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MAINTAINING ALERTNESS IN RAILROAD LOCOMOTIVE CREWS

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16. Abstract

The problem of assuring alertness in railroad locomotive crews is defined. Principles for maintaining alertness are derived from the experimental literature on vigilance and several unresolved questions are explored through three experiments. The findings are summarized in a set of criteria for evaluating alerting devices and techniques, and devices currently in use on the railroads are evaluated against these criteria. Recommendations are offered for improving current devices and for exploring new techniques.

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Symbol	When You Know	Multiply by	To Find	Symbol
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in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
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yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
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oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
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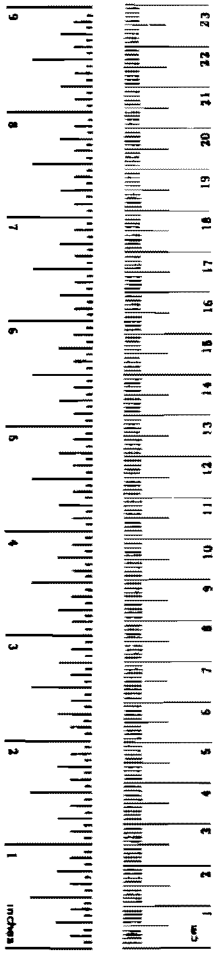

Approximate Conversions from Metric Measures

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cm	centimeters	0.4	inches	in
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m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
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km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
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l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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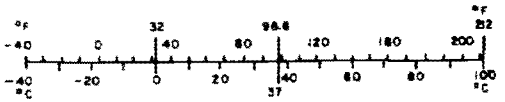

PREFACE

The work summarized in this report was conducted by the Transportation Systems Center (TSC) for the Federal Railroad Administration, Office of Research and Development. Lawrence Johnson and Associates, Inc. (LJA) performed three experiments under contract with TSC as a part of the study.

The authors gratefully acknowledge the contributions to this report made by C. Burnette of TSC in reviewing literature and by J. Jones, M. Lewis, and B. Shapiro of LJA in collecting and analyzing the experimental data.

EXECUTIVE SUMMARY

Introduction

Maintenance of engineer alertness in railroad operation has long been recognized as a basic safety requirement. Therefore, most locomotive cabs contain one or more types of alertness devices. This study was aimed at summarizing the literature on theories and experiments in human vigilance in a form that could be used to evaluate current alerting devices and techniques and to suggest ways of improving them.

Literature

The literature review revealed eighteen principles of alertness and attention having potential applicability to problems of alertness in locomotive cabs. There were still some unresolved questions regarding these problems so three experiments were performed to provide more information.

Experiments

The experiments were conducted in a full-scale, realistic mockup of a locomotive cab that simulated moving along straight tracks at 50 mph at dusk. A subject placed in the engineer's seat was required to monitor the scene through the front window, to detect an occasional signal comprised of two dim lights, and to respond to the signal indication by pressing appropriate keys.

By manipulating the schedule of signals, the experimenters could lead the subject to expect a signal different from the one presented. Motivation was changed by introducing rewards for correct responses in one experiment. Several secondary signals and tasks were superimposed on the primary task to determine their effectiveness as alertors in combatting the effects of loss of attention due to boredom and fatigue.

The subjects' key responses and such measures as response delay, brain waves (EEG), muscle potentials (EMG), heart rate (EKG), and bodily movement were recorded and analyzed. A total of 2664 responses were recorded from 26 subjects in 166.5 hours of testing.

Criteria for Alerting Systems

The information obtained from the literature and the experiments generated the following criteria for evaluating alerting techniques for locomotive engineers.

An ideal alerting system will:

1. Provide one or more secondary tasks to occupy the engineer during periods of low job demand.
2. Require activity of the engineer at fairly regularly spaced intervals.
3. Provide periodic rest breaks for the engineer.
4. Provide positive rewards for appropriate performance.
5. Give the engineer feedback on how well the job is being done.
6. Provide primary and secondary signals that are conspicuous.
7. Provide advance warning of impending signals or tasks.
8. Provide secondary signals and tasks that are related to the primary job and that focus attention on the requirements of the primary job.
9. Provide secondary signals and tasks that never interfere with primary signals and tasks.

These nine criteria were used to evaluate the following devices and techniques:

Pneumatic foot valve ("dead man" pedal)
Cycling pneumatic foot valve
Electronic alertness control
Periodic acknowledgment devices
Cab signaling

Automatic train speed control
Intermittent inductive automatic stop system
Signal matching.

Recommendations

The literature, the experiments, and the evaluation of devices and techniques led to the following recommendations for those seeking to improve alerting techniques currently in use or to advance the state of the art in maintaining alertness in the locomotive cab:

1. Replace the pneumatic foot valve with some device that requires acknowledgment from the engineer during periods of inactivity and that accepts operation of train controls as acknowledgments.
2. Support development of a system that requires the engineer to make an entry that matches each traffic control signal.
3. Support development of techniques for giving an engineer advance warning when approaching a signal.
4. Support research and development on ways to inform the engineer of the accuracy of responses and to reward good job performance.
5. Utilize the preceding criteria in evaluating new ideas for improving engineer alertness.
6. Monitor developments in the recording and analysis of human physiological behavior to determine when the state of the art has advanced enough to warrant further evaluation for alertness applications.

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1. INTRODUCTION

1.1 PURPOSE

The purpose of this study was to evaluate current devices and techniques for maintaining crew alertness in railroad locomotive cabs and to provide criteria for the selection and improvement of such devices and techniques.

1.2 SCOPE

This study was conducted for the Office of Research and Development, Federal Railroad Adminsitration (FRA), by the Department of Transportation's Transportation Systems Center (TSC). TSC reviewed current alerting devices and the technical literature on human alertness and vigilance. Lawrence Johnson and Associates conducted a series of vigilance experiments under contract to and with the technical direction of TSC.

1.3 BACKGROUND

In response to requirements of the Federal Railroad Safety Act of 1970, the FRA has been conducting research on ways to improve the safety of railroad operations. Train accidents are a costly consequence of safety problems, and some twenty to twenty-five percent of train accidents are presently ascribable to human error. There were 2238 train accidents caused by "human factors" in 1974 (FRA, 1974), causing 16 deaths, 192 injuries, and $29,000,000 in damages. For the ten preceding years, the number of such accidents was roughly the same, but inflation caused the costs to double over the same period. Therefore, as a part of its research program, the FRA commissioned TSC to investigate several areas in railroad operations where safety was particularly dependent on characteristics of human performance. One such area involved the alertness of locomotive crew members.

The FRA statistical summaries do not provide enough details to identify accidents involving alertness. However, two detailed analyses of narrative reports of serious train accidents have been made at TSC. An analysis of 30 train accidents showed that 43 percent involved loss of alertness to some degree on the part of locomotive crew members, and a supplementary analysis of 23 additional crew-caused accidents yielded the same percentage. Related to this situation also was the finding that in 14 (26 percent) of the 53 accidents analyzed, responsible crew members had false expectations about the operational situation ahead. One American railroad man states that vigilance is a great factor in the prevention of train accidents (Staeheli, 1972, p. 36). Davis (1966) interviewed 34 British drivers (engineers) who had failed to respond correctly to traffic control signals. Twenty-nine of the drivers had made errors related to alertness, 14 had seen the signal too late to stop, 5 had misread the signal, 6 had read the wrong signal, and 4 had failed to see any signal at all. Although it is not well defined, crew alertness can be identified as a problem area.

1.4 APPROACH

The approach to the problem of alertness in the locomotive cab involved four efforts: problem definition, literature review, establishment of a research facility, and performance of a series of experiments.

Section 2 defines the problem; Section 3 summarizes principles of alertness in the technical literature; Section 4 describes the experiments; Section 5 presents a set of criteria for evaluating alertness devices and techniques and rates devices currently in use, and Section 5 offers recommendations drawn from the study.

2. PROBLEM DEFINITION

2.1 ALERTNESS AND ATTENTION

"Alertness" is a readiness to detect stimuli in the environment requiring a response and to react to them quickly and appropriately. (The term "vigilance", a synonym for alertness, appears so frequently in both railroad and psychological literature that both terms will be used interchangeably in this report). Our senses are continuously bombarded with more stimuli than we can possibly respond to; we survive because of an ability to select and respond to sets of these stimuli that are critical to us in some way, filtering out all others. This focusing process is called "attention". Alertness, then, readies us to detect and respond; attention determines what we will detect and respond to. A loss of alertness, or a diversion of attention, can result in a failure to detect and respond to critical events in the environment; in the locomotive cab, this can be disastrous.

It is well known that alertness declines during periods of little or no stimulation -- if nothing much happens for a while, we are caught unprepared when something does occur. An unchanging stimulus or repetition of the same or similar stimuli will also induce a loss of alertness. Our loss of responsiveness to continuous or repetitive stimuli is called "adaptation". Let us examine the job of the locomotive engineer for situations where alertness may decline.

2.2 THE LOCOMOTIVE ENGINEER'S JOB AND ALERTNESS

2.2.1 Complexity of the Job

The locomotive engineer (sometimes called engineman in the United States, driver, elsewhere) controls the movement of the train. Much of the safety and efficiency of train operations is dependent on the engineer's skill and judgment. In freight operations, a train, on the average, consists of some 4,000 tons (sometimes as much as 20,000 tons) of a loosely coupled, heterogeneously distributed mass, snaking and undulating for a mile or two behind the engineer at speeds up to 70 miles per hour. Any adjustment the engineer may make on the power units (several multi-thousand-horsepower locomotives working together, but sometimes grouped in different parts of the train) can induce waves of compression or extension (slack run-in or run-out) to pulse through the train. Misjudgment by the engineer can set in motion forces that can cause discomfort or injury to passengers, damage to lading and at worst can result in derailment of the train. Operating a train is not like driving a truck. According to one railroad man, it is more like driving a hundred trucks all at once, with some going up hill and others going down hill at the same time (DeButts, 1975, p. 40).

2.2.2 Engineer Qualities

Analyses of the personal qualities necessary in a locomotive engineer (e.g. Grant, 1971; Hale and Jacobs, 1975) always include alertness or vigilance along with such attributes as information processing, memory, anticipation and perceptual-motor coordination. Hale and Jacobs stress this capability: "Foremost among his many talents, the engineer must demonstrate vigilance or the capacity to be attentive to all critical, informational inputs throughout a several hour trip within a relatively confined workspace (the locomotive cab)." (Hale and Jacobs, 1975, p. 10).

2.2.3 Periods of Inactivity

It may seem strange that loss of alertness can occur on a job as complex and demanding as train handling. The explanation is that the demands on the engineer are not uniformly distributed in time. Sometimes an engineer is exceedingly busy, but there are other periods when the train essentially runs itself. If the track is straight and level, the train is dynamically balanced to cruise at the required speed, and no events occur in the external environment to affect the train's progress, then there is very little in the job to stimulate the engineer. This is not to say that there is nothing to do. In fact, because of the slow and complex response of the train to changes in the controls, the engineer must continually anticipate what is definitely going to happen (changes in grade, curvature, and speed requirements) and what might happen unexpectedly (obstructions on or near the tracks, unanticipated signal indications, breakdwons or malfunctions in the train, and the like). The engineer must respond quickly and accurately when an action is required. Thus, the safety of the train is dependent on the continual alertness of the engineer throughout these periods when there is little stimulation from the job situation.

