

Driver Inattention and Highway Safety

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ABSTRACT

The Transportation Systems Center, in support of research carried out by the National Highway Traffic Safety Administration's Crash Avoidance Division, has reviewed research into driver attentional processes to assess the potential for the development of methods and techniques for reducing the number of accidents related to attentional lapses. Contained in this paper is a summary of the results of the review with regard to the (a) safety implications of inattention, (b) psychological and physiological indices of inattention, and (c) in-vehicle instrumentation for detecting inattention. Areas of research are suggested that could be valuable in the development of practical attention monitors for in-vehicle use.

The Transportation Systems Center, in support of research carried out by the National Highway Traffic Safety Administration's (NHTSA) Crash Avoidance Division, recently completed a review of driver attentional processes. A summary of the results of that review are contained in this paper.

Lapses in driver attention have been identified as a significant contributing factor in as many as 90 percent of traffic accidents. In light of this fact, an effort was conducted to determine the potential value of developing a system to monitor driver attention. This effort consisted of a review of the state of the art of research into driver attentional processes, analysis of the 1982 National Accident Sampling System (NASS) data, and investigation of the current technology available for sensing degradations in driver alertness. The material in this paper is abstracted from a report prepared for NHTSA's Crash Avoidance Division entitled, Potential for Driver Attention Monitoring System Development (1).

The status of research into driver attentional processes has remained fairly constant since Shinar et al. documented their review of the concepts of attention in 1978. More recent research has confirmed the general conclusions drawn by the studies reviewed by Shinar et al., as well as reiterating the complexity of driver attentional processes. It was apparent from reviewing the available data that combining indicators of the attentional state with indicators of the driving environment could significantly improve the accuracy of driver-attention monitoring.

NHTSA's accident data base is a valuable resource for estimating the impact of driver attention on highway safety. The 1982 NASS data were analyzed to develop hypotheses on the influence of driver inattention on traffic accidents. The 1982 data were selected because they represented the first file that emphasized driver-related factors in crash avoidance. The data showed that in accidents where an avoidance maneuver might have been of value, a large portion (37 percent) of the drivers involved took no action to avoid the collision. This supports the hypothesis that attentional lapses are a major factor in highway accidents. Another possibly large portion of drivers did not take action until it was too late to avoid the accident. It is suspected that driver inattention played a major role in these accidents as well.

Several devices have been developed over the years to monitor driver alertness and to stimulate the driver when a degradation in performance occurs be-

cause of inattention or drowsiness. A number of these devices are currently commercially available. These devices range from a simple head-droop alarm to a microprocessor-based monitor of steering wheel motion, driving-pattern, and time patterns fully integrated into an automobile system as original equipment. Both physiological and behavioral inattention indicators were investigated with respect to the technology of sensing the indicator and relative advantages and disadvantages of each as a practical monitor of inattention.

BACKGROUND

To a large extent, the safe operation of any system requiring direct human control depends on the level of attention that the human controller provides. In the case of motor vehicle operation, the driver must sample the driving environment, select the critical aspects of the environment, determine the proper response(s), make the response(s), and evaluate the outcome(s) of the response(s). To the extent that the driver does not sample the environment with sufficient frequency, does not select the appropriate stimuli, or does not respond in a timely manner, safety will be diminished.

Available driver inattention countermeasures include work-rest scheduling, educational campaigns, use of chemical stimulants, and the detection of degraded alertness (as inferred from changes in performance) through the use of sensor systems. In industrial and military settings, the alleviation of alertness-related safety problems generally is handled through the establishment and enforcement of duty schedules. The establishment and enforcement of work-rest schedules is not a practical countermeasure for dealing with the vast majority of road vehicle accidents because they involve either private automobiles or owner-operated trucks. Educational and public information campaigns range from defensive driving courses to public service announcements before national holidays. Perhaps the most popular countermeasure is the use of legal and illegal chemical stimulants (particularly caffeine) to improve alertness.

ATTENTIONAL PROBLEMS

As Zaidel, Paarlberg, and Shinar noted in their comprehensive review (2), lapses in driver attention

can be assumed to be a significant contributory factor in traffic accidents. They cite estimates from 15 to 90 percent as the proportion of traffic accidents related to inattention. This great range can, to a large extent, be attributed to differences in definitions of attention-related problems.

For the purpose of examining the impact of such failures on driving safety, it is valuable to consider physical and psychological states that are likely to degrade alertness and to describe their impact on driving performance as follows:

1. Drowsiness: Except in cases where there is a known organic cause, such as narcolepsy, drowsiness can be attributed to a lack of sleep or a disturbance to the sleep-rest cycle (dysynchronosis). There are complex hypotheses that explain the need for periodic sleep and dreaming. These relate to the diurnal, hormonally regulated rhythms that cause the periodicity of sleep and the need for a reorganization of information acquired during waking hours, respectively. Whatever the causes of the need for sleep and concomitant dreaming, it is clear that "sleep deprivation leads to increased performance degradation as a result of an increase in the frequency of automatic periods of light sleep during enforced wakefulness and a heightening of the threshold of stimulation required to keep the individual from falling asleep" (3). It is the occurrence of the light microsleeps that is a problem in highway safety. During these microsleeps, the driver neither attends nor responds to the driving environment.

