

A MINING RESEARCH CONTRACT REPORT
DECEMBER 1983

FB84-183276

ALERTNESS MONITOR EVALUATION

Contract H0222012
Washington University Behavior Research Lab

Bureau of Mines Open File Report 77-84

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR



REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U.S. Government.

Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

REPORT DOCUMENTATION PAGE	1. REPORT NO. BuMines OFR 77-84	2.	3. Recipient's Accession No. PB8 4 183276
4. Title and Subtitle Alertness Monitor Evaluation			5. Report Date December 31, 1983
7. Author(s) John A. Stern, Robert Goldstein, and Barbara D. Strook			6. Performing Organization Report No.
9. Performing Organization Name and Address Washington University Behavior Research Lab 1420 Grattan St. St. Louis, MO 63104			10. Project/Task/Work Unit No.
			11. Contract() or Grant() No. <input checked="" type="checkbox"/> H0222012 <input type="checkbox"/>
12. Sponsoring Organization Name and Address Office of Assistant Director--Mining Research Bureau of Mines U.S. Department of the Interior Washington, DC 20241			13. Type of Report & Period Covered Contract research, 8/17/82--1/16/83
15. Supplementary Notes Approved for release April 11, 1984.			14.
16. Abstract (Limit: 200 words) Procedures were developed to evaluate the nature and timing of eye blinks and closures and have related these variables to alterations in performance. Impaired performance is frequently indexed by alterations in these variables, suggesting that monitoring aspects of oculometric activity, such as the eye blink, may become useful predictors of impaired performance. What may be equally, or more important, is that such information can be used to alert equipment operators and prevent accidents. The analyses suggest that impaired performance is associated with the occurrence of eye closures, even in tasks where vision is not used, such as making judgments about durations of auditory stimuli. If such closures occur in conjunction with slow eye movements in the horizontal plane, the likelihood of a signal being missed is further enhanced. Blinking during the period of stimulus presentation also results in an enhanced likelihood of a signal being missed.			
17. Document Analysis & Descriptors Mining research Human error Alertness Computer Attention Human factors Electrooculography Electroencephalography Vigilance Accidents Eye blink Personnel selection Sleep b. Identifiers/Open-Ended Terms c. COSATI Field/Group 081			
18. Availability Statement Release unlimited by NTIS.		19. Security Class (This Report) Unclassified	21. No. of Pages 26
		20. Security Class (This Page) Unclassified	22. Price

FOREWORD

This report was prepared by Washington University Behavior Research Lab, 1420 Grattan St., St. Louis, Missouri, under USBM Contract number H0222012. The contract was initiated under the Research and Development Program. It was administered under the technical direction of the U.S. Bureau of Mines, TCRC, with Guy A. Johnson as Technical Project Officer. Howard Cole was the Contract Administrator for the Bureau of Mines. This report is a summary of the work recently completed as part of this contract during the period August 17, 1982 through August 16, 1983. This report was submitted by the authors on December 31, 1983.

Personnel responsible for this research are Drs. John A. Stern, Robert Goldstein and Barbara D. Strock. The first author assumes full responsibility for the contents of this report.

TABLE OF CONTENTS

<u>Item No.</u>	<u>Description</u>	<u>Page No.</u>
	EXECUTIVE SUMMARY	7
1.0	THE NEED	9
2.0	THE PROBLEM	10
3.0	RESEARCH PROCEDURES	12
4.0	EYELID ACTIVITY ASSOCIATED WITH DISCRIMINATION ERRORS AND TIME-ON-TASK	14
4.1	Eye Blink Parameters	14
4.1.1	Timing of Blink	14
4.1.2	Blink Closure Duration	15
4.1.3	Descent Time	15
4.2	Non-Blink Eyelid Closures	17
5.0	COORDINATED HORIZONTAL EYE MOVEMENTS AND CLOSURES	17
5.1	Closures Without Horizontal Eye Movements	18
5.2	Closures With Half-Wave SEM	18
5.3	Closures With Full-Wave SEM	18
6.0	EEG MEASURES	18
7.0	OCULAR TEMPERATURE	18
8.0	SUMMARY	19
8.1	General	19
8.2	Summary - Current Year's Effort	20
8.3	Summary - Work Still in Progress	20
9.0	RECOMMENDATIONS FOR FUTURE RESEARCH	21
9.1	Personnel Selection	21
9.1.1	Can one identify persons who have a high (or low) likelihood of frequent periods of microsleep during the normal work day?	21

TABLE OF CONTENTS (Continued)