Periods of inactivity can be fairly long. Observers of Canadian train crews noted: ". . . the distribution of activity is such that there are long spells (5 to 20 minutes) during which the crews had little to do or care about" (Michaut & McGaughey, 1972, p. 5). TSC personnel have recorded events in locomotive cabs on a variety of freight service runs. From these records, periods can be identified during which the engineer did not operate any major controls; there were no significant changes in instrument indications, and there were no major accelerations or jolts recorded in the cab. Even in undulating territory, 30 to 50 percent of the time the train was in motion was time of inactivity, in periods ranging from one minute to eleven minutes. In one run of three hours, half of the inactive periods were longer than two minutes and one-fourth exceeded four minutes. On a run of five hours and twenty-three minutes in very level country, 86 percent of the running time was inactive. The fifty-six recorded inactive periods ranged from one minute to thirteen minutes, with nearly half in excess of three minutes, over one-fourth in excess of eight minutes. On such runs, there is ample time for an engineer to become distracted, daydream, and even doze off.

2.2.4 Other Complicating Factors

The engineer's principal task is to monitor the situation during these dull periods. Many of the stimuli that are present are essentially continuous, such as the drone of the engines and the background noise of the radio. Other stimuli are repetitive and thus monotonous, including the swaying of the cab, the click of the wheels on rail joints, the passage of track and wayside telegraph poles in the field of vision -- all rhythmic in nature and rapidly adapted to as an unstimulating background. At night, lights passing in the visual field may be irregular, but they flow by at a constant speed that is also lulling. Often the cab is warm, contributing to the soothing atmosphere. Even the chatter on the radio may fade into the background.

These soporific effects are aggravated at night by a natural daily cycling of human activity (circadian rhythm) that reaches a low point around 3:00 to 4:00 a.m. Michaut and McGaughey (1972), reporting the results of many observations of train crews at work, noted that crew members (other than the engineer) are liable to fall asleep after midnight -- an occurrence that they never observed during daylight hours. Branton, in discussing the cabs of British locomotives, observes that instances when a driver has become drowsy or has fallen asleep on duty are common (Branton, 1970, p. 86). Many American engineers have had the frightening experience of dozing off at the throttle (often just before sunrise), fortunately awakening before anything serious had developed (an experience shared by many automobile drivers). These experiences are unrelated to the hours the engineer has been on duty.

The engineer does have duties during the dull periods. The most frequent requirement is to watch for wayside traffic control signals. But many times, the signal is "clear", requiring no control action. And the very act of watching for signals can result in eye fatigue and a feeling of wanting to shut the eyes.

Physical fatigue is probably less of a problem than monotony, since the engineer's job is not physically demanding. However, the laws in the United States that limit the hours of continuous work for train crews cannot control the way the engineer spends time between work shifts. Grant (1971) refers to "mental fatigue". He asserts that the knowledge that one is rushing along the tracks in front of an enormous mass of metal, difficult to control, creates stress that continually constitutes a more or less steady drain on the engineer's capacity to perform (Grant, 1971, p. 113).

He goes on to note E. Grandjean's observation that the fatigue of engineers arises, not from overload of the human system, but from underload or monotony and boredom due to inaction, combined with stress (Grant, 1971, p. 114).

2.3 CURRENT COUNTERMEASURES

The problem of maintaining an engineer's readiness to act through these many periods of inactivity has long been recognized by the railroads. Two approaches have been adopted. One approach is to require the presence and activity of additional people in the cab. The second approach is to install devices in the locomotive that will either keep the engineer active or apply the train's brakes if the engineer becomes inactive.

2.3.1 Multiple Occupancy of the Cab

It is common practice in the United States railroads to require crew members in addition to the engineer (firemen or front brakeman or both) to be present in the lead locomotive during train operation. Although practices vary among carriers, generally, all crew members are required to sight and call out the aspects of all wayside signals controlling the train and to apply the emergency brake if the engineer should become incapacitated. This practice has several advantages: The requirement to call signals keeps the crew members active and focuses their attention on the signals themselves. A crew member across the cab can often see signals on turns before the engineer can see them, thus compensating for the engineer's limited visual field. Companions provide stimulation during otherwise dull periods. However, this latter stimulation is not necessarily job-related; distraction of the engineer by conversation in the cab is noted as critical by Staeheli, (1972, p. 36).

On the other hand, there are many commuter trains in which the engineer (or motorman) is alone. The position of fireman has been abolished on many United States railroads in recent years, and there is a continuing trend toward reduction of train crew size. Thus, there will be increasingly more situations in which the engineer is alone for long periods while operating the locomotive, without assistance in sighting and interpreting signals.

2.3.2 Alerting and Safety Devices

a. Pneumatic Foot Valve ("Dead Man" Pedal)

The oldest and most commonly used alerting device in the locomotive cab is the pneumatic foot valve -- the familiar "dead man" control. The engineer is required to keep this foot pedal depressed while the train is in motion. If he releases it (by lifting or removing his foot), a warning whistle sounds continuously. The engineer must respond to the warning in four to six seconds by depressing the pedal again or by applying the train brakes. If the engineer fails to respond, the brakes are applied automatically. Keeping the foot on the pedal restricts the engineer's range of movement and can become uncomfortable over a long time period. There are innumerable, widely practiced ways to tamper with the pedal. Furthermore, foot pressure on the pedal does not guarantee alertness.

b. Cycling Pneumatic Foot Valve

One approach to meeting objections to the "dead man" device is to add a cycling valve. This feature requires the engineer not only to keep his foot on the pedal but also to periodically lift his foot from the pedal to avoid a warning and possible penalty brake application. "Up" and "Down" time can be varied; typically an "up" time of 6 seconds and a "down" time of 20 to 95 seconds are used. To avoid leg fatigue, the AMTRAK Turbotrains permit the engineer to operate either of two pedals. The system includes a warning horn for excessive "down" time, a whistle for excessive "up" time, and actuation of locomotive controls may be substituted for "up" releases. Numerous other variations are possible, including use of manual controls in place of the pedal. These cycling devices, by requiring periodic activity by the engineer, increase the probability of engineer alertness, and they are more difficult to tamper with. However, there may be busy times when the response to the safety system can be a distraction or interfere with other duties and thus actually be hazardous. According to manufacturers, about one-third of the new locomotives entering service in 1976 will be equipped with a cycling "dead man" device.

c. Electronic Alertness Control

An electronic alertness control senses activity on the engineer's part from the output of a copper-screen antenna built into the engineer's seat. If no activity is sensed over a period of 20 seconds, audible and visible warnings are actuated. The engineer must respond to the warning in 10 to 12 seconds by touching a metal object or, if touching a metal object, by breaking that contact. Failure to respond initiates a penalty brake application. In theory, a normally active engineer will satisfy system requirements. In practice, however, the antenna may fail to sense normal activities, thus initiating too many false alarms, to the distraction of the engineer. According to the manufacturer, one U.S. railroad has about 1000 locomotives equipped with this type of device, and two others are testing it.

d. Periodic Acknowledgment Devices

These devices require an engineer to actuate a special control periodically (generally once every 45 seconds). Failure to respond activates some kind of warning, and if there is no response to the warning in a fixed period of time, a penalty brake application is initiated. One such system requires the engineer to actuate a toggle switch every forty-five seconds. The switch is sensitive, has a long handle, and is located generally between the throttle and the air brake control. It can be actuated by a simple brushing motion (for example, while moving the hand from brake to throttle). If the switch is not actuated within the time required, two red lights are illuminated, and 10 seconds later, a whistle sounds. Failure to actuate the switch within 5 to 7 seconds after the onset of the whistle causes penalty application of the brakes. In another version of this type of alerting system, the two warning lights flash alternately, and instead of operating a toggle switch, the engineer pushes a reset button. During periods of high workload, requirements of these systems can be distracting and can constitute a hazard. To overcome this disadvantage, the systems may be modified to accept a variety of routine control actions as substitutes for the actuation of the toggle switch. Manufacturers claim that periodic acknowledgment devices are used in about 1200 locomotives of one U.S. railroad, 80 of a second carrier, and are being tested by 3 additional lines.

e. Cab Signaling

Cab signaling is not primarily an alerting technique, but it does incorporate an alerting feature. In automatic block signal territory, the coded block signal being transmitted along the rails is picked up by receivers mounted ahead of the locomotive's wheels, amplified, and presented in the cab on a visual display similar to the external wayside signals. Whenever, the signal changes to a more restrictive aspect, a distinctly toned whistle sounds, and continues to sound until the engineer presses an acknowledging button. As with other alerting devices, acknowledgment does not guarantee that the engineer is fully attending to his job, nor even that he has correctly perceived the signal.

f. Automatic Train Stop (ATS)

This system adds a penalty brake application to the cab signal system. A change of block condition to a more restrictive aspect initiates the whistle warning and, after a brief time delay, a full service application of the locomotive train brakes. This braking may be forestalled if the engineer acknowledges the audible warning within the time permitted.

g. Automatic Train Speed Control (ATC)

This system adds further refinements to the ATS system. Train speed is sensed from the locomotive axle and compared with the speed limit determined by the cab signal condition. At any time that the train exceeds the maximum speed displayed by the cab signal (either through the engineer's loss of vigilance or a change in block condition), the audible alarm sounds. If the engineer applies the brakes appropriately within 6 seconds of the onset of the alarm, he can release the brakes again when he has reached a safe speed. Should he fail to respond, a full service brake application is initiated automatically and maintained until the train stops or reaches a predetermined safe speed.

h. Intermittent Inductive Automatic Stop System

This system is activated by trackside devices at selected locations, such as at signals or entrances to interlockings. An automatic brake application is initiated at the location, unless the engineer forestalls it by manually operating an acknowledging device on approaching the location. There are no cab signals with this system. To negotiate these locations successfully, the engineer must know where they are and anticipate by operating the acknowledgment device just before his arrival at the control point.