2. Physical fatigue: This can be a result of continued physical exertion or exposure to environmental stresses such as temperature and humidity extremes, excessive acoustic noise levels, and severe physical vibration. Physical fatigue is likely to result in distraction or an increased concern with internal stimuli and a concomitant decrease in attention to external stimuli. This change in focus from external to internal stimuli can be hypothesized to result in the driver missing critical signals. Further, fatigue can result in decreased response accuracy by the driver. This can cause a greater number of responses to be required to achieve a desired maneuver, which will further distract the driver from concentrating on external events. Physical fatigue is often a problem in military and industrial settings. It is less likely to be a problem for passenger car drivers than for the operators of heavy trucks who are often subjected to high noise and vibration levels.

3. Excess mental workload: Here, the driver has too many stimuli to attend to or too many responses to make in a limited amount of time. Skilled drivers learn to handle this situation by restricting their attention monitoring to the most critical inputs and meeting only the most critical control requirements. Less-skilled drivers may choose to monitor inappropriate inputs or to make noncritical responses. Some drivers may go into saturation and make no response, or they may freeze.

4. Intoxication due to alcohol, drugs, or other chemicals: Reductions in alertness are a direct or side effect of the use and/or abuse of a large number of substances. The exposure to pollutants, chief among them carbon monoxide, produces drowsiness, unconsciousness, and eventual death. The effects of the ingestion of illegal drugs and legal medications vary as widely as do their chemical formulae, ranging from depression and drowsiness through agitation to hallucination. Although alcohol abuse by motor vehicle operators is perhaps the single greatest cause of traumatic injury in the United States today, there is still considerable debate with regard to

the particular behavioral changes caused by alcohol ingestion that result in dangerous driving practices.

5. Simple inattention: In this case, the driver either is not attending to any stimuli or is not attending to the proper external stimuli. This behavior can be described as daydreaming, woolgathering, or any of a number of colloquial terms. This inattention may be the result of any or all of the previously described problems, or many simply result from introspective behavior by the driver or a distraction of the driver. The operational result is that the driver makes a delayed response, an inappropriate response, or no response at all.

While the previously described conditions have a wide range of physiological concomitants, they have one particular behavioral similarity: in a nonalert state, the driver is less likely to respond in a fashion timely and appropriate to his or her environment than in the alert state.

In a laboratory setting with a controlled environment, the reduction in response frequency and appropriateness can be readily measured. The challenge is to discriminate accurately and reliably between changes in responses due to driver alertness and those changes imposed by driving conditions in the real world. Described in this paper is an attempt to assess the near-term feasibility of driver alertness measurement.

ACCIDENT STATISTICS

Accident Descriptions

To develop hypotheses about the impact of driver inattention on traffic accidents, data were obtained from the NASS Files. The 1982 NASS file was chosen because it was the first file to provide detailed information on the driver's role in traffic accidents. Data from a particular subset of accidents were selected to investigate inattention. These data came from reportable accidents where the vehicles involved were moving and the role of the drivers involved had been recorded. The following paragraphs contain descriptions on the factors used in analyzing the file.

Vehicle Factors

Vehicle factors are described as follows:

- Vehicle Role--Striking/Struck and Single-Vehicle Accidents: Striking and struck were extracted to eliminate vehicles involved in chain reaction accidents (both striking and struck). Driver attention clearly is more important with regard to the role of the driver in the striking vehicle. However, in some cases, if the driver of the struck vehicle properly responds in a preaccident situation, the accident can be avoided or the severity of impact reduced. To reduce the ambiguity with regard to the role of the struck vehicle's driver, only cases where the vehicles were in motion were considered (see Vehicle Speed). Based on the NASS definitions of vehicle role, single-vehicle accidents are included in the striking/struck categories. Both a vehicle striking another vehicle and a vehicle striking a roadside object are classified as striking vehicles. A struck vehicle in a single-vehicle accident would have been hit by something other than another vehicle, such as a pedestrian or some form of debris.

- Vehicle Speed: Only cases where vehicles had speeds greater than 0.5 mph before the accident were considered because it was assumed that driver re-

sponse was likely to be critical only when his or her vehicle was moving.

Driver Factors

The following driver factors are described:

- Attempted Avoidance Maneuver: Two levels were examined: cases where no avoidance maneuver occurred and cases where any avoidance maneuver occurred.
- Driver Drowsy: This driver factor reflects cases where the driver's being drowsy, asleep, or fatigued was considered a cause of the accident.
- Driver Drugs--Medication: This factor reflects cases where the use of legal drugs was considered to be the cause of the accident.
- Driver Other Drugs: In these accidents, the cause was attributed to the driver's use of illegal drugs.
- Driver Inattention: In these accidents, the cause was attributed to the driver's lack of attention.
- Alcohol Abuse: In these cases, the measured blood alcohol content (BAC) of the driver was in excess of 0.07 percent.
- Age of Driver: Drivers were grouped by age from 20 to 70 years old in 5-year intervals.

Accident Factors

Accident factors are described as follows:

- Land Use: Land use groups the accidents in terms of urban or rural sites.
- Time Period: The day was divided into five time periods: early morning (accidents that occurred between the hours of midnight and 5:59 a.m.), the morning rush hour (all accidents that occurred between 6:00 a.m. and 9:59 a.m.), midday (10:00 a.m. to 3:59 p.m.), the evening rush hour (4:00 p.m. to 6:59 p.m.), and evening (7:00 p.m. to midnight).
- Road Alignment: The data were grouped into accidents that occurred on curved and straight sections of roadway.
- Number of Occupants: The data were examined to determine the influence of the presence of passengers in a vehicle (greater than one) on the accident. Vehicles having the driver as the only occupant were designated as occupant equal to one.
- Day of Week: The week was divided into weekdays (Monday through Friday) and weekends.