<u>Item No.</u>	<u>Description</u>	<u>Page No.</u>
9.2	Development Of "On-Board" Monitoring Devices Reflecting Periods of Impaired Performance Potential	22
9.2.1	Utilization of Twin Cities Research Center Haulage Truck Simulator	22
9.2.2	Utilization of, or Collaboration with, John Deere Company Off-Road Vehicle Simulation Facility	22
9.3	Direct Extension of Current Research Efforts	22
9.3.1	Introduction of Infrequently Occurring Signals during Periods of Lowered Alertness	22
9.3.2	Evaluating other Alertness Monitoring Measures	23
9.3.3	Field Testing of "Alertness Monitor"	24
9.3.4	Motor Response Correlates of Altered States of Alertness	25

LIST OF FIGURES

<u>Figure No.</u>	<u>Description</u>	<u>Page No.</u>
4.1.2-1	Typical blink with points set for determining parameters. I = blink initiation; F = full amplitude; H _c = half amplitude in closure phase; H _o = half amplitude in opening phase	16

EXECUTIVE SUMMARY

During the past year we have continued our work on the development of laboratory procedures that will produce impaired performance. We have continued to investigate dynamic measures of the activity of the eyes and eyelids to index and predict impaired performance. Our oculometric measures allow us to predict the occurrence of 40% of missed signals (impaired performance) when such signals are presented in the auditory mode. For visually displayed signals predictability is approximately 90%. Predictors of impaired performance include the occurrence of eye blinks during the period of stimulus presentation (the stimulus to which the operator must respond is an auditory signal), the occurrence of long closure duration eye blinks, and the occurrence of eyelid closures, especially if such closures occur in conjunction with slow rolling eye movements in the horizontal plane. We conducted one study in which subjects were tested on our laboratory task on four occasions during the day. Performance impairment was greatest during the post-lunch test. The occurrence of eye closures in conjunction with rolling eye movements in the horizontal plane also were most likely to occur during this evaluation period. Approximately 3% of the total trial time, as compared to 0.3% for the 11 AM trial period, was occupied by such oculomotor activity. Though either 3% or 0.3% of total time is a brief period, the identification of such periods of lowered attention in field situations is important and should lead to the development of procedures that reduce the likelihood of occurrence of one type of human error, namely, that caused by lapses in attention. It is our contention that unexpected environmental events have a high likelihood of not being responded to by an equipment operator during such periods of lowered attention, though he may well be able to perform the routine aspects of his job. The nonperception of, or the nonresponding to, such unexpected events is, we believe, a major contributor to industrial accidents on the part of equipment operators.

Attempts to develop other alertness monitoring devices that have the potential for remote monitoring in the cab of mining vehicles were also explored. We evaluated the potential utility of measuring caloric output from the eyes as another procedure for indexing eye closures and eye blinks. On the basis of our work, we came to the conclusion that, because of temperature changes at the level of the eyes (produced by respiration), this procedure has little likelihood of becoming a useful measure.

TOWARD THE DEVELOPMENT OF ALERTNESS MONITORING DEVICES

1.0 THE NEED

That human error is a major contributor to accidents is well documented in both factory and field situations. It has been estimated, for example, that more than 80% of aircraft accidents have human error as a major component. The figure for automobile accidents is as high, if not higher.

Factors which lead to or enhance the likelihood of accidents include variables such as time of day, drug intake, skill level, etc. For example, a disproportionate number of single vehicle accidents occur during the early morning hours (4-6 AM) and alcohol intoxication is a major contributor to vehicular accidents.

We visited a local mine near St. Louis where we had the opportunity of talking with the safety engineer as well as spending two hours riding in one of the large coal haulage vehicles. The truck had many of the problems described in other Bureau of Mines publications. Access to the cab was via a ladder whose bottom rungs were invitations to accidents. Visibility to the side and rear of the vehicle was far from ideal. At least one problem occurred during the trips on the haulage vehicle and the backing-up alarm system did not appear to be functioning. The problem which occurred was that the truck operator had left his dump gates open after depositing his load. An alert shovel operator noted the problem and brought it to the attention of the truck operator. Here we have one example of a human error which, fortunately, was identified by a fellow worker and corrected before it could become a problem.