2.3.3 Proposed Techniques

Several additional techniques for maintaining alertness in the locomotive cab have been proposed and are in various stages of experimentation.

a. Signal Matching

A device has been proposed that requires the engineer to punch into a keyboard the aspect of each wayside signal passed. Coupled with a cab signal system in the locomotive, such a device could provide feedback to the engineer on his signal matching accuracy. It could also compare the engineer's entry with the actual signal and trigger a warning and braking sequence in response to wrong entries. Such a technique promotes vigilance, focuses the engineer's attention onto the job, and provides an automatic safety backup if the engineer is incapacitated. Safety experts have enthusiastically endorsed this concept in both the United States (NTSB, 1971, p. 8) and Great Britain (Robertson, 1969, p. 18-19).

b. Motion Sensing

One manufacturer designed an ultrasonic transmitter and sensor system to detect the motions of the engineer. In theory, lack of sensed activity would be interpreted as loss of attention or loss of consciousness in the engineer, and a given period of inactivity would cause the system to awaken the engineer or, failing that, to stop the train. Development of this system was discontinued, primarily because vibrations of the locomotive cab could not be distinguished from the engineer's activity.

c. Physiological Sensing

Certain changes in physiological responses are known to occur as a person loses alertness. Changes may occur in brain wave activity, electrical potential of forehead and neck muscles, heart rate, eye movements, blood pressure, urinary metabolites, oral temperature, oxygen uptake, and skin conductance. Laboratory studies have related these changes to loss of alertness, and attempts have been made in the past to sense some of these physiological characteristics while people were at work and to use changes in these measurements to trigger warning devices. Unfortunately, practical limitations have prevented the development of physiological sensing equipment that can operate reliably under the the rigors of locomotive cab conditions. For example, some early researchers built a device which attached to the forehead and would detect states of alertness and automatically warn the subject of an approaching dangerous inattention during monotonous tasks (Travis and Kennedy, 1947). They tried using it to maintain alertness in truck drivers, but encountered several problems. Some were technical: there were electrode movement artifacts, eye movement artifacts, suspicion of brain wave interference, and the electrodes would often fall off or otherwise disconnect. A serious non-technical problem was the objection of the truck drivers to the discomfort and interference of being "wired-up".

Although technical problems have defeated the past attempts to develop a practical physiological alertness indicator, this approach should not be considered a dead issue. Technology advances so rapidly that, periodically, new techniques should be reviewed for their applicability to old problems.

A technique has been demonstrated recently that has implications for alertness. One component of the electrical activity of the brain (called _theta_ activity) is known to increase when alertness decreases (O'Hanlon, 1970). Beatty et al. (1974) were able to train people to increase or decrease their theta activity and to show that those who could decrease theta also performed better at a two-hour radar monitoring task. It is still a long step from the laboratory to the locomotive cab, but the future use of theta suppression as a technique for screening out engineer candidates who may have alertness problems, or theta control as a means of maintaining alertness in the cab, should not be overlooked.

3. PRINCIPLES OF ALERTNESS AND ATTENTION

3.1 INTRODUCTION

From the voluminous published literature on factors affecting alertness and attention, some principles can be extracted that have been established experimentally and are generally considered as scientifically acceptable. A review by Stroh (1971) provides an exceptionally useful summary of such principles. From Stroh's review, thirteen principles of alertness and five principles of attention were identified as being applicable to locomotive cab problems. These have been further grouped according to their applicability to primary tasks, secondary tasks or signals.

In the text that follows, each principle will be introduced with a simplified title for convenience of reference, followed by a short, definitive statement of the principle. Following the definition of a principle (or in some cases two or three related principles), the text will review the ways the principle (or principles) have been applied in the design of currently used alerting and warning devices.

For convenience of discussion, terminology has been standardized as follows: A signal is a stimulus that is part of the job; readiness to respond appropriately to the signal constitutes alertness. The primary task (or simply the task) is that part of the job which involves detecting and responding to a signal. A secondary stimulus is a stimulus that is added to the job to promote alertness; it may or may not be related to the primary task. A secondary task is a task (related or unrelated to the primary task) imposed on a person to keep the person alert.

3.2 PRINCIPLES OF ALERTNESS

3.2.1 Principles Related to Primary Tasks

a. Complexity

Alertness improves with increased task complexity (within reasonable limits). Conversely, the duller the job, the more likely is a decrease in alertness. The caution on reasonable limits simply acknowledges that if a person is given too much to do, alertness to the primary signals will suffer.

The cycling "dead man" devices and those requiring periodic acknowledgment apply this principle by adding a task to the engineer's job, thus maintaining activity and alertness during dull periods. Their weakness is that the same extra task may overload the engineer during busy periods. The basic "dead man" device violates this principle, since maintaining a constant pressure on a foot pedal is not stimulating; it adds to the dullness of the job.

b. Intersignal Range

Alertness improves when the range of intersignal intervals is decreased. Regular (rather than irregular)spacing of signals in time is preferred. (The studies leading to this principle did not use such short intersignal intervals that the stimuli would seem rhythmic-- in which case we might expect adaptation to lead to a loss of alertness).

Regular spacing of secondary stimulating activity is a feature of the cycling "dead man" and the periodic acknowledgment devices. However, the principle is more applicable to the primary task--in this case, responding to the signals and other events of the real world, which generally can not be arranged to occur at regular intervals. A possible application of this principle would be to break up long blocks with intermediate signs or signals requiring the engineer's acknowledgment.

c. Expectancy

A person is more likely to detect a signal if it occurs when expected, and is more likely to miss an unexpected signal. It is easier to determine when to expect a signal if preceding signals have occurred at fairly regular and small intervals (consistent with the principle of intersignal range).

This principle is incorporated in the devices with cyclic or periodic tasks. Because the task is predictable, the engineer is kept in a state of readiness to perform. Again, we should note that this is readiness to perform the secondary task; we can't be sure that it is readiness to perform the main job. The intermittent inductive automatic stop system requires expectancy. The engineer must learn where the external sensors are located and be ready to operate an override control just before reaching them.

d. Motivation

Alertness improves when greater rewards are provided for good performance.

If we consider the avoidance of a penalty brake application as a reward, then nearly all current safety devices make use of this principle. The possibility of associating more positive rewards with safe behavior might be worthy of consideration as a future approach.

Incentive programs could be based on safety records with cash, time off, special recognition or merit promotions as rewards. Perhaps a lottery could be based on the sequence of observed signals. Certainly the industry can conceive of other techniques to make alert behavior more rewarding.

e. Feedback

Alertness improves with knowledge of results of prior performance.

Failure to receive a penalty brake application in a sense informs the engineer of the appropriateness of present control actions, just as the application of brakes is a clear indication that something was done wrong. As noted in Section 2.3.3, one of the most promising additional applications of this principle would be a device requiring the engineer to match the signal indication and providing feedback as to the correctness of response. A weakness of most current devices is that they do not guarantee that the engineer is perceiving the job demands correctly.

f. Breaks

Alertness improves with the introduction of short periods of rest, conversation, and exercise.

None of the current safety devices provide rest breaks. In fact, those imposing constant or periodic secondary activity are in violation of the principle to some extent, interrupting conversational breaks.

The application of this principle can be realized operationally in two ways, but both are difficult to achieve in a practical sense. One application would be to schedule trains to stop for rest periods. Of course, normal freight operations routinely involve many stops during which the engineer may rest, but there are also long periods of continuous operation without breaks. The practical difficulties associated with interrupting schedules do not need to be enumerated here.

A second way of achieving rest breaks for engineers is to have a second person take scheduled turns at the throttle. Many firemen are qualified engineers; however, there are also typically many operations where the assigned engineer is the only qualified engineer in the cab. In present operations, it is not unusual for qualified firemen to operate the train; however, the institution of a regular schedule of such breaks also would involve a host of practical problems.

Partial breaks, such as conversation while in motion, are more feasible, but to the extent that they divert the engineer's attention from the primary job, they are hazardous and unacceptable.

3.2.2 Principles Related to Secondary Tasks

a. Secondary Task

Alertness improves with the inclusion of a secondary task in the vigilance situation. (This follows from the complexity principle.)

b. Frequency

Alertness improves with increased frequency of non-signal stimuli. However, if the primary signal occurs at the same time as a non-signal stimulus, alertness is better with a decreased frequency of non-signal stimuli. That is, alertness is better when monitoring a busy rather than a dull background, provided that the background doesn't interfere with the primary signal.

The "dead man", both constant and cycling, and the devices requiring periodic acknowledgment are examples of the application of the secondary task principle. They assure some activity on the part of the engineer during the periods when the primary job makes no demands. The weakness of relying only on a secondary task is that it does not assure that the engineer's attention is focused on the primary job; it only assures activity.

The "dead man" is the weakest secondary task, since adaptation to the constant foot pressure on the pedal soon disqualifies the function as an "activity". This is a violation of the frequency principle. Of course, the cycling requirement was added for this very reason, and the periodic acknowledgment devices serve the same purpose...to avoid long periods of time when nothing happens.

These devices also represent violations of the frequency principle. As originally designed, their secondary warnings and penalties continue to operate when the engineer is busy, violating the principle of decreased frequency of a secondary signal when it occurs at the same time as the primary signal. Many of these devices can be made to accept the operation of major controls as acknowledging signals. This feature is highly desirable, and when in use will generally prevent the safety device from distracting the busy engineer.

c. Other Senses

Alertness improves when, in a complex vigilance task, there is a decreased amount of novel stimulation to the sense organs not involved in the vigilance task. For simple tasks, alertness improves with increased stimulation of the other senses. (For example, background music disrupts complex industrial tasks but leads to improved performance on simple tasks.)

During dull periods, devices with audible warning signals conform to this principle, but during busy periods (complex task) they violate the principle by attracting attention to the secondary sense.

3.2.3 Principles Related to Primary and Secondary Signals

a. Combined Senses

Alertness improves when signals are combined audio-visual events rather than just audio or visual events.

All the devices using audio-visual alerting or warning signals have applied this principle.

b. Visual Area

When a signal must be detected visually, alertness improves with a decrease in the area of the visual field to be scanned.

c. Position

When a signal must be detected visually, alertness improves when the signal is most likely to appear near the center of the area to be scanned.

The location of warning lights and cab signals is left to the discretion of the individual carrier. The warning devices are usually given a preferred position in the engineer's visual field, but this location is not inherent in the design of the device. Many locomotive cabs have such restricted views of the outside world that great care must be taken to avoid blocking the view with cab instruments. With so many instruments and signals competing for preferred positions in the engineer's visual field, we can not recommend reliance on visual area and position of devices as the principal means of assuring alertness.

d. Training

Alertness improves following training under conditions of appropriate signal probability.

Trainees should be given instruction and practice on the operation of any safety devices that they may use on the job. The alerting signals and tasks used in training should faithfully match (in frequency, brightness, loudness, color, etc.) those used on the road.

3.3 PRINCIPLES OF ATTENTION

a. Magnitude

Stimuli that are the largest (in intensity, size and time) are the most likely to attract attention.

b. Novelty

Stimuli that are novel are likely to attract attention.

c. Change

Stimuli that involve movement or change (moving objects, flashing lights) are likely to attract attention.

These three principles simply mean that, to attract attention, a signal should be conspicuous. All of the current devices except the intermittent inductive automatic stop system use unique, loud and/or bright warning signals (magnitude and novelty principles). The principle of change has been used in one model of the periodic acknowledgment devices that has two lights that flash alternately.

d. Need Fulfillment

Stimuli that fulfill a need are likely to attract attention.

Need fulfillment is interpreted here in terms of the engineer's desire to know the information conveyed by the device. The principle is considered to apply in devices having signals directly related to the job (the electronic alertness control and those that work from cab signals). The principle of need fulfillment is considered to be violated in devices whose signals convey information the engineer doesn't really feel a need for.

e. Interest

Stimuli that are of particular interest to an individual are likely to attract his attention.