The NASS file provides a number of methods for estimating the role of attentional factors in crash

avoidance. For the purposes of this document, the NASS file output was structured to examine the relationship between the previously listed driver factors and crash frequency. Although the report this paper is abstracted from deals with all of the factors listed, perhaps the most suggestive information comes from considering the vehicle role.

1982 NASS DATA

Failure to Make a Precollision Response

The broad operational definition of driver inattention used in this paper is as follows: the attentional state where the driver fails to respond to a critical situation. Figure 1 shows the frequency of all collision accidents where the role of the vehicle was known to be either striking or struck (vehicles whose roles were unknown or were involved in chain reaction collisions were not included) and the vehicles were in motion. In the 1982 NASS file, there are 11,868 vehicles involved in accidents that meet these criteria. In these accidents

- 2,665 (or 22.5 percent) were striking vehicles whose driver took no avoidance action before the collision;
- 1,838 (or 15.5 percent) were struck vehicles whose driver took no avoidance action before the collision;
- 5,916 (or 49.8 percent) were striking vehicles whose driver took avoidance action before the collision; and
- 1,449 (or 12.2 percent) were struck vehicles whose drivers took avoidance action before the collision.

Drowsiness

Figure 2 represents breakdowns of the frequency of all collision accidents where the driver was judged to be drowsy, the role of the vehicle was known to be either striking or struck (vehicles whose roles were unknown or were involved in chain reaction collisions were not included), and the vehicle was in motion. In the 1982 NASS file, 176 (or more than 1 percent) of all collisions involved vehicles in accidents that met these criteria. In these accidents

- 104 (or 59.1 percent) were striking vehicles whose driver took no avoidance action before the collision;

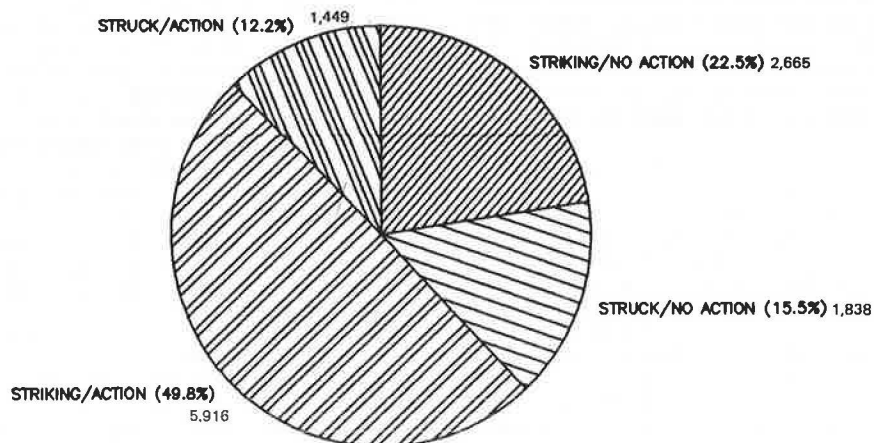


FIGURE 1 Driver responses in all collision accidents.

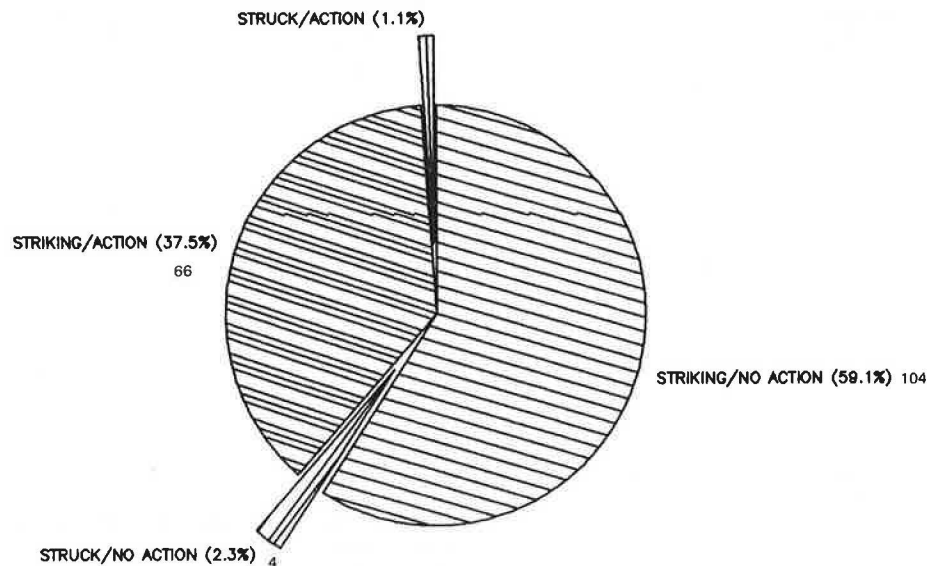


FIGURE 2 Accidents attributable to drowsiness.

