lights was poorer at the periphery and better at the center. Performance on the tracking task showed a vigilance decrement in the quiet condition but remained stable in the noise condition. It seems then that in the noise condition, subjects attended to high-priority or dominant aspects of their task (tracking task and central lights) at the expense of the other aspects. This effect has also been found in incidental learning tasks (*62*). It should be noted that in industrial accidents, many of the precipitating events are unexpected or unrelated to the dominant task at hand.

A study by Sussman and Morris (*63*) offers further evidence of this effect. Subjects were exposed to a simulated driving task for 4 h under conditions of high and low task complexity and three levels of noise (based on noise amplitudes found in realistic driving situations). Vigilance decrements were found on various dependent measures over the 4-h vigil, including road position error rate, steering wheel movements, and a simulated driving emergency. The interesting finding was that noise levels were not a significant variable for most of these measures. In fact, only the simulated driving emergency, which occurred randomly once per subject, was influenced negatively by high noise levels. Again, it appears that tasks that are not the dominant one, or are unexpected, are adversely affected by noise.

The importance of using SDT as a basis for many of the vigilance studies has been to show that noise has its primary effects, not on the breaking down of sensory input directly, but in strategy changes that individuals make. The implications of these results are that accident causation and risky behaviors may be increased under noisy conditions and that workers may change their strategy or criterion for safe behavior across a vigil. The confusing results found when attempting to look at specific task requirements should not mean that these variables should be ignored. On the contrary, they need to be carefully controlled so that their effects can be better understood. However, the promising results found in looking at strategy changes during vigilance and noise conditions are crucial in understanding behaviors that could lead to accidents.

VIGILANCE PERFORMANCE UNDER VIBRATION CONDITIONS

Exposure to vibration is a common condition in many industrial settings. The mineral industries are no exception. In fact, there are many different forms of vibration that are prevalent in mining. Blasting of overburden and ore exposes surface miners to both air and ground vibrations of short duration. Plant workers are exposed to the constant vibration from crushers, vibrating screens, and other pieces of plant equipment. Heavy-equipment operators, such as haulage truck drivers and bulldozer operators at surface operations and continuous miner and shuttle car operators underground, are exposed to vibration for the majority of the workday. The surfaces over which the vehicles travel, as well as the vibrations emanating from the engines of the vehicles, contribute to the overall exposure to vibration.

When vibration is transmitted to workers either through supporting structures, such as the plant floor or the vehicle's operator seat, it is referred to as "whole-body" vibration. When vibration is through a handheld object, the vibration is called hand-arm vibration (*64*). Physical disorders of the spine, legs, arms, digestive system, and circulatory system have been associated with exposure to whole-body vibration from operating vehicles.

The International Organization for Standardization has developed a standard, titled "Guide for the Evaluation of Human Exposure to Whole-Body Vibration," (*65*), which considers the direction, frequency, intensity, and duration of vibration to which an individual is exposed. Vibration is then rated against three criteria. The first criterion is the reduced comfort boundary, which defines the vibration levels and durations that should not be exceeded if one wishes to preserve comfort. The second criterion is the fatigue-decreased proficiency (FDP) boundary, which ensures preservation of working efficiency. The final criterion is the exposure limit (EL), which ensures the preservation of health or safety.

In a study of whole-body vibration exposures of mining machine operators (*66*), it was determined that about half of all surface mining machine operators were exposed to vibration in excess of the FDP level and about 15 pct were exposed to vibration in excess of the EL. The primary sources of vibration in surface mining were scrapers, bulldozers, and loaders. For underground operations, about one-third of the machinery operators were exposed to vibrations in excess of the FDP level and about 12 pct in excess of the EL. The primary sources of vibration underground were shuttle cars and scoop trams.

The effects of vibration on human health have been studied extensively in the aerospace and trucking industries. These studies have focused primarily on the vigilance performance of commercial and military pilots and over-the-road truck drivers. This report deals primarily with the effects of vibration on the vigilance performance of individuals.