As with need fulfillment, the interest principle is considered to be applied in the job-related warning of the electronic alertness control and those devices involving cab signals. However, devices with warning signals not directly related to the job are not considered to violate the interest principle, since, although the engineer may not desire the information, it is of interest.

4. EXPERIMENTAL PROGRAM

4.1 QUESTIONS TESTED

The foregoing principles of alertness and attention, although providing a basis for evaluating alerting techniques, fail to answer a number of questions when one tries to apply them to the problems of the locomotive cab. This is to be expected, since the literature was not derived from railroad problems, and the experiments leading to the principles were based on tasks and situations unlike those in the locomotive. To increase confidence in the use of these principles, some of the unanswered questions were explored further through a set of experiments with tasks and a setting more closely related to conditions in the locomotive cab.

The specific questions that were investigated are given below, together with the reasons for selecting them for study.

4.1.1 Questions Related to Principles of Alertness

a. False Expectations

If an engineer expects a particular signal indication, is he more likely to make an erroneous response to an unexpected signal indication? The "expectancy" principle in the literature refers to when to expect a signal and can be applied to prevent the crew from missing signals. However, accident reports suggest that false expectations about what a signal will indicate can lead to wrong responses to a signal even when it is detected. This question was studied to provide some experimental data on false expectations.

b. Job-Related Task

Will an engineer make fewer errors in the primary job when alerted by a signal related to the primary job than when alerted by a signal unrelated to the primary job? The literature includes studies in which the secondary task was similar to the primary task and studies in which the two tasks differed greatly, but information is lacking comparing the relative effectiveness of related and unrelated secondary tasks in maintaining alertness on the primary task. Complaints of railroad personnel that some alerting devices distract their attention from their primary tasks make this a desirable question to examine experimentally.

c. Warning Schedule

Is a secondary warning signal more effective when presented at regular intervals or when presented at random intervals? The principles of "expectancy" and "intersignal range" suggest the use of a regularly spaced signal, but the principles of "complexity" and "novelty" suggest some value for an unpredictable alerting task. This paradox seemed worthy of further study.

d. Second Person

Does a second person in the cab reduce the engineer's errors in responding to signals by keeping him alert, or does the second person increase the engineer's errors by distracting attention from the primary job? This is a practical question in view of the trend to reduce crew size. There is no literature on the relative effectiveness of a person as the source of secondary stimuli.

e. Motivation

Does rewarding engineers for correct responses to signals improve performance? This question was selected to test the applicability of the "motivation" principle to cab problems.

4.1.2 Questions Related to Indices of Alertness

a. Physiological Responses

Do changes in an engineer's brain waves (EEG), particularly alpha and theta waves, muscle potential (EMG), or heart rate reliably predict changes in response accuracy? Certain physiological responses have been found to change as alertness declines. Although previous attempts to use these changes to operate alerting devices were unsuccessful, (Section 2.3.3), the possibility that improved methods of measurement and analysis might make such techniques feasible was judged worthy of checking.

b. Behavioral Responses

Do changes in an engineer's rate of eye blinks, frequency of eye movements, bodily activity, or response latency reliably predict changes in response accuracy? Research has shown that as a long, dull task continues, general behavior tends to slow down. Some indices of this slowing that are relatively feasible to measure include the frequency of eye blinks, the extent of eye movements, the frequency of body movements, and reaction times. (With regard to the latter variable, the elapsed time between the onset of a signal and the beginning of a subject's response to the signal -- response latency -- was selected for analysis). This question was tested to determine whether some of these reactions might be measured in the locomotive cab and used to trigger warnings of diminishing alertness.

4.2 RESEARCH FACILITY

4.2.1 Cab Mockup and Basic Task

The experiments generated in response to these questions were performed using a research facility centered on a fullscale mockup of the right half of a standard EMD locomotive cab, with space in the left half for equipment and an experimenter, when required. Monitoring and control of all stimuli and recording equipment and communications with the cab were accomplished in a control room adjacent to the cab.

The cab was equipped with an engineer's seat and a facsimile AAR Standard Control Stand with associated controls and displays. The engineer's side window was opaque. The transparent front window (27 inches high by 16 inches wide) was approximately three feet from the seated subject's eyes and framed a rear-projection screen one foot outside the window. Behind the screen, a well illuminated 30 foot tunnel contained several parallel, continuous belts. A belt on each side contained model shrubbery; on two central belts were painted pairs of tracks. An optical system at the screen end of the tunnel projected an image of the tunnel onto the screen.

When viewed from the cab seat, the system created a realistic illusion of looking down a pair of straight, foliage-bordered railroad tracks. From a darkened cab, the illumination of the scene was similar to real-life conditions at dusk. When the belts containing shrubbery were set in motion toward the screen, a realistic illusion of moving down the tracks was created. During all experiments, the belts were run to simulate travel at 50 mph. The illusion was augmented by playing an audio tape of locomotive noise at a sound level of 73 dbA.

In all of the experiments, each subject sat in the engineer's seat of the mockup for several hours of simulated train operation. The subject's primary task was to monitor the scene through the front window, detect an occasional colored light signal, and respond appropriately to the signal by pressing a button with his right hand. The experimental questions were studied by manipulating the schedule of signal presentations and the rewards for correct responses, and sometimes by adding a secondary task. The secondary task involved responding to secondary signals in the cab with a button held in the left hand.

4.2.2 Signals

One set of primary signals, selected in the basis of considerable preliminary experimentation, was used in all experiments. They consisted of three different combinations of three colored lights in a vertical array. The colors, from top to bottom, were yellow, red, and yellow. Each light was one-quarter inch in diameter, and the separation between each pair of lights was one-quarter inch. The three signal combinations consisted of the following pairs (top to bottom): yellow-yellow, yellow-red, and red-yellow. The yellow-yellow and yellow-red were always designated non-critical signals; the red-yellow was always called the critical signal. The signals were optically combined with the external scene, appearing as dim lights to the left of the tracks and at a fixed distance into the scene. At the subject's eye, each signal light and the space between two lights subtended an angle of fourteen minutes of arc.

In one experiment, warning signals were used. These were two neon lights, one inch in diameter. One was mounted on top of the control stand to the subject's left; the other was mounted to the left of the window on the front wall of the cab, above the speedometer. Ten seconds after illumination of the warning lights, a buzzer sounded until appropriate responses cut off both lights and buzzer. An alternative warning was provided vocally by an experimenter in one experimental session.

4.2.3 Response Buttons

A four-by-six inch response box was attached near the end of the right arm of the engineer's seat. Near the top of the box were two pushbuttons, three-quarters of an inch in diameter and horizontally separated by one and one-half inches. The right button was always used for responses to critical signals, the left button for non-critical signals. Centered below these response buttons was a small, rectangular pressure sensitive monitoring button which required no force to activate it. The subject was required to keep his right index finger on the monitoring button at all times when he was not operating one of the control buttons.

In one experiment, the subject held a push button in his left hand, activation of which cut off the warning lights and buzzer.

Figure 1 shows a subject in the engineer's seat, wired for recording, monitoring the window for primary signals, with the right index finger on the monitor button, the left hand holding the secondary response button. One of the warning lights can be seen.

4.2.4 Tasks

The primary task in each experiment was to monitor the scene through the front window while holding the right index finger on the monitor button. Whenever a two-light signal appeared, the subject was to respond by lifting his finger from the monitor button, pressing the appropriate response button (right for critical signals, left for non-critical signals), and returning his finger to the monitor button.

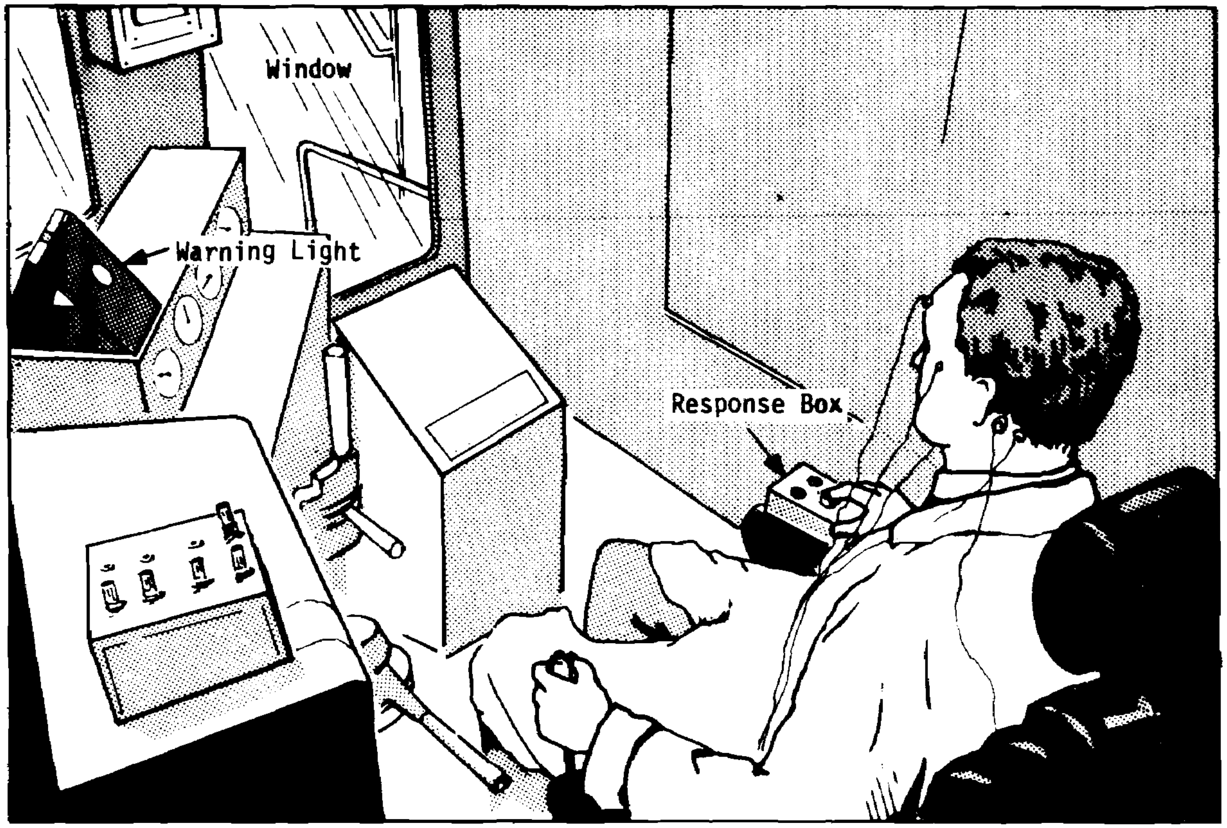

FIGURE 1. SUBJECT SEATED WITH RIGHT INDEX FINGER IN MONITORING POSITION AND LEFT HAND HOLDING THE SECONDARY RESPONSE BUTTON

In conditions b and c of Experiment 3, a secondary (alerting) task was added to the primary task. In addition to detecting and responding to the primary signals, the subject was required to respond to a secondary (warning) signal by pressing the secondary response button in his left hand as soon as he detected the warning. If the subject failed to respond within ten seconds, a penalty buzzer was also activated.