- 4 (or 2.3 percent) were struck vehicles whose driver took no avoidance action before the collision;
- 66 (or 37.5 percent) were striking vehicles whose driver took avoidance action before the collision; and
- 2 (or less than 1.1 percent) were struck vehicles whose driver took avoidance action before the collision.

Drunkenness

Figure 3 gives breakdowns of the frequency of all collision accidents where the driver had a BAC in excess of 0.07 percent, the role of the vehicle was known to be either striking or struck (vehicles whose roles were unknown or were involved in chain reaction collisions were not included), and the vehicle was in motion. In the 1982 NASS file, 376 (or 3 percent)

of all collision-involved vehicles in accidents meet these criteria. In these accidents

- 157 (or 41.8 percent) were striking vehicles whose driver took no avoidance action before the collision;
- 11 (or 2.9 percent) were struck vehicles whose driver took no avoidance action before collision;
- 195 (or 51.9 percent) were striking vehicles whose driver took avoidance action before the collision; and
- 13 (or 3.5 percent) were struck vehicles whose driver took avoidance action before the collision.

Medication--Legal and Illegal

Drivers involved in accidents meeting the previously mentioned collision criteria who were found to have

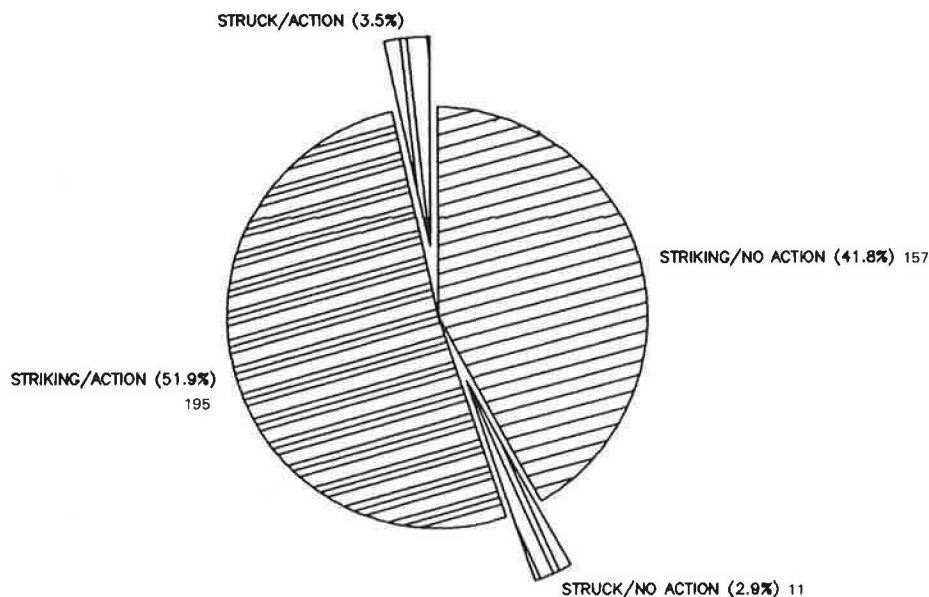


FIGURE 3 Accidents attributable to drunk drivers.

TABLE 1 Percentage of Drivers Making No Precollision Maneuver

Driver Age	Striking (%)	Struck (%)
Under 20	24	47
20-24	30	54
25-29	29	52
30-34	33	58
35-39	29	53
40-44	33	57
45-49	37	61
50-54	36	57
55-59	35	60
60-64	39	58
65-69	43	64
Over 70	52	74

used legal or illegal drugs before the collision, respectively, represent less than 0.1 percent of the cases meeting the collision definition.

Driver Age

Table 1 and Figure 4 depict driver responses in accidents attributable to inattention versus age. The data indicate that younger drivers were more inclined to make avoidance maneuvers than older drivers. The relationship between failure to respond in a collision-type accident and age appears to be linear. As would be expected, the number of cases in which the driver fails to respond is greater in accidents in which the driver's vehicle is struck than when it is the striking vehicle.

Time of Day

Table 2 gives a distribution of accidents due to inattention by time of day. Between the hours of 6:00 a.m. and 4:00 p.m. (morning rush hour to midday), a higher percentage of drivers took no action to avoid

TABLE 2 Accidents Attributable to Inattention (1982 NASS)

Time of Day	Avoidance Action		No Avoidance Action	
	Total	Percent	Total	Percent
Morning rush hour	68	13	78	21
Midday	150	30	127	34
Evening rush hour	91	18	59	16
Evening	114	23	68	18
Early morning	81	16	40	11

Note: Data are for 946 of 11,868 accident cases.

an accident. After 4:00 p.m., drivers were more inclined to attempt an avoidance action.

SUMMARY

Thus, in all collision accidents in which the vehicles were under way and a driver response conceivably might have avoided the collision or lessened the severity of the collision (11,868 accidents), the NASS investigators found that

- Eight percent of the cases were specifically related to the driver being inattentive;
- One percent were related to the driver being drowsy;
- Three percent of the drivers were drunk;
- Less than 0.15 percent were attributable to the use of legal or illegal drugs;
- Thirty seven percent of the drivers made no precrash response of any kind; and
- The frequency of precrash response decreases as a function of driver age.

