TESTING OF COMMERCIALLY AVAILABLE FATIGUE MONITORS

by

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**Abstract:**

This report presents an evaluation of three commercially available fatigue monitors (the Onguard eye closure monitor, a head nodding monitor - Dozer's Alarm, and an analogue of the Roadguard reaction time monitor) based on laboratory testing.

The devices showed an ability to detect fatigue in some cases but were not able to maintain alertness and thus prevent performance deterioration. There were few instances of a startle response to the presentation of an auditory warning signal by Dozer's Alarm or Roadguard. Equipment faults with the modified version of Onguard made it impossible to assess the frequency of startle responses to the alarm.

**Key Words:**

(IRRD except when marked*)

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EXECUTIVE SUMMARY

This is the third and final report of a programme of research into driver fatigue in truck accidents. This report presents an evaluation of three commercially available fatigue monitors based on laboratory testing. The research programme was commissioned by the Victorian Road Freight Transport Industry Council and funded by the then Road Construction Authority in May, 1988.

The first report, Fatigue in truck accidents (Haworth, Heffernan and Horne, 1989), presented two estimates of the involvement of fatigue in Victorian truck accidents and a review of in-vehicle fatigue countermeasures. The second report was entitled Information for development of an educational program to reduce fatiguerelated truck accidents (Haworth and Heffernan, 1989).

Based on the recommendations of the first report, the Onguard eye closure monitor, a head nodding monitor (Dozer's Alarm) and a laboratory simulation of the Roadguard reaction time monitor were tested.

The criteria applied in this evaluation were reliability, threshold and degree of intrusiveness. An examination of the driver fatigue literature showed that eye closure and subsidiary reaction time (the measures used by the eye closure monitor and the Roadguard reaction time monitor) have been found to be valid measures of driver fatigue.

Laboratory testing took place at night. Subjects watched a videotape which showed the driver's eye view of daytime driving around a circular test track. All subjects performed a tracking task which was superimposed on the road scene.

The performance of subjects using the monitors was compared with that of subjects in the control condition. The three questions addressed were

- Was the monitor able to detect the onset of fatigue?
- Did use of the monitor allow the subject to drive for longer without falling asleep?
- Did use of the monitor result in less deterioration in performance?

The answer to the first question was generally "yes" for the Roadguard device and "sometimes" for the other two devices. The answers to the second and third questions were "no".

Subjects who used the Onguard, Head nodding or Roadguard devices did not drive for longer without falling asleep. The results may have differed with a larger group of subjects but this is unlikely based on the lack of clear trends in the four groups of six subjects used in this study.

The reaction times before and after simulated driving and the measures recorded during simulated driving (number of long eye closures, total time eyes closed, tracking error) showed deterioration in performance with time on task but the amount of deterioration was not affected by which monitor was used (or whether a monitor was used).
The fatigue monitors were also evaluated by examining critical incidents. Performance just before and just after warning signal was analysed to clarify the immediate effect of the warning. The analyses looked for evidence of

1. An improvement in alertness and vehicle control behaviour following the warning signal (evident for at least five minutes).

2. A startle response to the warning signal (a deterioration in performance of less than one minute in duration).

There was mixed evidence of an improvement in alertness and vehicle control behaviour following the warning signal. Tracking errors appeared to be somewhat reduced in the two minutes following presentation of the Head nodding alarm. There appeared to be fewer long eye closures following the presentation of the Roadguard alarm. No corresponding reduction in tracking errors was noted, however.

There were few instances of a startle response to the presentation of an auditory warning signal by Dozer’s Alarm or Roadguard. Equipment faults with Onguard, which had been modified to enable continuous recording, made it impossible to assess the frequency of startle responses to the alarm.

Subjects rated the head nodding monitor (Dozer’s Alarm) as the least annoying of the three monitors and considered it to be the most effective and said they would be more willing to use and purchase this device. However, these trends were not significant when subjected to analysis of variance, possibly because of the small number of subjects in each group. There were no overall correlations between the number of warning signals presented and responses to questionnaire items.

The reliability of the Onguard eye monitor and, to a lesser extent, the Dozer’s Alarm is reduced by the tendency to slip from the correct position. Redesign of the devices or more secure attachment could correct this problem, however.

There may be legal issues involved if a driver fell asleep and crashed while using a fatigue monitor. This issue, while outside of our brief, needs to be investigated.