4.2.5 Apparatus

Signal selection and presentation were programmed on a Grayson Stadler Series 1200 Behavioral Programming System. In Experiments 1 and 2, an experimenter commanded each signal manually, following a printed script; in Experiment 3, commands for primary signals and warning lights were executed automatically from pre-programmed paper tapes.

Physiological and behavioral responses were sensed as follows:

Two gold cup electrodes were attached to the scalp, one to the occipital lobe and one to the vertex, for EEG (brain wave) measurement. Monopolar recordings were made between each of these electrode sites and two gold cup mastoid reference electrodes tied together.

Two miniature Beckman biopotential electrodes were used for eye blink recording, one placed above and one below the left eye. Two additional Beckman biopotential electrodes were placed beside the outer junction of the eyelids of each eye to record horizontal eye movement.

Two gold cup electrodes were placed over the lower right neck muscle for EMG (muscle potential) recording.

Heart rate was recorded between two gold cup electrodes, one placed on the sternum (breastbone), and one on the lower left of the chest.

A strain-gage transducer, attached to the subject's chair, sensed bodily activity.

The time of each switch action, including both activation and release, was recorded.

All sensed signals were fed directly into a paper drive Type R Beckman Dynograph for immediate graphic representation of data. All of these data were simultaneously recorded on a Sangamo 3500 FM Tape Recorder from the output of the amplifier of the dynograph (i.e., parallel to the input of the dynograph pens). The tape recorder recorded frequencies from D.C. to 2.5 KHz. The taped data were analyzed on an off-line Digital Equipment Corporation PDP-9 computer.

4.3 DESCRIPTION OF EXPERIMENTAL CONDITIONS

Two preliminary experiments were run to select the procedures, apparatus, schedules, data analyses, and other details most suitable for testing the questions of Section 4.1. Then the three major experiments were performed, using a different group of subjects for each experiment.

4.3.1 General Description

In all experiments, each subject experienced one or more long, dull sessions in which he appeared to move at a constant speed along straight tracks, occasionally pressing a key in response to a primary signal dimly seen beside the tracks.

To test the questions of Section 4.1.1, relating to principles of alertness, the experimental procedure was varied in some way, and the resulting changes in the number and type of errors made by the subject, were analyzed as evidence of the effects of the change in procedure. The procedural changes included changes in the sequence of primary signals and the introduction of different secondary alerting tasks.

To test the questions of Section 4.1.2, relating to physiological and behavioral indices of changes in alertness, the behavior in question was measured throughout an experiment and the results analyzed to determine if the indices varied consistently as a function of time on the task.

These approaches were combined into the three major experiments. Experiment 1 tested the questions on physiological and behavioral indices and generated error data that could be compared with the results of subsequent experiments. Experiment 2 presented a sequence of signals contrived to lead the subjects into making more errors than were made in Experiment 1 if the hypothesis of false expectation was correct. In Experiment 2, physiological and behavioral measures were repeated to see if the results of Experiment 1 would be confirmed.

In Experiment 3, secondary alerting tasks and rewards were studied. Each subject was run five times -- first on a repetition of Experiment 2, but with a monetary reward for correct responses, then with four different alerting conditions. Except for response latency, physiological and behavioral measures were not made in Experiment 3.

The following paragraphs describe the details of each experiment.

4.3.2 Experiment 1

The primary purpose of Experiment 1 was to obtain measurements of response accuracy, response latency, physiological responses and general activity as a function of time on a long, dull task. The effect of signal frequency on response accuracy was also sought. Eight paid male volunteers were subjects. Four were experienced locomotive engineers and four were men of roughly the same age but with no railroad experience. Ages ranged from 43 to 56 years, with a mean of 50.8 years. Each subject performed the primary task of monitoring the scene and pressing the appropriate response button for critical and non-critical signals for an uninterrupted period of 3 hours. The schedule of signals included 2 critical and 6 non-critical signals every half hour, presented in random order, for a total of 48 responses per subject. The interval between signals varied randomly from one-half minute to 12 minutes, with a mean of 3.75 minutes. Physiological reactions and general activity were recorded together with the time of activation and release of each response button.

4.3.3 Experiment 2

The purposes of Experiment 2 were to obtain additional data on the variables of Experiment 1 and to determine the effects on response accuracy of false expectations about the signals. The subjects were ten paid male volunteers, ranging in age from 31 to 50 years, with a mean of 42.8 years. Each of these subjects made 52 responses in 3.25 hours on the primary task. However, the schedule of signals used in Experiment 1 was changed to increase the probability of false expectations. Signals always occurred in pairs, the second always one minute after the first, occurring 4 times (8 signals) every half hour. In general, the paired signals were non-critical, always in the sequence yellow-yellow and yellow-red. A critical signal (red-yellow) was randomly substituted for one or the other non-critical signal twice every half hour. The hypothesis was that the recurring pattern of non-critical signals would induce an expectancy for the non-critical signals, resulting in more errors in response to the rarer critical signals. The interval between signal pairs was variable, averaging 6.5 minutes. Again physiological responses and general activity were recorded.

4.3.4 Experiment 3

In Experiment 3, the value of rewarding correct responses was studied, and several secondary alerting techniques were compared for their effectiveness in averting loss of alertness. The subjects were eight male volunteers, ranging in age from 30 to 56 years, with a mean age of 43.3 years. They were paid the same basic hourly fee as the subjects of the other experiments. However, to manipulate motivation, they were given an additional bonus, to which money was added for each correct response, and from which money could be deleted for failure to respond in two sessions.

In this experiment, each subject was tested in five sessions of 2.75 hours each on five separate days. The schedule of signals each day was on the same pattern as in Experiment 2 (pairs of non-critical signals a minute apart, 4 pairs per half hour at random intervals, with 2 critical signals randomly substituted each half hour), with a different sequence and different intervals each day.

Physiological responses and general activity were not recorded. Each day's session constituted a separate condition, as follows:

3a. Control. On the first day, every subject was tested on Condition 3a, which was a repetition of Experiment 2 except for the shorter duration and the reward for correct responses.

3b. Random Warning. This condition added an unrelated secondary task to the primary task in the form of two warning lights that were illuminated at random time intervals averaging one every 50 seconds. The subject was required to extinguish the lights as soon as they were detected by activating the secondary response button in his left hand, while continuing to monitor and respond to the primary signals. (A penalty buzzer and a monetary fine resulted if the warning was not acknowledged within 10 seconds; however, no subjects incurred these penalties).

3c. Regular Warning. This condition was identical to Condition 3b except that the warning signals were illuminated at regular intervals of 50 seconds.

3d. Light Warning. This condition involved job-related warning lights requiring no response. The warning lights (placed as in Conditions 3b and 3c) were illuminated regularly 10 seconds before the onset of every primary signal. The subject made no response to the warning; he simply prepared to respond to the primary signal.

3e. Voice Warning (Second Person). In this condition an experimenter occupied the left-hand side of the cab mockup. The warning lights (operating as in Condition 3d) were relocated so that only the experimenter could see them. When the lights illuminated ten seconds before each signal, the experimenter called to the subject: "Signal!" In one sense, this procedure simply amounted to substituting a vocal warning for a visual warning. However, the psychological effect of having a second person in the cab was added. To enhance this effect, the experimenter engaged the subject in conversation throughout the session, covering such topics as sports, politics, and the weather. The subject was reminded to watch the external scene at all times.

4.3.5 Summary of Experimental Conditions

The principal features of the three experiments are summarized in Table 1. Note that in Experiment 3, the control condition was administered first to all subjects, but the sequence of the other conditions was counterbalanced.

4.4 PROCEDURE

The general procedure was the same for all experiments. Each subject was tested individually. Prior to an experimental session, he filled out a consent form and questionnaires covering name, address, birthdate, social security number (for purposes of payment), previous medical history, and present physical condition. If the subject had any railroad experience or knowledge, this was noted. He was then told that he would be participating in an experiment having to do with the behavior of railroad engineers. An overview of the experiment was given, including a brief explanation of the nature of railroad operations, and of physiological recording. Electrodes were then attached if physiological recordings were to be made.

Following this preparation, the subject was tested for visual acuity and color perception. He was then seated in the engineer's seat and instructed to keep his right index finger on the monitor key at all times, except when responding to signals by depressing one of the response buttons. He was told that: (a) his task was that of a railroad engineer, (b) he must pay attention at all times to signals that would appear on the screen in front of him, and (c) he was responsible for the general safety of the train, which depended on making quick, accurate responses to the signals. He was informed that railroad engine noise would accompany the apparent movement of the train. The right response key was to be used when a critical, (red-yellow) signal appeared; the left response key was to be pressed in response to a non-critical (yellow-yellow or yellow-red) signal. He was told to press as quickly as possible, and then return his finger to the monitoring position. The signal schedule was then explained.

TABLE 1. SUMMARY OF EXPERIMENTS

Experiment 1	Physiological and Behavioral Indices
Experiment 2	False Expectations and Physiological and Behavioral Indices
Experiment 3	Motivation and Alerting Tasks

Experiment 3 Conditions

3a Control

Secondary Task

3b Random Warning
3c Regular Warning

Job-Related Warning

3d Light Warning
3e Voice Warning (Second Person)

Sequence of Conditions

Subj.	Sequence
1	a d c b e
2	a d b c e
3	a c d e b
4	a b d e c
5	a b e d c
6	a e c b d
7	a c e d b
8	a e b c d

		Experiments		
		1	2	3
Number of Subjects		8	10	8
Number of Sessions		1	1	5
Signals per Session:	Total	48	52	44
	Non-Critical	36	39	33
	Critical	12	13	11
Hours of Experimentation per Session		3.00	3.25	2.75

If a subject was wearing a watch, it was removed. The experimenter then left the room, and allowed the subject to dark adapt and become familiarized with the projected moving image for approximately 10 minutes. The railroad engine noise was then turned on. The subject was given ten to fifteen minutes of practice in responding to signals, following which the test session began.

4.5 RESULTS

Because the questions raised in Section 4.1 involve comparisons of experimental results in a variety of combinations, Table 2 is presented as a guide to the principal results that bear on each question. Table 3 summarizes the combined responses of all subjects to all signals in all three experiments. We will first examine the correct responses in more detail and then note any additional information yielded by the types of errors made.

4.5.1 Performance Accuracy

a. Performance Decrement

The primary concern with alertness is the decline of effective job performance as time continues on a dull task. All experimental sessions were divided into 30-minute periods for analysis for such a decrement. (In experiments 2 and 3, data were averaged for a 15-minute initial period, indicated as "period 0" in the figures). As an index of performance effectiveness, the total number of correct responses to primary signals was determined for each period, expressed as a percentage of the total number of signals.

In Figure 2, the percentage of correct responses across time periods is plotted for each experiment. Since the first (control) session of Experiment 3 constituted a special test of motivation, both Condition 3a and the combined performance on the other four conditions are shown.