INDICATORS OF INATTENTION

Indicators of inattention have been extensively studied, including such physiological measures as

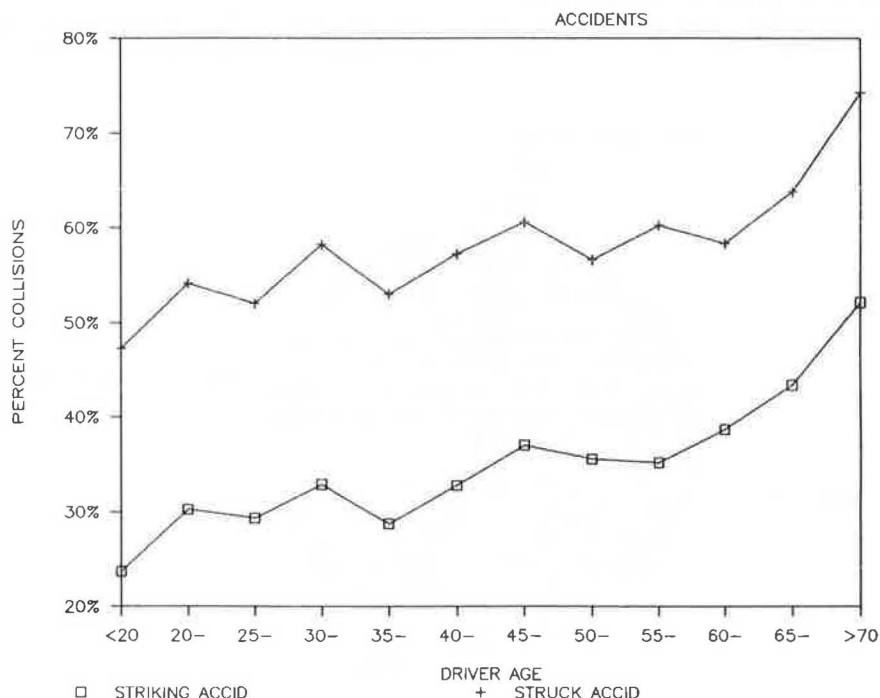


FIGURE 4 Percentage of drivers not making avoidance maneuver in collision accidents.

TABLE 3 Physiological Indicators of Driver Attention

Indicator	Sensor	Measurement Dimension	Active ^a or Passive	Obtrusive ^b or Remote	Advantages	Disadvantages
Heart rate and variability (EKG)	Electrode or transducer	Voltage or pressure	P	O	Easy to monitor. Could be made remote by incorporation into steering wheel. Easy to interpret.	May require detailed spectral analysis. Individual variations are large.
Brain electrical activity (EEG)	Electrode	Voltage amplitude and frequency	P	O	Established relationship to fatigue and drowsiness.	Difficult to monitor or interpret. No remote sensing possible in the near term.
Skin conductance and electrodermal response (EDR)	Electrode	Voltage resistivity	P	O	Could be made remote by incorporation into steering wheel.	Individual variations in galvanic skin response are large. Relationship to inattention is not well established.
Muscle electrical activity	Electrode	Voltage amplitude and frequency	P	O	Relatively easy to monitor.	Relationship to inattention is weak. Remote monitoring is not possible in near term.
Body activity	Observer or switches	No. of movements State change frequency	P	R		Requires observer. No established correlation to inattention.
Respiratory pattern	Transducer	Frequency	P	O		Difficult to monitor. Correlation with vigilance is inconsistent.
Critical flicker frequency	Self-assessed	Null frequency	A	R	Easy to administer. Could be built into vehicle dashboard.	Driver would have to stop vehicle to administer. Weak correlation with fatigue.
Head nod angle	Switch	State change	P	O	Cheap, commercially available.	Measures last stage of drowsiness.

^a"Active" (A) requires activity on the part of the driver. "Passive" (P) does not.

^b"Obtrusive" (O) requires physical attachment to the driver. "Remote" (R) does not.

EKG, EEG, pulse and heart rates, and eye blinking. Behavioral indicators would include looking patterns, driver steering wheel use, accelerator and brake applications, lane drift, and closure rate. The physiological indices reviewed are given in Table 3 and the behavioral indices are given in Table 4. Although a number of indicators have potential utility for use in an inattention detection system, they tend to be ambiguous and unreliable when taken singly. These indicators are reviewed in detail in the previously mentioned report.

COMPLEX PERFORMANCE SIGNATURES

In response to this problem, a number of investigators have attempted to define combinations of indicators that would be more useful than single indicators alone. Some examples of recent efforts to develop complex performance signatures are described briefly in the following sections. For purposes of organization, they have been considered in two groups. The categories are chosen for convenience, and primarily imply a difference in perspective and

TABLE 4 Behavioral Indicators of Driver Attention

Indicator	Sensor	Measurement Dimension	Active ^a or Passive	Obtrusive ^b or Remote	Advantages	Disadvantages
Steering wheel reversals	Potentiometer, optical or magnetic transducer	Rate and angle	P	R	Easy to monitor. Studied extensively. Commercially available.	Affected by vehicle/driving environment. Individual variations.
Accelerator pedal movement	Linear potentiometer pressure transducer	Rate and amplitude	P	R	Easy to monitor.	No established relationship to attention. Individual variations.
Brake pedal movements	Linear potentiometer, pressure transducer	Rate and pressure	P	R	Easy to monitor.	No established relationship to attention. Individual variations.
Vehicle position (longitudinal, lateral, and heading)	Observer, sensitive guidance system, road-side edge monitor, radiation detector	Frequency, amplitude and angle, relative distance	P	R	Correlated with alcohol and drug use.	Difficult to monitor. Complex interactions.
Looking behavior	Observer, TV monitor, oculometer	Eye position and fixation frequency, pattern and duration	P	O or R	Correlated to all dimensions of attention. Can be made remote.	Interpretation difficult. Not useful in real time.
Blink rate	As above	Rate and duration	P	O or R	Can be measured remotely.	Weakly correlated with attention.
Secondary tasks	Many variations, usually tracking		A	R	Can be a simple device.	Distracts from main task.