We have reviewed some statistical data on surface mine accidents involving heavy haulage vehicles and came away with the impression that, as is true of other industrial and highway vehicular accidents, mine accidents are not rectilinearly distributed across a work shift, but that peaks are likely to occur during the two-hour period preceding shift change. This is reminiscent of automotive accidents reported through the Missouri State Highway Patrol during 1980 and for earlier reporting periods as well. The frequency of vehicular accidents peaks during the

early evening hours (4-6 PM). Though the number of vehicles on the road during this time period is no greater than is true of the 7-9 AM period, the incidence of vehicular accidents is markedly higher during the PM period. Operator factors, involving human error, are the most likely contributors to this phenomenon. The focus of this research effort is the investigation of one of these operator factors, namely, momentary lapses in attention or alertness (also referred to as periods of micro-sleep), and the development of procedures to index their occurrence. It is hoped that once this is accomplished appropriate counter measures can be developed to reduce the occurrence of such lapses in attention.

2.0 THE PROBLEM

It is our conviction that many accidents occur during periods of lowered alertness or attention. Most workers can perform routine, over-learned and over-practiced skills under conditions of low levels of attention or alertness. We refer to this type of skilled performance as "automatized." For example, an expert post office letter coding operator can perform the keying task and concurrently listen to a radio. However, if low levels of alertness coincide with the need to respond to some unusual (unanticipated) source of stimulation in the environment, the likelihood of error is markedly enhanced. In the case of the coding operator, mistakes are likely to occur; in a vehicle, the probability of an accident is increased.

Contemporary skilled work, whether piloting an aircraft, controlling processes in a chemical refinery or atomic energy power plant, or driving a truck or tractor, involves long periods of relatively low work load demands on the operator, with infrequent and unpredictable periods of high mental and/or physical demands. For example, the task of the military pilot has been described as consisting of 90% boredom interspersed with 10% sheer terror. In our opinion, it is these periods of lowered task demand which markedly increase the likelihood of altered levels of alertness in the operators of high performance vehicles. It has been suggested that the introduction of cruise control for motor vehicles, for example, has increased the likelihood of highway accidents. The need for operator alertness and attention to aspects of vehicular control in this situation has been reduced to a level where the driver functions

semiautomatically and the speed with which he responds to "unusual" events is reduced.

This suggestion runs counter to much of the current concern in the arena of work load assessment. Most organizations (such as the U.S. Air Force) are concerned with overloading the operator of high performance aircraft with information about which he must make decisions. The assumption is that too many concurrent inputs cause operator errors. We do not deny that this problem exists and that solutions to it must evolve. However, the converse of the coin, information "underload," is an equally important problem deserving of more attention than it currently receives. We are not alone in our concern with this problem. A recent report¹ from the National Research Council alludes to this issue.

1/ National Research Council, National Academy of Science, Committee on Human Factors, Research Needs for Human Factors, National Academic Press: Washington, D.C., 1983.

"...the introduction of computers and automation in many systems has come to mean that for long periods of time operators have nothing to do...the workload may be so low as to result in boredom and serious decrement in alertness. The operator may then suddenly be expected to observe events on a display and make critical judgments indeed, even to detect an abnormality, diagnose what failed, and take over control from the automatic system. One concern is that the operator not being "in the loop," will not have kept up with what is going on, and will need time to reacquire that knowledge and orientation to make the proper diagnosis and take over control."
(p. 65)

Data collected under this USBM contract suggest that periods of lowered alertness may develop over fractions of seconds, and persist for seconds or longer. Such transient dropouts are affected by such variables as time-of-day, adequacy of prior night's sleep, work load, work history, drug intake, etc. In addition, there appear to be marked individual differences in the frequency of occurrence of such lowered levels of alertness. These phasic changes in alertness can be distinguished from the longer term tonic changes associated with aspects of the Basic Resting Activity Cycle (BRAC). This suggests that the need to monitor operator levels of

alertness, rather than becoming a less important problem with increases in automation, may be a more serious problem today than it was years ago.

The focus of concern in the recent past has been on lowered levels of alertness as a function of fatigue. We believe that equal attention should be devoted to lowered levels of alertness induced by boredom. Current technological advances make it possible to monitor levels of alertness and predict the likelihood of occurrence of errors in judgment through the use of physiological monitoring procedures. Our studies², sponsored in part by the U.S. Bureau of Mines (USBM), have

2/ A Study to Determine the Comparability of Pupillographic and Electrooculographic Measures in Determining Fatigue Effects in Truck Drivers. Final Report, January 4, 1982, Contract No. J0205064, Washington University Behavior Research Lab. John A. Stern, Larry C. Walrath & Robert Goldstein.

generated consistent data in support of this conviction, and reinforced our belief in the ability to devise instrumentation that can be used both to monitor the operator and to provide information about his state of alertness.