It has been found that vibration is not always detrimental to the individual. Several studies have found that exposure to particular levels of vibration may improve, or at least not hamper, an individual's performance on vigilance tasks (*67*). Holland (*68*), for instance, assessed performance at a compensatory tracking task during 6 h of continuous exposure to random vertical vibration. Random aperiodic vibration was used since it more closely approximates the vibrations reported in operating motor vehicles. Each of the four vibration conditions tested led to a decline in tracking performance compared with the control conditions. A secondary vigilance task of responding to warning light signals was also evaluated. However, the warning light task was not significantly affected by the four vibration levels tested. The average time to respond to warning signals increased over the 6-h testing period. In addition, it was observed that the vibration in some instances served to keep the subjects alert. This finding was supported by the comments of the subjects.

Gray, Wilkinson, Maslen, and Rowlands (*69*) studied the effects of a 3-h exposure to vertical vibration at 5 Hz on the performance of four separate tasks: audio vigilance, visual search, compensatory tracking by hand, and handwriting. During the audio vigilance task, subjects listened to short tones (0.5 s at 600 Hz) given at 2-s intervals. The signal to be detected was a shorter tone (0.4 s at 600 Hz) presented on the average once every 1.5 min. The subjects responded by pressing one button signifying the detection of the signal and by pressing another button signifying their level of confidence that the signal was detected correctly. The number of signals detected, the number of false detections, and the levels of confidence were recorded for each of eight subjects. The overall difference in performance of the vigilance task was moderate but was not statistically significant. It was found that vibration did impair performance over time only when the subjects had no knowledge of test results. The performance at the other three tasks– visual search, tracking, and handwriting–was impaired by vibration but again the impairment was not statistically significant.

Poulton (*70*) suggested that the positive effects of vibration depend not only upon the quality of vibration but also on the nature of the task itself. Individuals experiencing whole-body vibration at frequencies between 3.5 and 6 Hz can decrease amplitude by tensing their trunk muscles. Poulton suggests, therefore, that individuals naturally tense their muscles to lessen the effects of vibration. During boring and monotonous tasks, the tensing of muscles can serve as an alerting mechanism. During an interesting, short, and challenging task, this would interfere with performance. Further, as an individual's alertness falls and his or her trunk muscles relax, the shoulders vibrate again, thereby alerting the individual. Such a reaction does not occur at frequencies above or below this range. These results have only been found in vigilance tasks of duration of up to 3 h. Whether these benefits occur throughout a full workday remains to be seen.

VIGILANCE PERFORMANCE UNDER ADVERSE LIGHTING CONDITIONS

The lighting conditions in underground mines are often considered to be of the poorest quality of any industrial setting. The illumination is completely from artificial sources, which creates a problem with the quality or quantity of light available. The main source of light underground is the battery-powered cap lamp. However, the cap lamp creates problems with glare, loss of peripheral vision, and lighting of the immediate task only. A series of general recommendations about improving mine lighting underground is presented by Trotter (*71*). Surface mines often operate two or three shifts that require people to work at night. Again, similar problems arise because of artificial light sources. Haulage roads are usually only illuminated by vehicle headlights. The difference in lighting levels from one section of the mine to another, both on the surface and underground, may itself cause vision-related problems among the mine workers.

There is very little literature on how differing amounts and types of illumination affect an individual's vigilance performance. However, there have been numerous reports on how certain levels of illumination can cause eye strain and eye fatigue and can affect a person's visual acuity, especially with respect to video display terminal (VDT) operations. An excellent review of occupational stress in VDT operations was published by Dainoff (*72*). The studies reviewed included an assessment of visual fatigue and/or performance, musculoskeletal symptoms, and operator attitudes toward job demands and quality of working life. The studies showed that increased VDT work time related to higher levels of boredom, fatigue, monotony, and physical stresses, which can result in lowered job performance. Dainoff concludes that work at VDT's raises the incidence of physical disorders and lowers job satisfaction in many situations and may be attributed to a number of factors: visual, postural, environmental, and task organization. The visual factors include the display attributes of the video display screen as well as the contrast, glare, and illumination levels of the environment. Postural factors are dependent upon type of furniture used and the VDT location. Environmental factors of temperature, humidity, and presence of air conditioning may affect individual performance. Task organization factors such as level of cognitive complexity, perceived control over daily activities, and the length of time operating a VDT, are relevant characteristics to visual performance at VDT tasks.