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assumed starting points of the investigators. The studies included in the first group are characterized by the use of multivariate statistical techniques to analyze and combine measures on selected variables. These measures are used to develop complex signatures or ad hoc models to assign a driver to a given behavioral group. The studies included in the second group, in comparison, are characterized by the assumption of some prior model of the driver. Statistical techniques may be used to determine parameter values or changes that may be used to categorize a driver.

STATISTICAL PROCESSING

A number of investigators have attempted to use multivariate statistical techniques to identify combinations of measures with greater discriminatory power than univariate indicators. In most cases, the focus of the effort has been on problems other than attentional performance; however, the approach has been fruitful, as shown in the following examples.

Lemke (4) used factor analysis and canonical correlation to establish multivariate relationships between changes in EEG patterns and changes in driver control activity during long periods of driving in a simulator and on the road. A more popular approach, however, has been to use discriminant function analysis. Hagen (5) derived discriminant function vectors using variables derived from four basic measures on subjects driving a point light source simulator. He found mean accelerator reversal rate, mean speed, lateral position error, and accelerator variability made the largest contributions to vectors discriminating between male and female subjects. Using this approach, he was able to develop vectors that discriminated between a number of groups including, for example, sex/violation, sex/accidents, sex/driving experience, and sex/risk taking.

Wilson and Greensmith (6) also used multivariate discriminant analysis to develop combinations of driving performance scores of males and females during 40 to 50 min of on-road driving. They found that combinations of seven variables were useful for discriminating between males and females. These were: number of speed changes, number of fine- and coarse-steering reversals (less than 2 degrees and greater than 20 degrees, respectively), moderate (0.15g) and strong (0.3g) lateral acceleration for a period of 1 sec or more, accelerator pedal activity, and clear road speed.

Attwood (7) obtained five measures of driving performance during 70-mi trips driven by experienced and inexperienced drivers. He found that no single variable was useful for discrimination between the groups. He derived 71 variables from the five base measures, and using multivariate discriminant analysis, he was able to develop a number of combinations that discriminated between the driver groups. For example, a driver's group could be predicted with a combination of scores on (mean lateral position) + (minimum lateral position), or a more complex combination of scores on (lateral position standard deviation) + (mean lateral position) (lateral position standard deviation) + (steering wheel reversals) + (accelerator pedal reversals).

Attwood et al. (8) used a similar approach to the development of a linear discriminant function that could be used to identify sober and intoxicated drivers. In another study, Attwood and Scott (9) applied this approach to the detection of sleepy drivers. In this latter experiment, they obtained behavioral and vehicle measures during two 3-hr driving periods separated by 21 hr of maintained

wakefulness. By using these scores, they developed linear discriminant functions that could be used to identify drivers in the first and second driving periods. The smallest n-variable function was based only on measures of vehicle lateral position and steering wheel activity. It was expressed as

$$D(30) = 256 V(1) - 159 V(2) - 1.4 V(3)$$

where $V(1)$ and $V(2)$ are the mean and maximum vehicle lane position, respectively, and $V(3)$ is the steering wheel reversal rate in the range between 1.0 and 1.5 degrees. For longer sampling periods of 45 or 70 sec, the best functions included lane position and accelerator pedal activity rather than steering wheel activity. The function $D(30)$ was applied to the performance scores obtained during a second set of 3-hr driving periods for one driver on one task. The power of the simple function for assigning the driver to the drowsy class, although limited, was reasonably good and demonstrated the potential utility of the approach.

FORMAL MODEL-BASED SIGNATURES

In recent years, there has been considerable interest and success in the development and application of general operator/vehicle models. Most work has used either the now classic quasi-linear, describing-function representation or the more recent optimal control, state space representation. Recent and accessible reviews of these developments are presented, for example, by Allen (10), McRuer et al. (11), Reid (12), and Rouse and Gopher (13). Although the optimal control, state-space approach eventually may prove to be of greatest value for describing complex, multivariate operator-system behavior, the quasi-linear describing function models are currently the most well-developed.

A number of simulator and on-road studies have been conducted in recent years to evaluate model and parameter requirements, and changes for different driving situations. For example, Donges (14) studied straight and curved road driving, Reid et al. (15) studied obstacle avoidance maneuvers, Allen (16) studied driver adaptive behavior, and Smiley et al. (17) studied changes with driving experience.

In some recent studies, changes in the values of parameters of models have been used as indicators of changes in operator attentional state. Most of the studies have focused on changes associated with conditions requiring changes in the allocation of attention.