TABLE 2. RELATIONSHIP OF RESULTS TO EXPERIMENTAL QUESTIONS

Question	Measures	Results to be Compared
False Expectations	Errors	Experiment 1 with Experiment 2
Job-Related Task	Errors	Experiment 3b and 3c combined, with Experiment 3d and 3e combined
Warning Schedule	Errors	Experiment 3b with Experiment 3c
Second Person	Errors	Experiment 3d with Experiment 3e
Motivation	Errors	Experiment 2 with Experiment 3a
Physiological Responses	EEG EMG Heart Rate	Time trend of measures, Experiments 1 and 2
Behavioral Responses	Eyeblinks Eye Movements Bodily Activity Response Latency	Time trend of measures, Experiments 1 and 2 Time trend of measures, Experiments 1, 2 and 3

TABLE 3. SUMMARY OF PERFORMANCE IN ALL EXPERIMENTS

	Experiments				Not Rel		Related	
				Con	Ran	Reg	Lit	Vce
Critical Signals	1	2	3	3a	3b	3c	3d	3e
Missed Responses	8	33	8	4	1	1	1	1
Wrong Responses	12	22	22	6	7	1	3	5
Right Responses	76	75	410	78	80	86	84	82
Total	96	130	440	88	88	88	88	88
Non-Critical Signals								
Missed Responses	27	130	50	13	16	19	0	2
Wrong Responses	16	7	13	5	2	3	0	3
Right Responses	245	253	1257	246	246	242	264	259
Total	288	390	1320	264	264	264	264	264

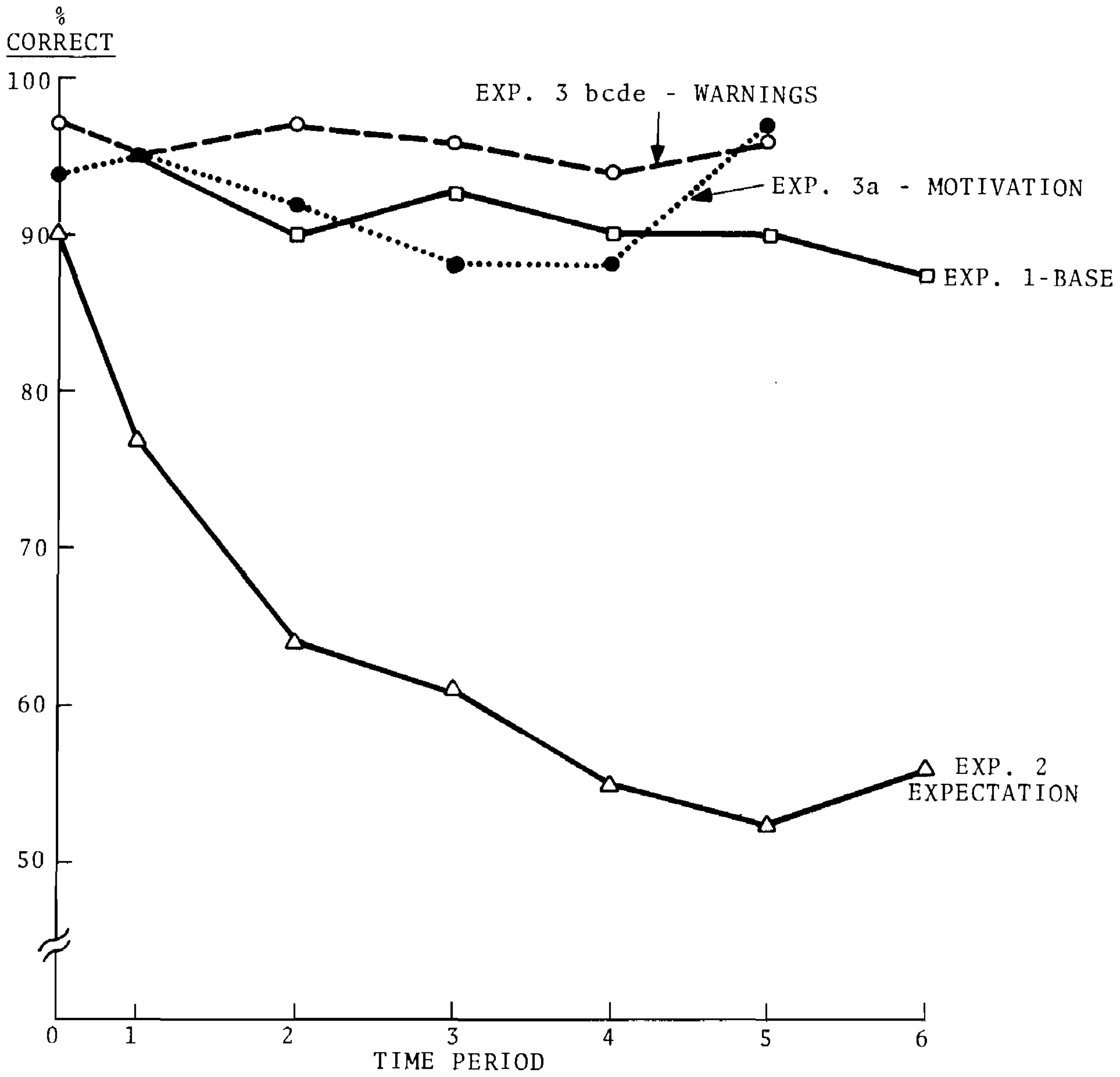

FIGURE 2. PERFORMANCE ACCURACY, ALL EXPERIMENTS

A slight tendency for poorer performance as time on the task increased can be seen for Experiment 1, although it lacks statistical significance[1] because of considerable variability in performance among the subjects. On the other hand, a clearly significant performance decrement occurred in Experiment 2, as was predicted by the hypothesis of false expectations.

In Experiment 3, rewards were introduced to improve motivation, and various warnings were tested as aids to alertness. Condition 3a, with no warnings, differed from Experiment 2 only in rewarding correct responses. The curve for Condition 3a resembles that for Experiment 2 in shape--a decline in performance, tending to level off, with an end-spurt of improvement, although at a much higher level of performance. The shape of the curve suggests that there was an alertness problem in Condition 3a, but the high level of performance indicates that the subjects of Experiment 3 were much better motivated than those of Experiment 2.

The curve for the combined (abcd) warning conditions of Experiment 3 fails to show any consistent decrement in performance with time, with the group averaging about 95 percent accuracy throughout. This result demonstrates the general effectiveness of alerting signals over no signals. Figure 3 breaks down the data to show the effects of the individual conditions. Figure 3a shows consistently accurate performance in both the light warning and the voice warning (second person) conditions. Performance levels off at a slightly lower level for the second person condition, suggesting that the second person might have distracted the subject's attention; however, the difference is not statistically significant.

There was no significant difference between conditions 3b and 3c as shown in Figure 3b, indicating that random and regular schedules of secondary alerting signals were equally effective in this experiment.

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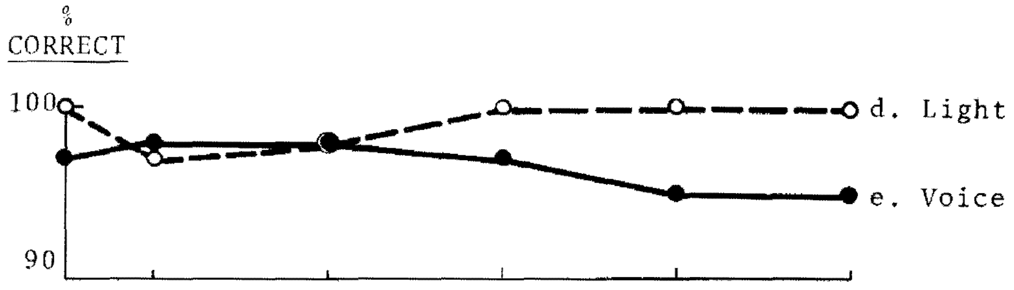
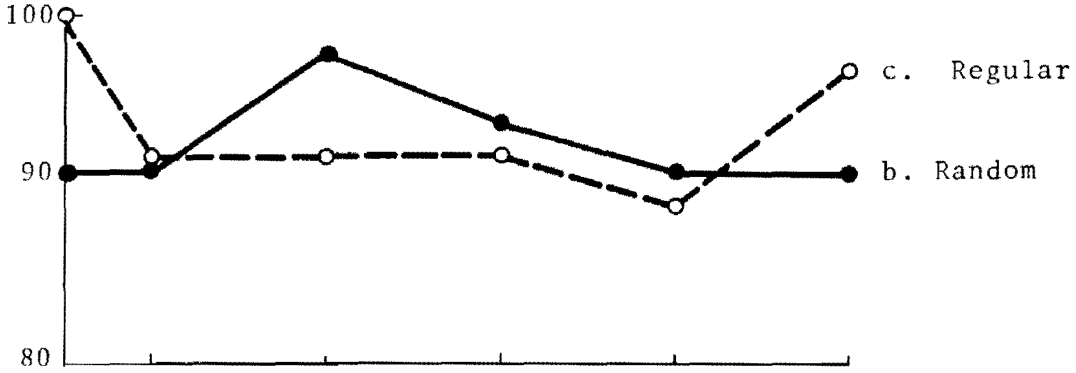
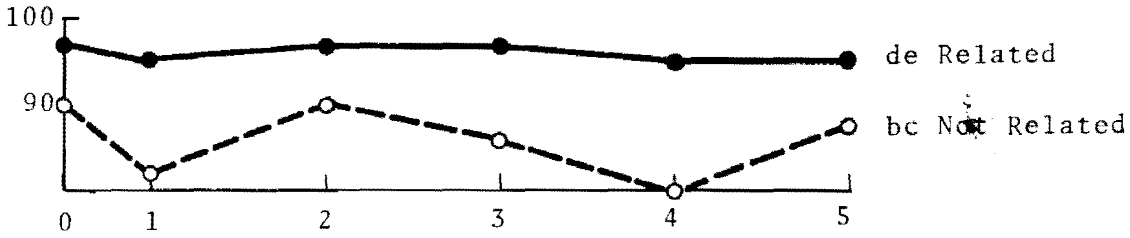
[1] Statistical significance indicates the likelihood that the obtained results were not due to chance alone. In this report, "significant" results are those that would occur by chance no more than five times out of a hundred.



a. Light and Voice (Second Person) Warnings



b. Random and Regular Presentation of Secondary Warnings



c. Warnings Related and Not Related to Signal

FIGURE 3. PERFORMANCE ACCURACY, CONDITIONS OF EXPERIMENT 3.

Conditions 3d and 3e both involved a warning given just before the appearance of each signal, with no response required of the subject. Conditions 3b and 3c both involved a secondary alerting signal, unrelated to the primary signal and requiring a secondary response. In Figure 3c the combined results of conditions 3d and 3e (warning related to signal) are compared with the combined results of conditions 3b and 3c (warning unrelated to signal), showing that signal-related warnings were significantly more effective than unrelated warnings in maintaining accurate responses (giving 5 percent greater accuracy).

b. Errors

Two kinds of errors were made: a signal was missed altogether, or the wrong key was pressed in response to a signal. Table 3 presents both types of error for all subjects in each experiment. The errors are further broken down by type of signal--critical or noncritical. Figure 4 graphically represents these errors as percents of total responses.