There have been studies that have looked at the effects of performing a central task on the amount of illumination necessary to see peripheral stimuli. Although these studies are not directly related to vigilance performance, they may have practical significance to vigilance tasks where the performance on peripheral tasks has been shown to deteriorate. Leibowitz and Appelle (*73*) investigated the change in luminous energy required for detection of peripheral stimuli when a centrally presented task was more demanding. It was found that higher levels of luminance were needed as the peripheral stimuli were located farther from the central task. This finding is important to the mining industry since lighting conditions are generally poor underground and in surface mines during the evening and night shifts, when the majority of light is supplied by point sources either mounted on mining vehicles or on the miners' hard hats. Any hazard that occurs on the periphery of an individual's vision may not be noticed before an accident or injury occurs.

Several studies have been conducted that consider the relationship between illumination and mining accidents at underground operations. Van Graan, Greyson, Viljoen, and Strydom (*74*) conducted illumination surveys of 19 underground gold mines. It was stated that when a task is visually exacting and vigilance is necessary, illumination must be good if the work is to be done in an efficient manner and without strain. If the task is visually simple, then comparable efficiency can be achieved at much lower levels of illumination. The mean light intensities found ranged from 8 lx in haulageways to 82 lx at electrical substations. This wide range in illuminance may result in an impairment in the ability of a miner to adapt to conditions rapidly and maintain some degree of visual acuity in underground operations. The resulting poor vision may be a safety hazard to the individual miner as well as to any nearby coworkers.

Martin and Graveling (*75*) considered the loss of peripheral visual awareness when an area is illuminated solely by a miner's cap lamp. Since the cap lamp is a point light source and is highly directional, being mounted on the front of a miner's hard hat, the peripheral surroundings around a miner are not illuminated by the cap lamp. This in turn may lead a miner to fail to recognize nascent hazards in the vicinity. The experimenters measured peripheral vision in four lighting conditions: cap lamp only, cap lamp with 5-lx background illuminance, 5-lx ambient illuminance only, and a control condition of 450 lx. For all subjects, the area of peripheral vision was greater with the combination of cap lamp and background illumination than with just the cap lamp. This improvement in peripheral field of view averaged 9° greater on the temporal side in the horizontal plane.

CONCLUSIONS

Four environmental stressors–extreme heat, noise, adverse illumination, and vibration–have been evaluated in relation to their effects on performance on vigilance tasks, especially in industrial settings. Relatively few studies have been done on the effects of illumination and vibration on vigilance tasks. The studies that have been conducted on heat and noise have often been contradictory or limited in generalizability by the use of laboratory settings and variance in methodologies. It may be concluded that, in many instances, heat and noise do cause a worsening of the vigilance decrement. It should be noted, though, that some studies have found no effects of heat and noise on performance, while a few studies even found that heat and noise improved performance. These inconsistencies lead to the conclusion that any particular situation involving an interaction between an environmental stressor and a vigilance task should be looked at as a unique situation with unpredictable results.

It should be a major concern that illumination and vibration have not been thoroughly examined. The consideration of noise without vibration may be misleading since noise does not usually occur separate from vibration in most industrial settings. While no one would dispute the importance of proper illumination for ideal performance, the effects of lesser amounts of illumination on vigilance have not been thoroughly explored. This lack of information is especially important in the mining industry, where work is often done outside, during evening and night shifts, or underground, where the primary light source is a narrow band of light.

Several basic points derived from the literature are outlined below and should be considered for future work in this area:

1. Most studies confirm the notion that extreme heat and noise have a negative effect on vigilance tasks. However, just how much of the stressor is needed before an effect is manifested is unknown but may depend upon the task conditions and ability levels of the individuals.

2. The effect may not be manifested in the primary task itself. The decrement in performance may be measured on peripheral or secondary tasks or in reaction to unexpected events that are unrelated to the primary task. The primary task may even show an improvement.

3. In order to study particular occupations for vigilance decrements, experiments need to be as realistic to the task as possible. Many of the differences in results have, at least in part, been due to slight differences in methodology.

4. Baseline data are needed for the effects of these environmental stressors, especially for illumination and vibration.

5. Future research should be concerned with the interaction of these stressors among themselves. In most industrial settings, noise and vibration are associated; heat is often accompanied by noisy conditions and poor illumination.

As mentioned in the "Introduction" section, it was found that one-third of the occupations in mining were rated as having the major components of vigilance-type tasks. One occupation in particular, driving, has been explored in previous studies and has shown interactions with heat and noise on measures of performance. It is likely, therefore, that studying similar mining tasks may prove worthwhile in finding and eventually controlling stressors that affect the health and safety of miners.

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