In studies of simple tracking behavior, interest has commonly focused on the parameters of gain, effective delay, lead-lag adjustment, and remnant. As Wickens and Gopher (18) indicated, open-loop gain is attenuated, lead is decreased, and/or remnant is increased with diversion of the operator's attention. These authors also observed an increase in the number of holds (no tracking response) related to the addition of secondary tasks and changes in both gain and power at low and high frequencies related to changes in primary and secondary task priorities.

The results of a driving simulator study by Allen et al. (19) generally confirm the results of the tracking test studies. In this study, the effects of changed attentional state related to the imposition of a secondary visual detection task and those related to the effects of driver BAC were examined in the framework of a quasi-linear, describing-function model. The effects of task loading and BAC were similar in that both resulted in reduced gain, particularly at low frequencies; increased remnant;

increased steering wheel activity; and increased heading and lateral position errors. There were also differences in the effects of the two types of conditions. Phase margin was not affected by driver BAC, but was increased with the addition of the secondary task. Crossover frequency, on the other hand, was not affected by the additional task loading, but decreased with increased BAC. Holds (no tracking response) on steering behavior were noted with intoxicated drivers during the visual response period, but were not observed with sober drivers.

Driver-vehicle models appear to provide an excellent means for expressing complex signatures necessary as a basis for an inattention detection system. Changes in the values and relations of variables and parameters of both ad hoc and formal models have been shown to be related to changes in driver physiological and psychological states and task demands. Research such as that of Attwood and Scott suggests the possibility of developing relatively simple, useful, ad hoc models with the use of multivariate analytical techniques. This approach provides flexibility in the choice of measures to be used, but the resultant models provide little guidance for the selection of measures or derived variables to establish or improve their discriminative power. Formal models, such as those used by Allen et al. (19) provide a fairly well-known and applied conceptual framework, but may be both more restrictive and demanding with respect to the measures that may and must be used. The possible requirement for input data to establish such model parameters as crossover frequency or phase margin, for example, may limit the use of formal models to research settings. Further research is necessary, however, to establish the minimum nonperformance input data for either type of model, technical means of providing this data, and the possibility of using predictive techniques to calculate probable input on the basis of driver and vehicle performance measurements.

DRIVER ALERTNESS MONITORS

The report reviewed the state of the art in driver alertness monitors. Currently, there are a limited number of such devices commercially available. These range from the unsophisticated head-droop alarm to the microprocessor-based monitor of steering-wheel driving pattern/driving-time patterns that is available in Japan on Nissan's Bluebird line of vehicles. (The monitors reviewed in the report are given in Table 5.)

Although not directly related to driver attention per se, the status of systems related to the vehicle and its environment were considered. These include radar warning and braking systems, navigational aids, roadside monitors, and automated highway systems. These systems could be considered as part of a multivariate approach to developing a driver alertness monitor.

The state of the art in automotive electronics was briefly reviewed in the report. The practical utilization of any of the aforementioned devices depends, to a large extent, on the development of sophisticated electronics for sensing, data handling, and analysis.

CONCLUSIONS

The material reviewed in the report suggests the following:

Accident Data

The fact that a large portion (37 percent) of drivers involved in automobile crashes, as reported in the 1982 NASS file, took no action to avoid the collision suggests that attentional lapses are a major factor in the causation of highway accidents and that these

TABLE 5 Driver Alertness Monitors

Monitor System	Sensor	Measurement Dimension	Active ^a or Passive	Obtrusive ^b or Remote	Advantages	Disadvantages	Availability	Cost (\$)
Reli "Stay-A-Wake"	Optical transducer	Steering rate	A	R	Alerts driver when steering wheel movement rate drops below a given rate.	Standard steering movement rate must be set by driver. System effectiveness can be defeated.	Available from the manufacturer.	170
	Voltage	Vehicle speed	A	R	Will sound an alarm when vehicle reaches or exceeds a set speed.	Speed at which alarm sounds is set by driver.		
Slarner "Driver Alert Warning Device"	Switch	State change	A	O	Sounds an alarm when driver's head droops.	Warning does not occur until the driver is asleep.	Available from AAA.	33
Safex "Drive Alert"	Switch	State change	A	O	Sounds an alarm when driver's head droops.	Warning does not occur until the driver is asleep.	No longer available.	—
Nissan "Safety Drive Advisor"	Optical/velocity sensor	Rate and frequency	P	R	Monitors and records driver's initial steering reversal rate and alerts the driver if steering reversal rate differs from this standard.	Little detail of operational principle is known to date.	Available on Nissan Bluebird models. Not imported into USA.	85 (approx.)
	Electronic clock	Elapsed driving time	P	R	Alerts driver to take periodic breaks. Interval between signals is decreased by activation of headlights or windshield wipers.			
Life Technology/Ford "Owl"	Optical sensor	Rate	P	R	Monitors and records driver's initial steering reversal rate and alerts the driver if steering reversal rate differs from this standard.	Standard steering reversal rate can be adjusted by driver. System effectiveness can be defeated.	No longer available.	—

^a"Active" (A) requires activity on the part of the driver. "Passive" (P) does not.

^b"Obtrusive" (O) requires physical attachment to the driver, "Remote" (R) does not.

attentional lapses probably become a more important factor as a driver's age increases.

Research Findings

Changes in performance associated with task duration or drowsiness include: (a) a reduction in the frequency of control responses, (b) periodic "blockage" of all responses, (c) an increase in the amplitude of responses, and (d) an increase in the variability of the responses.