In conclusion, the devices showed the ability to detect fatigue in some cases but were not able to maintain alertness and thus prevent performance deterioration. The need to develop more reliable detectors of driver fatigue still remains. Fatigue detectors can only be used as a warning to stop driving and rest, not as an aid to prolonging driving.
1 INTRODUCTION

This report presents an evaluation of the effectiveness of three commercially available fatigue monitors:

- the Onguard eye closure monitor
- a head nodding monitor (Dozer's Alarm)
- the Roadguard reaction time monitor.

A review of in-vehicle fatigue countermeasures in Stage 1 of this study (Haworth, Heffeman and Horne, 1989) concluded that these devices showed promise and recommended that they undergo laboratory testing.

In the first section of this report the fatigue monitors are described and the criteria to be applied in testing are outlined. These were identified in the earlier report as reliability, criterion level (or threshold) and degree of intrusiveness. The validity of the fatigue measures underlying the monitors is also examined.

The second section of the report deals with the laboratory testing of the monitors. The procedures used and results obtained are presented in detail.

1.1 A description of the fatigue monitors

1.1.1 Eye closure monitor

Onguard is an optical electronic eye monitor developed by Xanadu Ltd, an Israeli company. It is not currently available in Australia. The device consists of a small infra-red sensing unit which observes the eye, and an electronic processor which contains batteries, alarm buzzer, and switch (see Figure 1). The device is designed to be mounted on any standard eyeglass frame.

The electronic sensing unit directs a beam of infrared light at the eye and measures the reflected light. Eye closures are detected as reductions in the amount of light reflected when the eyelid covers the surface of the eye. The electronic sensing unit emits an audible alarm when eye closures of longer than 0.5 seconds are detected.

Figure 1. The Onguard eye closure monitor.
I.1.2 Head nodding monitor

A number of companies have marketed simple devices to monitor head nodding by drivers. The devices consist of an ear piece which hooks over the ear and contains a battery, an alarm and an angular rotation detector (see Figure 2). When the driver's head nods forward beyond a predetermined angle, the device buzzes loudly.

The monitor tested in this study was the Dozer's Alarm which is marketed in Australia.

Figure 2. The Dozer's Alarm head nodding monitor. The on-off switch (A) and sensitivity adjuster (B) are shown in the left panel. Positioning of the monitor is shown in the right panel.

I.1.3 Reaction time device

A fatigue monitor based on a visual signal and reaction time clock has been developed by a Danish company. The device is called Roadguard and consists of an electronic circuit which is activated when the vehicle is put into top gear. A timer comes on which stops at random periods after 4 to 14 seconds. When the timer stops, a red lamp lights up on the instrument panel. The lamp can be switched off using either of two light touch contacts on the steering wheel or a foot switch. If it is not switched off within three seconds an alarm buzzer begins to sound. If the lamp is switched off the timer begins a new sequence.

The device was the invention of a Danish haulage contractor and the manufacturer claims that it can be fitted to most trucks in approximately two hours.
2 CRITERIA APPLIED IN EVALUATING FATIGUE MONITORS

The review of in-vehicle fatigue countermeasures identified three criteria which should be applied in evaluating fatigue monitors. These were reliability, criterion level (or threshold) and degree of intrusiveness.

There is a more basic criterion which can be applied to a fatigue monitoring device: is the measure used a valid one? For the eye closure monitor and the Roadguard reaction time device, this can be answered, at least partly, by reference to data we have collected in studies of the fundamental nature of fatigue conducted for the Federal Office of Road Safety (Haworth, Vulcan, Triggs and Fildes, 1989). The issue of validity will be addressed in Section 2.4.

2.1 Reliability

The reliability of in-vehicle fatigue countermeasures has been identified as an important issue by other researchers (e.g., Laurell, personal communication, 1988). If drivers learn to depend upon the device it needs to always detect the presence of fatigue and rarely give false alarms.

2.2 Threshold

The threshold of a device is the level of driver fatigue that is reached before the device warns the driver of danger. A warning given too early is equivalent to a false alarm but failure to warn the driver before he or she falls asleep at the wheel may render the device ineffective.

The threshold of the Roadguard device may be inappropriate. The length of time which elapses between the light coming on and the device sounding an alarm is three seconds. For the device to be useful, fatigue must be detected quickly in order to enable the driver to avoid a possible accident. Lisper, Laurell and van Loon (1986) found that drivers who fell asleep at the wheel, in an experiment involving driving around a closed circuit track, did so for brief periods only, ranging from 0.5 to 1.5 seconds. By setting the threshold reaction time (RT) at three seconds it is possible that detection of drowsiness may not be sufficiently rapid to prevent accidents. This was further investigated in the laboratory evaluation of the device.