3.0 RESEARCH PROCEDURES

Our major efforts to date have focused on the eye as the source of information to be used to monitor levels of alertness. We have done so for a variety of reasons:

- a. Most tasks in the mining industry involve a considerable amount of visual monitoring.
- b. The instrumentation required for the recording of oculomotor activity is relatively inexpensive, less influenced by "artifacts" (or noise) than measuring the output of many other biological systems that can be considered for monitoring states of alertness.
- c. In addition, the potential exists for obtaining the oculomotor information without placing sensors (electrodes) on the operator.

To evaluate oculomotor variables suggestive of altered states of alertness, we developed a laboratory-based procedure that will insure a high likelihood of occurrence of such states. Equally important, it incorporates a performance component as the criterion variable. Only if the presumed alterations in alertness are associated with performance decrements can we be assured of the usefulness of the physiological measure in predicting altered levels of alertness.

Our earliest Bureau of Mines' sponsored study investigated a number of procedures for accomplishing the above.

In these initial studies³, we explored a number of technologies

3/ Work cited in footnote 1/.

for inducing performance decrements associated with alterations in vigilance. A large number of vigilance tasks were considered and the majority rejected because they did not provide sufficient behavioral information. Most vigilance test scenarios provide for infrequent probe stimuli (stimuli requiring a response). Thus, if alterations in alertness occur for brief periods of time, the likelihood of coincidence between a probe stimulus and such a period of microsleep will be minimal. The early studies focused on the use of a pupillometric measure to measure the possibility that narcolepsy might be a contributor to observable performance decrements as well as to evaluate a Honeywell-designed and built alertness monitor that remotely sensed eye closures and triggered an alarm if the eyes were closed for an extended period. We ruled out narcolepsy as a major contributor to the likelihood of occurrence of performance lapses and identified a number of problems with the alertness monitoring device that preclude its utilization in laboratory investigations, or the immediate application of the device in field settings.

As part of these investigations we utilized video recording procedures of the output of our monitoring equipment and concurrent recording of one of the subject's eyes. This investigation provided us with

valuable insights into electrooculographically measured components of the blink and has spawned a series of investigations under U.S. Air Force sponsorship which are being conducted at Brooks Air Force Base, School of Aerospace Medicine and, more recently, at the University of Texas at Arlington.

The task we have used for the past three years in producing alterations in alertness, meets our goals rather well. It requires subjects to make repeated discriminations of either auditorily or visually presented signals, and calls for a simple response.

The task involves the making of time duration judgments. The subject has to discriminate between "long" and "short" duration tones or light signals. The task can be made easy or difficult by altering the duration of the two stimuli to be discriminated. For example, requiring the subject to respond to a 200 msec stimulus but not to a 400 msec stimulus is relatively easy. A difficult task would have him discriminate between 350 and 400 msec stimuli. Most of our studies have utilized the easy discrimination (200 vs. 400 msec duration), and we can demonstrate changes in a number of oculometric components associated with impaired performance as well as time-on-task effects utilizing the auditory version of the discrimination task.

The oculometric variables investigated in this laboratory all have been aspects of spontaneous eye blinks and eye closures. Computer programs for on-line detection of eye blink parameters have been completed. While the development of programs to identify eye closures has begun, a working program is not yet available.

4.0 EYELID ACTIVITY ASSOCIATED WITH DISCRIMINATION ERRORS AND TIME-ON-TASK

4.1 Eye Blink Parameters

4.1.1 Timing of Blink

If a blink occurs during the period of stimulus presentation, even if the stimulus is auditory in nature, the likelihood of erroneous responses is markedly increased. We have previously reported on the timing of blinks during task performance, and in a number of experiments

have demonstrated that blink timing is associated with aspects of perceiving and processing of information. There is inhibition of blinking during these periods with the blink marking the termination of such decision making processes. We suggest that the occurrence of blinking during stimulus presentation may well be an early indicant of an alteration in attentive processes.

4.1.2 Blink Closure Duration

Since it is impossible, under free-looking conditions (i.e. unrestrained head), to identify when the eyelid has obscured vision during a blink, we have developed a procedure for defining blink closure duration that approximates this period reasonably well. The algorithm used performs the following analysis to define closure duration. After the computer identifies an eyelid movement as a blink (cf., Figure 4.1.2-1), it calculates the full amplitude of the blink and then locates the point in time at which the eyelid is half of the distance between blink initiation (Point I) and full amplitude closure (Point F). It next locates the point in the opening portion of the blink where the lid passes the same half amplitude level. The time difference between these two half amplitude points ($H_o - H_c$) is identified as closure duration, or in this instance "50% window closure duration." Other windows can also be set.