In controlled experiments, averaging across subjects who are exposed to the same conditions, there are reliable changes in performance that are monotonically related to attentional state.

Examination of the performance of the individuals in these studies indicates that while performance of selected tasks decreases with degraded attention, the relationship between the changes in performance and the attentional state varies significantly between the subjects.

The use of multiple performance indices will enhance the discriminative power of the attentional discrimination system. Although performance changes can reliably reflect modifications in attentional state, the most difficult problem in detecting degraded alertness will be to discriminate the effects of these changes from those imposed by the driving environment.

Driver Alertness Systems

Proprietary alertness indicators fall into two functional classes: those that evaluate performance and those that evaluate the physical or physiological state of the subject.

Indicators that are based on physiological or physical concomitants of attention are likely to be too cumbersome to achieve widespread use by private vehicle operators. Indicators that are based on the performance of an artificially constructed secondary task are likely to be distracting to the driver and, therefore, potentially hazardous. However, it may be possible to use performance measurements on non-critical tasks that are normally required, such as instrument scanning, as an index of alertness.

A driver attention indicator, regardless of its behavior, must be able to learn the shape of the normal performance curves that are particular to the individual driver. Then, it must be able to sense deviations from this norm that are not the result of changes in the environment and that provide warning of changes in alertness.

Of the proprietary devices reviewed, only one system is currently installed on production passenger vehicles in Japan. This system is based on a multivariate analysis approach and learns the patterns of driving performance of the individual driver, and represents a potentially promising approach.

The existing electronic systems and the near-term projected advancements lead to the conclusion that electronics will soon be available to reliably track and analyze any practical driver alertness monitoring system.

REFERENCES

1. H. Bishop, B. Madnick, R. Walter, and E.D. Sussman. Potential for Driver Attention Monitoring System DVPT. Report DOT-HS-806744. U.S. Department of Transportation, June 1985.
2. D.M. Zaidel, W.T. Paarlberg, and D. Shinar. Driver Performance and Individual Differences in Attention and Information Processing. Report DOT-HS-8-01819. U.S. Department of Transportation, 1978.
3. C.N. Cofer and M.H. Apply. Motivation: Theory and Research. John Wiley and Sons, Inc., New York, 1964.
4. M. Lemke. Correlation Between EEG and Drivers' Actions During Prolonged Driving Under Monotonous Conditions. Accident Analysis and Prevention, Vol. 14, No. 1, 1982, pp. 7-17.
5. R.E. Hagen. Sex Differences in Driving Performance. Human Factors, Vol. 17, No. 2, 1975, pp. 165-177.
6. F. Wilson and J. Greensmith. Multivariate Analysis of the Relationship Between Driveometer Variables and Drivers' Accident, Sex, and Exposure Status. Human Factors, Vol. 25, No. 3, 1983, pp. 303-312.
7. D.A. Attwood. The Effects of Driving Experience on Objective Measures of Driving Performance. Proc., 23rd Annual Meeting of the Human Factors Society, Boston, Mass., 1980, pp. 726-730.
8. D.A. Attwood, R.F.D. Williams, and H.P. Madill. The Effects of Moderate Concentrations of Alcohol on Closed Course Driving. Journal of the Studies of Alcohol, Vol. 41, No. 7, 1980, pp. 623-634.
9. D.A. Attwood and P.L. Scott. The Online Use of Performance Measures to Predict Driving Fatigue. Proc., 25th Annual Meeting of the Human Factors Society, Boston, Mass., 1981, pp. 726-730.
10. R.W. Allen. Stability and Performance Analysis of Automobile Steering Control. Paper 820303. SAE, Detroit, Mich., 1982.
11. D.T. McRuer, R.W. Allen, D.H. Weir, and R.H. Klein. New Results on Driver Steering Control Models. Human Factors, Vol. 19, No. 4, 1977, pp. 381-397.
12. L.P. Reid, E.N. Solowka, and A.M. Billing. A Systematic Study of Driver Steering Behavior. Ergonomics, Vol. 24, No. 6, 1981, pp. 447-462.
13. W.B. Rouse and D. Gopher. Estimation and Control Theory; Application to Modeling Behavior. Human Factors, Vol. 19, No. 4, 1977, pp. 315-330.
14. E. Donges. A Two-Level Model of Driver Steering Behavior. Human Factors, Vol. 20, No. 6, 1978, pp. 691-708.
15. L.P. Reid, W.V. Graf, and A.M. Billing. The Fitting of Linear Models to Driver Response Records. Paper 820304. SAE, Detroit, Mich., 1982.
16. R.W. Allen. Modeling Driver Steering Control Behavior. Proc., 1982 IEEE International Conference on Cybernetics and Society, Seattle, Wash., 1982.
17. A. Smiley, L. Reid, and M. Fraser. Changes in Driver Steering Control with Learning. Human Factors, Vol. 22, No. 4, 1980, pp. 401-415.
18. C.D. Wickens and D. Gopher. Control Theory Measures of Tracking as Indices of Attention Allocation Strategies. Human Factors, Vol. 19, 1977, pp. 349-365.
19. R.W. Allen, H.R. Jex, D.T. McRuer, and R.J. DiMarco. Alcohol Effects on Driving Behavior and Performance in a Car Simulator. IEEE Transactions on Systems, Man, and Cybernetics, Vol. 5, No. 5, 1975, pp. 498-505.

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