In Experiment 1, non-critical signals appeared three times as often as the critical. In Figure 4, it is apparent that proportionately more wrong responses were made to the non-critical signals than to the critical signals, with about the same rate of misses for all signals. On the assumption that the greater frequency of non-critical signals led to a false expectation for non-critical signals when the critical signals occured, thus inducing more wrong responses, the schedule of signals was purposely arranged to increase this expectancy in Experiment 2. The results justified the assumption; even a higher proportion of wrong responses to non-critical signals resulted. This second signal schedule was also used in Experiment 3, yielding similar proportions of wrong responses.

Experiment 2 produced a very high percentage of missed signals. This was attributed to poor motivation. The subjects were so bored that their attention wandered (perhaps they occasionally dozed), and they failed to see many signals. In Experiment 3, the subjects were offered extra pay for every correct response.

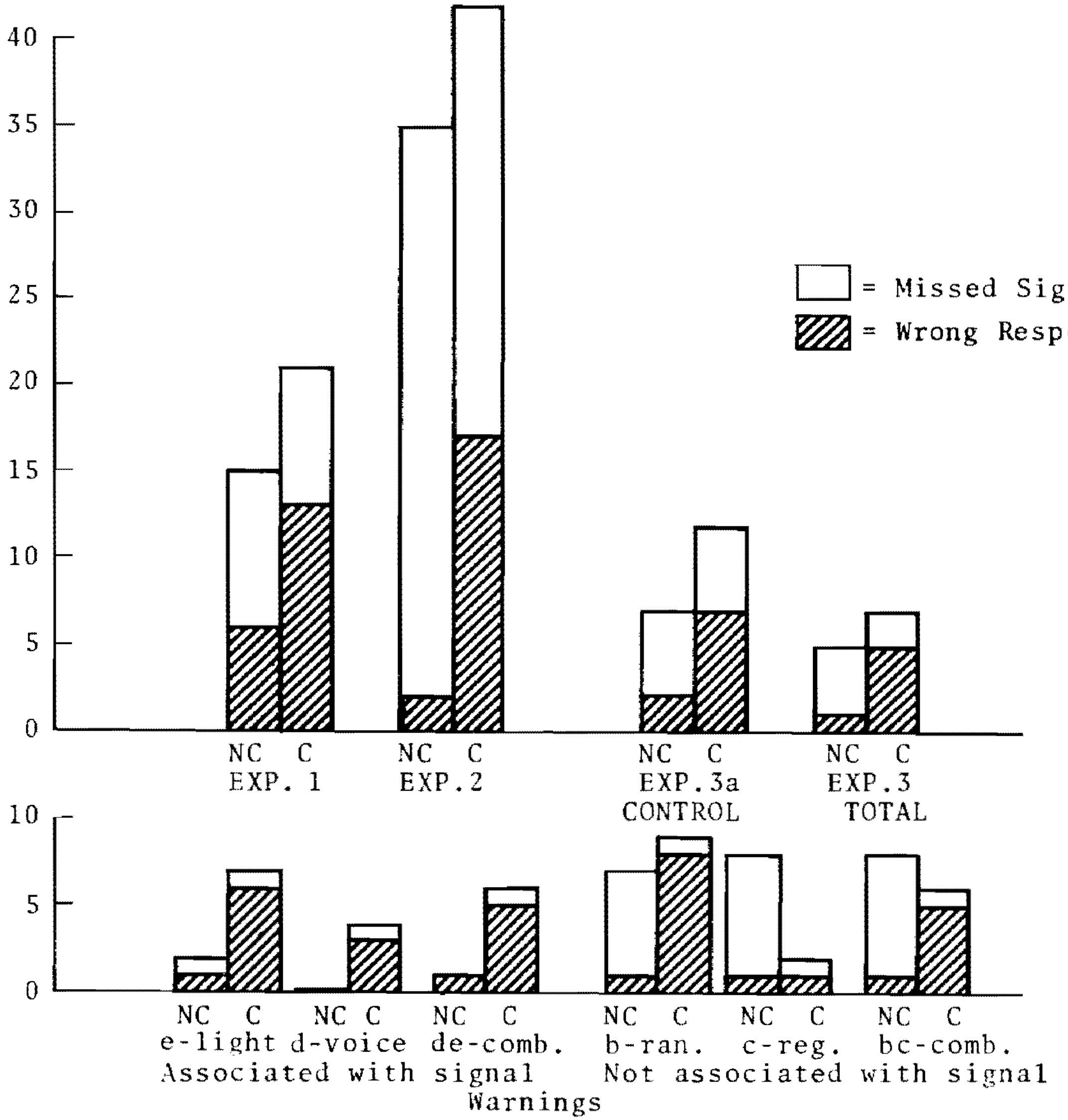


FIGURE 4. ERROR RATES

The control condition (3a) was identical to Experiment 2 except for this motivation factor, whose effectiveness is well demonstrated by the dramatic drop in both missed and wrong responses in Experiment 3.

We have already noted that performance was more accurate with signal-related than with non-related warnings. The lower portion of Figure 4 shows that the difference was primarily in missed signals. False expectations continued to generate some wrong responses to critical signals under all conditions, but when each warning was associated with an upcoming signal, missed signals were virtually eliminated. When a second person provided the warning, there were a few more wrong responses than when a warning light was used. Possibly the conversations distracted the subject occasionally; however, the number of errors was too small to have statistical significance.

c. Conclusions Based on Performance Accuracy

In summary, without some kind of alerting signal, performance accuracy tended to decline with time. When alerting signals were used, this decline did not occur. Alerting signals related to the primary signal were more effective than those unrelated to the primary signal in maintaining accurate performance, virtually eliminating missed signals. When a secondary alerting task was used, it made no difference whether the alerting signals were presented in a random or regular time sequence. A situation causing a false expectation for certain signals induced an increase in wrong responses to them. Monetary rewards for correct responses and threat of penalty for wrong responses (motivation) resulted in an improved level of performance accuracy.

4.5.2, Indices of Loss of Alertness

a. Physiological and Activity Measures

The tape-recorded data were reduced by computer. All of the brain wave (EEG), muscle potential (EMG) and bodily activity data were reduced by the Fast Fourier Transform (FFT) technique. FFT's were averaged for the first 8 seconds of each minute. EEG measures were recorded for each frequency in the band 1-44 Hz. They were then averaged for 4-7 Hz (theta), 8-12 Hz (alpha), and 14-20 Hz (beta); 40 Hz activity was summed over the frequency band 35-44 Hz. Power spectra were also produced for EMG data and bodily activity. The number of eye blinks within the first 8 seconds of each minute were recorded, and heart rate was averaged for the same time periods.

None of these measures showed any consistent relationship with performance. A few tendencies of theoretical interest were noted; principally that the ratio of alpha-to-theta activity and the 40 Hz activity were higher for good performers than for poor. However, there were no results that would warrant a recommendation for use of any of these measures to operate cab alerting devices.

b. Response Latency

On the basis of preliminary experimentation, the measured time between signal onset and the subject's release of the monitor key was selected as the measure of response latency. This measure showed how much time it took the subject to notice the signal and to start his response.

Response latencies varied so much in Experiment 1 that no trend with time on the task was apparent for the group as a whole. However, the subjects of Experiment 1 could be divided into two distinctly different groups of four based on response accuracy. The "good" performers averaged 95 percent accuracy; the "poor" performers averaged 78 percent.[2] The poor performers varied greatly in latency throughout the experiment, and no significant trend could be established. The good performers started responding much faster than the poor, with a significant slowing trend with time; so at the end of three hours, the good and poor performers had essentially the same latency. In Experiment 2, there

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[2] The locomotive engineers in the subject group split evenly on performance--two in the good group, two in the poor. Since they performed like the other subjects on all measures, locomotive engineers were not sought out as subjects for the subsequent experiments.

was a significant tendency for responses to become slower with time for the total subject group, but this relationship was not apparent in results of Experiment 3. There was a slight tendency (not significant) for the subjects of Experiment 3 to react faster when the alerting task was job-related than when it was unrelated; within job-related responses, there was a significant tendency to react slower to critical (unexpected) signals than to the non-critical signals.

Although both errors and latencies showed some tendency to increase with time, the variability with time could have masked out a stronger error-latency relationship. A comparison of mean group errors with mean group latencies regardless of time period did show a tendency for errors to be associated with slower responses. However, the variability between the subjects contributing to the mean latencies was so much greater than the variability between the means that no significance could be attached to the trend. Because of this variability in latencies even in the laboratory, the uncertainty as to whether an increase in latency represents an undesirable loss of attention or a desirable thinking-through of alternatives before acting, and the difficulties inherent with "wiring up" engineers in operating locomotives, the concept of measuring an engineer's response latency to operate an alerting device in the locomotive cab is not considered operationally feasible at this time.

4.6 CONCLUSIONS FROM EXPERIMENTS

With regard to the questions raised in Section 4.1, the results of the three experiments led to the following conclusions:

If an engineer expects a particular signal, he is more likely to make an erroneous response to a different and unexpected signal.

An engineer is likely to make fewer errors in the primary job when alerted by a signal related to the primary job than when alerted by a signal unrelated to the primary job.

Secondary warning signals presented at either regular or random intervals are likely to be equally effective.

A second person in the cab calling signals is as effective as a warning light in preventing missed signals. However, care must be taken that the companionship of a second person does not distract the engineer's attention in responding to signals.

Rewarding good performance reduces the likelihood of loss of alertness on the job.

The use of measures of response latency, brain or muscle electrical activity, or bodily activity to sense warning alertness and operate warning devices is not considered operationally feasible at this time.

5. CRITERIA FOR ALERTING DEVICES

5.1 SUMMARY OF FINDINGS

The literature on alertness and the confirming results of the experiments establish the fact that alertness regularly declines during periods of relative inactivity on tasks of several hours' duration. When signals in the environment must be detected and responded to during these periods, there is a risk that some signals may be missed or misinterpreted. A false expectation about a signal increases the chances that the signal will be misinterpreted. In railroad situations, the results of missing or misinterpreting signals are potentially disastrous. The use of alerting signals and alerting tasks, properly designed, can significantly reduce these risks. These findings have been combined into a set of criteria for the design of effective alerting systems, and the alerting devices currently in use on U.S. railroads have been evaluated in terms of these criteria.

5.2 CRITERIA DERIVED FROM FINDINGS

The following criteria are proposed as guidelines for evaluating systems for maintaining a locomotive engineer's alertness. The term "system" is used because no single device can incorporate all of the recommended features.

5.2.1 Secondary Task

An ideal alerting system will provide one or more secondary tasks to occupy the engineer during periods of low job demand. This criterion applies the principles of secondary task, complexity, and other senses.