Concern has also been expressed (Hulbert, 1972) that the head nodding monitor may have an excessively high threshold. It is possible that severe deteriorations in performance may develop before head nodding occurs.

2.3 Degree of intrusiveness

The degree of intrusiveness of each device also needed to be established. By this it is meant the degree to which the driver is aware of the device and the amount of interference with the driving task. In this study, level of intrusiveness was assessed by a questionnaire given to subjects at the completion of the laboratory experiment.

Onguard, the eye closure monitor, may not be reliable if it slips on the nose and might be considered intrusive by drivers because of the obstruction to vision which it produces. Roadguard, the driver reaction time device, may also be intrusive. While the manufacturer insists that switching off the lamp in no way interferes with the driver, the issue of intrusiveness required further investigation. In conducting the
laboratory evaluation of this device the degree of intrusiveness was assessed.

It should be noted that failure to conform to the criteria does not necessarily imply that the concept embodied in a device is a poor one. It may be that adjustment of parameters or redesign would result in an effective device.

2.4 The validity of measures used in the fatigue monitors

The fatigue measures on which the monitors are based are length of eye closure (Onguard), head nodding (Dozer’s Alarm) and length of subsidiary reaction time (Roadguard).

2.4.1 Eye closure

Evidence exists that eye closure is a valid measure of driver fatigue and also that it is a measure which can be directly related to crash risk.

Erwin (1976, cited in Skipper and Wierwille, 1986) reported a series of ten studies of drowsiness. He concluded that eyelid position was the "cleanest and most stable signal" of the physiological and physical variables which he measured.

Studies of fatigue which have measured the frequency of long duration eye closures have shown consistent results. Beideman and Stern (1977) found that blink duration increased over time in a simulated driving task but blink rate did not show the same effect. Goldstein, Walrath and Stern (1982, cited in Stern, Walrath and Goldstein, 1984) ran subjects in a discrimination paradigm for 128 minutes. From the first to the final five minutes of the task, mean blink duration increased significantly and the number of long duration closures increased. Similar findings were demonstrated in two 20-minute simulated driving sessions by Stern, Beideman and Chen (1976, cited in Stern et al., 1984).

Research conducted by the authors for the Federal Office of Road Safety has shown that the frequency of long eye closures (>500 msec, the criterion used by Onguard) increases with time on task in night-time driving whether on the test track or in the laboratory (Haworth, Vulcan, Triggs and Fildes, 1989).

The same research demonstrated a relationship between long eye closures and deterioration in lateral positioning. In field testing both the number of lane excursions and the frequency of long eye closures increased with time on task in night driving. In the laboratory, tracking errors and the frequency of long eye closures both increased with time on task. There was a significant positive relationship between frequency of long eye closures (greater than 500 msec) and tracking error for 5 of the 6 daytime subjects and 3 of the 6 night-time subjects.

A number of authors have pointed out the close relationship between eye closure and crash risk. Skipper and Wierwille (1986, p.529) stated that

Drivers simply cannot perform the driving task with their eyes closed.

The more closure there is, the more hazardous driving becomes. Even short periods of closure can cause delays in event detection and poorer lane tracking performance.

 Näätänen and Summal (1978), in a review of problems associated with operationally defining and validating fatigue measures, concluded that falling asleep at the wheel is the only aspect of fatigue that has been shown to directly cause accidents. Measuring eye closure is a reasonably straightforward method of determining whether the driver is about to fall asleep at the wheel, or has already done so.
2.4.2 Head nodding

While head nodding devices have been available for many years (Hulbert, 1972), less is known about the role of head nodding in driver fatigue.

Underlying the development of these products was the assumption that head nodding occurs at the onset of fatigue. Hulbert (1972) noted that alertness often decreases substantially before the head begins to nod. There is therefore some possibility that head nodding monitors may sound the alarm signal too late for safety.

2.4.3 Subsidiary reaction time

Subsidiary reaction time is the latency of responding on a task performed concurrently with driving. It should be distinguished from reaction times of tasks involved in driving, e.g., brake reaction time. The latter class of reaction times has not been found to provide satisfactory measures of driver fatigue (Mast, Jones and Heimstra, 1966; Dureman and Bodén, 1972).