Since the temporal distribution of blink durations suggested the possibility that there were two distinct underlying distributions, we have sorted blinks into two categories based on the 50% measure. Those below 200 msec in duration are distinguished from those between 200 and 500 msec., the latter being referred to as "long closure duration blinks" (LCDB). More recently we have also demonstrated that even if those blinks labeled as "long closure duration" blinks are excluded from the analysis there is still a significant increase in average closure duration as a function of time-on-task. The finding that closure duration is significantly affected by time-on-task led to the development of a third measure, "descent time."

4.1.3. Descent Time

Descent time starts at the time the blink enters the 50% window

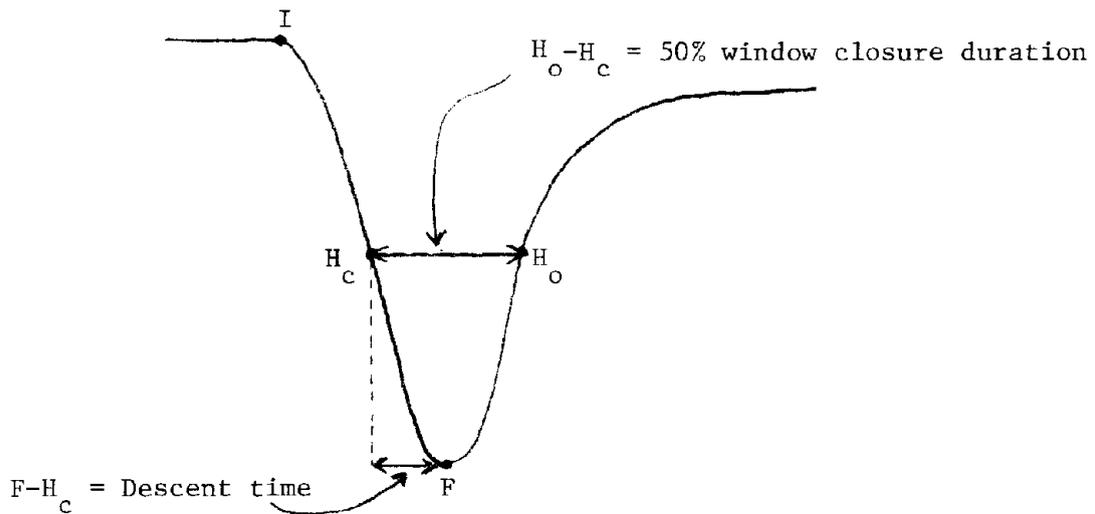


Fig. 4.1.2.-1 Typical blink with points set for determining parameters. I = blink initiation; F = full amplitude; H_c = half amplitude in closure phase; H_o = half amplitude in opening phase.

(H_c) and terminates at the point of full closure (F). Our current results suggest that descent time allows us to identify or predict the occurrence of long closure duration blinks.

4.2 Non-Blink Eyelid Closures

Eyelid closures in excess of 500 msec are not currently being automatically evaluated with the aid of a computer, but are identified by a trained operator.

Like long closure duration blinks (200-500 msec), lid closure frequency (those in excess of 500 msec) increases significantly as a function of time-on-task. The likelihood of an auditory signal being missed when it overlaps a closure is markedly greater than when no closure is occurring. We do not mean to imply that all signals are missed during closures, only that the probability of a miss is much greater during this period of time.

5.0 COORDINATED HORIZONTAL EYE MOVEMENTS AND CLOSURES

Up to this point we have restricted our discussion to information about changes in eyelid position. With our oculometric procedures we can also identify eye movements in the horizontal plane.

Subjects in these experiments were instructed to look straight ahead at a target which subtended approximately 25° of their visual field. A large target was selected to reduce complaints of "eye-strain" that had occurred in early experiments where the subject was required to focus on a spot the size of a light emitting diode.

Under eyes-open conditions subjects will occasionally use saccadic eye movements to shift their gaze from one to another portion of the target. We have not studied these saccades since they occur too infrequently to provide us with adequate data for analysis. However, as the eyes are closing, some interesting oculomotor phenomena occur which are associated with further increases in the likelihood of a signal being missed, viz., slow eye movements in the horizontal plane (SEM). We will describe three combinations of closures and SEM activity associated with distinguishable levels of performance.