5.2.2 Spaced Activity

An ideal alerting system will require activity of the engineer at fairly regularly spaced intervals. This criterion applies the principles of frequency and intersignal range. The results of Experiment 3 (random versus regular spacing of signals) suggest that <u>precise</u> spacing of secondary tasks is not essential.

5.2.3 Rest Breaks

<u>An ideal alerting system will provide periodic rest breaks for the engineer</u>. This criterion applies the principle of breaks.

5.2.4 Rewards

<u>An ideal alerting system will provide positive rewards for appropriate performance</u>. This criterion applies the principle of motivation, strengthened by the results of Experiment 3.

5.2.5 Feedback

<u>An ideal alerting system will give the engineer feedback on how well the job is being done</u>. This criterion applies the principle of feedback. It will help avoid the generation of false expectations.

5.2.6 Conspicuous Signals

<u>An ideal alerting system will provide primary and secondary signals that are conspicuous</u>. This criterion applies the principles of combined senses, visual area, position, magnitude, novelty and change.

5.2.7 Expected Signals and Tasks

<u>An ideal alerting system will provide advance warning of impending signals or tasks</u>. This criterion applies the principle of expectancy, strengthened by the results of Experiment 3 (warnings associated with signals). It will help avoid the generation of false expectations.

5.2.8 Job-Related Signals and Tasks

<u>An ideal alerting system will provide secondary signals and tasks that are related to the primary job and that focus attention on the requirements of the primary job</u>. This criterion applies the

principles of need fulfillment and interest. Its value was confirmed by the results of Experiment 3.

5.2.9 Non-Interfering Signals and Tasks

An ideal alerting system will provide secondary signals and tasks that never interfere with primary signals and tasks. This criterion applies the principles of frequency and other senses.

5.3 QUALITATIVE RATINGS OF CURRENT ALERTING DEVICES

The foregoing criteria for an ideal alerting system were used to evaluate the devices currently in use on U.S. railroads. The results of this evaluation are summarized in Table 4. A plus (+) entry shows that the device named at the head of the column meets the criterion listed at the left. A minus (-) entry indicates that the device violates a principle on which the criterion was established. No entry means that the device is essentially unrelated to the criterion.

The numerous positive entries in Table 4 show that the railroad industry has generally adopted devices and practices for maintaining cab alertness that are based on well-established principles for maintaining alertness and attention. However, the negative entries show that many devices also have features that violate some of the proposed criteria; together with the blank spaces, they suggest that even more effective devices and techniques may be possible through further research and development.

5.3.1 Pneumatic Foot Valve ("Dead Man" Pedal)

In terms of the number of negative ratings in Table 4, the dead man device appears to be the least desirable alertness aid now in use. Although pressing the pedal is required as a secondary task, the constant pressure actually comes to constitute "no activity". The device does not stimulate the engineer to stay alert; it limits his mobility, promoting muscle fatigue; it is unrewarding, uninformative, competetive with the primary job, and is easily tampered with.

TABLE 4. CURRENT ALERTING SYSTEMS COMPARED ON CRITERIA FOR IDEAL SYSTEM

DEVICES OR SYSTEMS	CRITERIA Secondary Task	Spaced Activity	Rest Breaks	Rewards	Feedback	Conspicuous Signals	Expected Signals & Tasks	Job-Related Signals & Tasks	Non-Interfering Signals & Tasks
Dead Man	±	-		-	-	+	-	-	-
Cycling Dead Man	+	+		-	-	+	-	-	-
Periodic Acknowledgment	+	+		-	-	+	-	-	-
Electronic Alertness Control		+			±	+	-	±	±
*Modification	+	+		-	+	+	-	+	+
Cab Signals						+		+	+
Automatic Train Stop					+	+		+	+
Automatic Train Control					+	+		+	+
Intermittent Inductive System					+	-	+	+	+
Signal Matching	+			+	+	+		+	±

No entry = Device unrelated to criterion
+ = Device meets criterion
- = Device violates criterion
*Modification = Device modified to accept control actions as acknowledgments

5.3.2 Cycling Pneumatic Foot Valve and Periodic Acknowledgment Devices

These two devices do provide a regularly spaced secondary activity and conspicuous warnings. However, since they can penalize an engineer who is properly performing his primary job, they are negatively rewarding. They provide no job-related information, and in continuing to require responses when the engineer is busy, they can interfere with the primary job.

5.3.3 Electronic Alertness Control

This device provides spaced activity by requiring acknowledgment when it senses a period of inactivity. However, since job activity is inferred from bodily activity, it can not determine whether sensed activity is job-related or not; it can penalize an alert engineer (false alarm), and it can interfere with primary tasks.

5.3.4 Modification

Some of the objections to the cycling "dead man", the periodic acknowledgment and the electronic alertness devices can be overcome by connecting them to accept certain control actions (operation of brakes, throttle, sander, or bell) as acknowledgments adequate to forestall alarms and penalties. The modification is feasible with current models of all of these devices. So modified, any of those devices is more job related, provides the engineer with feedback in that no alarm means the primary job is being done, and is unlikely to interrupt a busy engineer. Any one of these modified devices probably represents the best alerting method commercially available today.

5.3.5 Cab Signals, Automatic Train Stop, and Automatic Train Speed Control

Cab signals, and the train stop or train control systems operated with them, are designed to attract attention when a response is required rather than to maintain alertness. However, they are strong on the job-relevant criteria and provide a base from which improved alertness systems may be derived.

5.3.6 Intermittent Inductive Systems

These systems are of interest because they may include a trackside sign (board) in advance of the sensor. Although the passive board is not as conspicuous as the lights and alarms of other systems, it provided the only positive rating on expected tasks in Table 4.

5.3.7 Signal Matching

In Section 2.3.3, we noted that two sources had proposed development of a device requiring the engineer to key an entry matching each cab signal, thus assuring that the signal was correctly perceived. Rated on the nine criteria for an ideal system (Table 4), this concept appears promising. It is a job-related secondary task that provides immediate feedback on an important aspect of the job. Correct responses will be rewarding, and false expectations will be detected. There is the possibility, however, that the task could interfere occasionally with required control actions.

5.4 THOUGHTS ON AN IDEAL SYSTEM

If we consider an ideal alerting system as one that would receive positive ratings on all nine criteria, then Table 4 shows that all of the rated techniques fall short of the ideal. However, among them there is at least one positive rating in every column except "Rest Breaks", which we have already noted requires no device but an established operational policy. Using this raw material, we could synthesize an improved system--one well within the state of the art, although requiring research and development to achieve cost effectiveness.

A signal matching system coupled with cab signals provides a starting point. To fill in the periods when there are no operational signals, an additional (alerting) signal could be added periodically, to be matched like the operational signals, assuring spaced activity. Maintaining a record of signals and responses could enhance motivation, particularly if special rewards were offered for high scores. To avoid task interference when a signal requires an immediate control response, the appropriate control action could be accepted as a signal match--Automatic Train Speed Control currently provides the sensing and information processing needed for such a feature.

Providing an automatic preliminary cab signal before fixed signal points would be feasible but very costly. Likewise, even a simple trigger installed close to the track in advance of a signal would probably be prohibitively expensive to emplace in quantity in vandal-proof installations. However, track-side "Signal Ahead" signs would be relatively inexpensive and could be used effectively, particularly on long blocks, blind approaches, and in areas where landmarks are scarce or frequently obscured by weather.

Development based on such an approach is to be encouraged. It is hoped that readers will be stimulated to think of additional (and better) ways in which the nine criteria can be met reliably and economically as a positive approach to greater safety in railroad operations.

6. RECOMMENDATIONS

The following recommendations are offered for those seeking to improve alerting techniques currently in use or to advance the state of the art in maintaining alertness in the locomotive cab:

1. Replace the pneumatic foot valve with some device that requires acknowledgment from the engineer during periods of inactivity and that accepts operation of train controls as acknowledgments.
2. Support development of a system that requires the engineer to make an entry that matches each traffic control signal.
3. Support development of techniques for giving an engineer advance warning when approaching a signal.
4. Support research and development on ways to inform the engineer of the accuracy of responses and to reward good job performance.
5. Utilize the criteria of Section 5.2 in evaluating new ideas for improving engineer alertness.
6. Monitor developments in the recording and analysis of human physiological behavior to determine when the state of the art has advanced enough to warrant further evaluation for alertness applications.

REFERENCES

Beatty, J., Greenberg, A., Deibler, W.P. and O'Hanlon, J., "Operant Control of Occipital Theta Rhythm Effects on Performance in a Radar Monitoring Task," Science, 183 (4127), p.871-873, 1974.

Branton, P., "Train Drivers' Attentional States and the Design of Driving Cabins," COMPTE RENDU, TREIZIEME CONGRES INTERNATIONAL, Union Internationale des Services Medicaux des Chemins de Fer, Bruxelles Belgium, 1970.

Davis, D.R., "Railway Signals Passed at Danger: the Drivers, Circumstances and Psychological Processes," Ergonomics, 9, p.211-222, 1966.

DeButts, T.C., "What the Merger Taught BN about its Employees." Railway Age, July 14, 1975, p.36-41.

FRA. "Summary and Analysis of Accidents on Railroads in the United States," Accident Bulletin No. 143. U.S. DOT, Federal Railroad Administration, Washington DC, 1974.

Grant, J.S., "Concepts of Fatigue and Vigilance in Relation to Railway Operation," Ergonomics, 14, p.111-118, 1971.

Hale, A., and Jacobs, H.H., "Proposed Qualification Requirements for Selected Railroad Jobs," U.S. DOT, Federal Railroad Administration, Washington DC, Rep. No. FRA-OR&D-75-44, May 1975.

Michaut, G.M.E., and McGaughey, T.P., "Work Conditions and Equipment Design in Diesel Locomotives: Feasibility Study and Recommendations," Canadian Institute of Guided Ground Transport, Queen's University, Kingston ON, 1972.

NTSB, Special Study, "Signals and Operating Rules as Causal Factors in Train Accidents," U.S. DOT, National Transportation Safety Board, Washington DC, Rep. No. NTSB-RSS-71-3, 1971.

O'Hanlon, J., Jr., "Vigilance, the Plasma Catecholaminus and Rejected Biochemical and Physiological Variables," Human Factors Research, Inc., Goleta CA, Tech. Rep. 787-2, 1970.

Robertson, J.R.H., "Railway Accident Report on the Collision that occurred on 4th January 1969 between Paddock Wood and Marden, in the Southern Region British Railways," London: Her Majesty's Stationery Office, 1969.

Staeheli, G.A., "In Depth Evaluation of FRA Train Accident Reports," Ann. Proc. Railway Fuel and Operating Officers Assn., Chicago IL, 1972.

REFERENCES (CONTINUED)

Stroh, C.M., VIGILANCE: THE PROBLEM OF SUSTAINED ATTENTION, Pergamon Press, New York NY, 1971.

Travis, R.C., and Kennedy, J.L., "Prediction and Automatic Control of Alertness. 1. Control of Lookout Alertness," J. Compar. & Physiol. Psychol., 41, p. 457-461, 1947.

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