5.1 Closures Without Horizontal Eye Movements (have been described above).

5.2 Closures With Half-Wave SEM

Slow eye movements in the horizontal plane have their maximal spectral energy in the 0.2 to 0.8 cycles per sec range. The half-wave movements are initiated with the eyes approximately centered; the eyes then deviate laterally and return to the center position. Subsequent deviations within the same closure period will be in the same direction as the first half-wave. These half-waves are initiated during the eye closure and terminate concurrent with the reopening of the eyes. Termination of the SEM is tightly time-locked to the opening of the eyes.

The likelihood of occurrence of missed signals is augmented under this condition as compared to the closure only condition.

5.3 Closures With Full-Wave SEM

Full-wave SEM's are slow eye movements which cross the midline. These eye movements are generally of greater amplitude than the half-wave SEM's. Like the half-wave SEM, their time-locking is tighter with respect to the opening than the closing portion of a lid closure. These rolling eye movements indicate further augmentation of impaired performance beyond that associated with the half-wave SEM.

6.0 EEG MEASURES

We have recently collected electroencephalographic (EEG) information concurrent with the oculometric and performance data. Visual inspection of the EEG at points in time where closures with and without SEM occur, suggests that many closure and SEM conjunctions are not accompanied by electroencephalographic indices of lowered levels of alertness or arousal. Computer-based analyses of these data await funding.

7.0 OCULAR TEMPERATURE

We have explored the possibility of using alterations in caloric output of the eye to index the occurrence of a blink or closure. If it were feasible to identify blinks and closures from temperature changes,

it would be possible to develop a relatively inexpensive, reliable and accurate procedure for identifying closures and blinks.

We developed a number of techniques for placing temperature sensors (thermistors) in the vicinity of both eyes. Rhythmic changes in temperature which differed for the two eyes were readily apparent. We initially thought that these temperature differentials at the two eyes were attributable to differential probe positioning and/or problems of air flow in the room. Both sources of artifact were investigated and found not to be major contributors to the effect. We next explored the possibility that the temperature fluctuations, as well as the temperature difference between the eyes, might be attributable to the cooling and heating caused by respiratory activity. Proper shielding of the air flow induced by respiration eliminated most of the unwanted noise. Since the reduction of these respiration-produced artifacts was a tedious process, one which could not be implemented in the field situation, it was abandoned.

8.0 SUMMARY

8.1 General

8.1.1 During the period of our contract we have developed procedures that will produce performance impairment in most subjects.

8.1.2 Associated with such impaired performance are physiological indicants indicative (predictive) of lowered levels of alertness.

8.1.3 The physiological measures evaluated to date all involve measurements of the eye and eyelid.

We have demonstrated that impaired performance is associated with:

a. Blinks occurring at "inopportune" moments - for example, during tone stimulation.

b. The occurrence of long closure duration blinks (200-500 msec).

c. The occurrence of eyelid closures (closures greater than 500 msec).

d. The occurrence of lid closures in conjunction with slow rolling eye movements in the horizontal plane (SEM's).

e. Approximately 40% of missed signals occur under one of these four conditions.

8.2 Summary - Current Year's Effort

8.2.1 Time-of-day effects on performance impairment associated with oculometric indices of performance impairment have been studied. Evaluating persons throughout most of the normal day work shift produced significantly greater impairment in performance at 1 PM than any other time of day (the post-prandial lapse). The other times of day evaluated were 9 AM, 11 AM and 3 PM.

8.2.2 The pattern of performance impairment discriminated between subjects diagnosed as suffering from a type of insomnia identified as Subjective Disorder Initiating and Maintaining Sleep (S-DIMS) and both those not afflicted with insomnia and those with Objective, EEG-defined DIMS (O-DIMS).

8.2.3 The development of procedures to evaluate eyelid closures by measuring fluctuations in caloric output of the eye was abandoned. Technical problems of measuring the temperature with non-skin contact procedures were solved. However, such measurements were contaminated by unpredictable changes in temperature produced by exhaled air.

8.3 Summary - Work Still In Progress

8.3.1 For methodological reasons we have conducted a study in which two groups of subjects had to respond to either the shorter or the longer of two tone durations, respectively. Another group of subjects sat through the experimental procedure with instructions not to respond to either tone. With respect to our Bureau of Mines funded interest, we wish to determine whether the performance of a vigilance task is more likely to lead to electrooculographically determined indices of lowered levels of alertness than would occur under conditions of no task demands. Data to evaluate this question have been collected and are currently being analyzed.

8.3.2 To allow for better controlled comparisons between our auditory and visual vigilance tasks, we have used signal detection procedures to equate task difficulty. Three levels of difficulty (easy, moderate and difficult) have been identified for both modalities. Data have been collected and will be evaluated in the near future to determine the effect of task difficulty and sensory modality on the development of performance impairment.

9.0 RECOMMENDATIONS FOR FUTURE RESEARCH

9.1 Personnel Selection

9.1.1 Can one identify persons who have a high (or low) likelihood of frequent periods of microsleep during the normal work day?

Our current research has demonstrated that approximately eight out of ten persons tested (80%) will demonstrate eye and eyelid activities associated with impaired performance. Whether such impairment is in the nature of a personality "trait" or to what extent it is "state" dependent is not known. By "state" dependent we mean, for example, whether the person has had (or not had) a restful night of sleep before participating in these tests, whether he has just had a meal (post-prandial effects), or whether he is involved in some stressful on-the-job or off-the-job experiences. A personality trait is a more lasting state of affairs less influenced by the vagaries of every-day-living.

The procedure would involve testing subjects on many occasions rather than the single trial experiments we have conducted to date.

If, as we suspect, one finds that the likelihood of a high frequency of microsleep periods is a "trait" characteristic of individuals, a reasonable next step will be to evaluate persons with poor driving safety records and those with good safety records (all working in the same industrial setting), to determine if our tasks will discriminate between the groups. If they do, we could recommend the use of this psychophysiological assessment procedure as part of the normal evaluative procedure used to select personnel for specific job functions, such as driving a truck.

- 9.2 Development Of "On-Board" Monitoring Devices Reflecting Periods Of Impaired Performance Potential
- 9.2.1 Utilization of Twin Cities Research Center Haulage Truck Simulator
- a. Attempts to modify Honeywell Alertness Monitor to function more effectively.
 - b. Dual task performance: utilization of oculometric information suggestive of microsleep periods to introduce "danger" signals into driving task performance.
 - (1) Operator detection of such events.
 - (2) Computer-based detection algorithms.
 - c. Development of "on-board" sensing of manipulanda outputs (steering wheel, brake, gear shift, clutch, etc.) to relate timing of such operations (braking and gear shifting, for example) to states of alertness; i.e. Can behavioral parameters be used to index level of alertness or occurrence of microsleep?
 - d. Development of other biological sensors that can detect altered states of alertness and which have a high potential for application to field environments.
- 9.2.2 Utilization of, or Collaboration with, John Deere Company Off-Road Vehicle Simulation Facility.

9.3 Direct Extension Of Current Research Efforts

9.3.1 Introduction of Infrequently Occurring Signals during Periods of Lowered Alertness

Our prior studies demonstrated significant impairment in primary task performance during oculometrically indexed periods of lowered alertness. The procedures for identifying these altered states of alertness have only been partially automated (computer-based on-line identification routines). The eye closure and horizontal SEM detection routines have yet to be perfected to the point that they reliably identify the events of concern. In our laboratory, such developments have a high priority. Concurrent with such development it is desirable

to further test the effectiveness of the algorithm for lowered alertness detection, currently defined by visual inspection.

We propose, in future studies, to use a divided attention task in which one task, which is well-automated, e.g. auditory duration discrimination, is infrequently interrupted by a higher priority task. This higher priority task will essentially be a vigilance task in which the subject must detect the occurrence of a "danger" signal and take appropriate action. This task will involve detecting one of a number of visually or auditorily presented signals. High priority stimuli will occur relatively infrequently, half the time in the presence of oculometric indices of lowered levels of alertness and half the time during periods of oculometrically indexed periods of alertness.

This dual task experiment simulates situations encountered by operators of vehicles and complex equipment. That is, while an operator is performing an overlearned, well-automated task such as driving a truck, there suddenly occurs an unexpected and unpredictable event (tire blow-out). It is the delayed or inappropriate response or nonresponse to this type of event that leads to dangerous situations, accidents, etc.

9.3.2 Evaluating other Alertness Monitoring Measures

In previous reports² we have outlined a few such procedures,

4/ Work cited in footnote 2/.

including evaluating the transfer functions reflecting vehicle induced vibration on the operators. It is our belief that this transfer function is altered during lowered states of alertness.

A second measure previously mentioned, but not described, involves the monitoring of central nervous system activity indexed by the electroencephalograph (EEG). Though this is not a measure that can be used routinely in field settings, it can serve a role, for example, in identifying individuals with a high or low likelihood of developing performance deficits during a normal shift period. Current techniques for using the EEG as an index of momentary change in alertness have

focused more on what happens during different "stages" of sleep than on what transpires electroencephalographically as a subject approaches pre-sleep stages, such as periods of daydreaming, reverie, etc. A second problem is that the duration for which a given stage must be maintained in order to be reliably identified, is of the order of 20-30 seconds, far too long to index the momentary changes of alertness (from 1 sec to 20 sec) of major concern to us. Our initial approach to this problem would be to evaluate EEG data during electrooculographic (EOG) identified periods of lowered Alertness⁵.

5/ E. Otto, D. Brauer & M. Wilhelm. Merkmalscharakteristik und diskriminanzanalytische Klassifikation wachheitsabhangiger EEG-Aktivitätsmuster. Acta. Biol. Med. Germ., 1975, 34, 1471-1483.

9.3.3 Field Testing of "Alertness Monitor"

With no major modification in recording equipment we will be able to record our oculometric measures under field conditions.

We propose to monitor electrooculographic variables while subjects are engaged in driving an automobile. Driving will be done in the afternoon to take advantage of the post-prandial propensity for reduced levels of alertness, and would involve a 5-6 hour drive.

We would invite a group of subjects to participate in both the laboratory task and, based on their performance on that task, the driving experiment. We would select a group of subjects who demonstrate relatively frequent occurrences of lowered states of alertness and a group who maintain a high level of alertness in performance of the laboratory task. This would allow us to evaluate our EOG data collection procedures under automobile driving conditions, and to determine the generalizability of our laboratory procedure for inducing lowered levels of alertness to field situations.

We are reasonably sanguine about our ability to collect reliable eye movement and blink data under these conditions since we have in the past recorded such data while subjects were flying

helicopters⁶, and while subjects were driving automobiles^{7, 8}. By

6/ J. A. Bynum & J. A. Stern. Painted helicopter main rotor blades and flicker-induced vertigo. Aerospace Medicine, 1969, 40, 622-626.

7/ J. A. Stern, L. Beideman & S. C. Chen. Effect of alcohol on visual search and motor performance during complex task performance. In M. Horvath (Ed.), Adverse effects of environmental chemicals and psychotropic drugs: Neurophysiological and behavioral tests, V. 2. Amsterdam: Elsevier Scientific Publishing Co., 1976, Pp. 53-68.

8/ L. R. Beideman & J. A. Stern. Aspects of the eyeblink during simulated driving as a function of alcohol. Human Factors, 1977, 19, 73-77.

selecting subjects who fall at the two extremes of the continuum for maintaining alertness under low level task demands, we will be able to answer a most important question dealing with the prediction of who may have a high (or low) likelihood of accidents induced by periods of lowered levels of alertness. We have limited data on short-term test-retest reliability of our laboratory measure (within one day), but no measures across longer time periods.

9.3.4. Motor Response Correlates of Altered States of Alertness

A number of attempts to identify alterations in motor performance as a function of time-on-task have been made over the past 30 years. The best example, and probably illustrative of most such efforts, is the work of Greenshields and coworkers⁹. They instrumented the "manipulanda" in

9/ B. D. Greenshields. Changes in driver performance with time in driving. Transportation Institute, Department of Civil Engineering, University of Michigan, Ann Arbor, 1969.

an automobile (steering wheel, brake, clutch, accelerator) and measured outputs from each of these manipulanda independently. The measure selected by Greenshields as best demonstrating time-on-task effects was steering wheel reversals. Unfortunately, others have not been successful

in replicating these results. The measures, in general, have been crude. For example, for steering wheel reversals, rather than measuring the excursion of the steering wheel, Greenshields set two criteria for movement, a small and a large movement, and counted the number of such steering wheel reversals per unit time.

We would propose to collect, concurrent with two channels of EOG, and one channel of head movement (accelerometer) data, five analog channels of manipulanda output reflecting steering wheel position, brake activation, accelerator activation, clutch position, speedometer, one channel of discrete information (position of gear shift), and one channel for coded information and/or voice annotation.

These data will allow us to relate alterations in the state of alertness as measured electrooculographically, to alterations in performance. Rather than average performance measures over relatively long and arbitrarily defined time periods (such as successive 15 minute periods), we would evaluate performance parameters (manipulanda output) during and around periods of various levels of alertness, oculographically defined, and compare the performance variables, both individually and in combination, between such different levels of alertness. We hypothesize that the coordination of braking, stepping on the clutch, shifting gears, release of clutch and stepping on the accelerator, is more likely to be disturbed by lowered levels of alertness than the discrete movements required by each of these operations. It is likely that the breakdown of such patterned performance will differ among individuals in the pattern of performance impairment in such situations. Though this makes the task of developing an alertness monitor based on performance variables somewhat more problematic, current microprocessors can be programmed to perform such functions.