A large body of research utilizing subsidiary reaction time as a measure of fatigue has been conducted by Lisper in Sweden and Brown in the United Kingdom. They reported a consistent finding that subsidiary reaction time increases with hours of continuous driving, indicating that this measure is a reliable index of fatigue (Brown, 1967; Brown, Simmonds and Tickner, 1967; Lisper, Dureman, Ericsson and Karlsson, 1971; Lisper, Eriksson, Fagerström and Lindholm, 1979; Lisper, Laurell and Stening, 1971; Lisper, Laurell and van Loon, 1986).

Laurell and Lisper (1976) found that reaction time to an auditory stimulus increased with time on task for subjects who were driving but not for subjects travelling as passengers or for subjects in a stationary vehicle. This suggested that reaction time measurement per se does not promote its own deterioration. Laurell and Lisper (1978) found a high correlation between reaction time and detection distances to roadside obstacles, indicating that reaction time is a valid index of fatigue.
3 METHOD OF TESTING

3.1 Experimental design

The experiment had four conditions which corresponded to the testing of each of the three devices and a control condition. A different sample of six subjects served in each condition.

All subjects were tested between 9.30 pm and 3 am.

3.2 Subjects

Usable data were collected from 24 subjects (17 males, 7 females). Data from one subject in the Roadguard condition were discarded because of malfunctioning of the eye closure recording equipment. Another session was terminated by an electrical failure.

Subjects were recruited from local service and car clubs and Monash University. A Health and Driving History Questionnaire (see Appendix 1) was administered to potential subjects.

Persons with a history of epilepsy, seizures or unexplained periods of unconsciousness were not permitted to participate in the study. It was thought that the repetitive pattern of visual stimulation might have adverse effects on such persons.

Individuals who were taking prescription drugs which might affect their sensitivity to driver fatigue were excluded. Subjects were asked to report whether they were taking antidepressants, antihistamines (including cold preparations), sedatives or tranquilizers. They were also asked if they were taking any other type of medication.

One subject reported using Ventolin for asthma and four subjects smoked but not heavily.

Each subject held a current driver’s licence and was not required to display P-plates. Details of subjects’ age and driving experience are contained in Table 1. These data were collected because a Swedish study found that subjects with little driving experience appeared to be affected differently by an extended period of driving than were experienced drivers (Lisper, Laurell and Stening, 1973). The data collected from two older subjects did not appear to differ from those of younger subjects (see Appendix 4).

Estimates of yearly kilometres driven varied considerably among individuals, ranging from 1500 km to 110,000 km. Most estimates were between 10,000 and 30,000 km. Many subjects experienced difficulty in making an estimate and two subjects in the Roadguard condition were unable to do so. Because the accuracy of the estimates is likely to be very low, the results were not analysed as a function of estimated annual kilometres driven.
Table 1. Mean and standard deviation of age and driving experience of subjects.

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<tr>
<th>Group</th>
<th>Age</th>
<th>Experience</th>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
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<tr>
<td>Onguard</td>
<td>23.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Head nodding</td>
<td>34.1</td>
<td>17.2</td>
</tr>
<tr>
<td>Roadguard</td>
<td>23.0</td>
<td>3.6</td>
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<tr>
<td>Control</td>
<td>30.3</td>
<td>18.1</td>
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3.3 Equipment

A videotape of travelling around the circular track at General Motors-Holdens' Proving Ground at Lang Lang was used as the road scene. The circular track has four lanes each banked with neutral camber for a given speed. It has a circumference of 4.7 km. The surface is in good condition and is reasonably smooth.

The vehicle was driven in the second lane from the centre at 90 km/hr. The lane markings are single unbroken white lines on both sides of the lane which are in good condition.

Filming was from inside a VN Commodore station wagon using a CCD video camera mounted as near as possible to the driver's eye position. The videotape was VHS format and sound was recorded at the same time with the car windows closed.

Filming took place between 11.45 am and 12.30 pm on a sunny day with partial cloud cover. The 15 minutes of videotape which was steadiest and showed least movement of the vehicle within the lane was dubbed up to four hours.

The videotape was played on a VHS video cassette recorder and displayed on a 60 cm colour television monitor.

Tracking stimuli were superimposed on the road scene using a Matrox VGO-AT video superimposition computer board. The computer board was housed in an expansion box which was connected to the Toshiba T3100E portable computer.

The tracking target consisted of a small white empty square superimposed on the video screen. The target was continuously present and moved horizontally across the screen. The displayed motion was the sum of the movement generated by a ramp function with an amplitude of half of the screen width and input from the driver's steering actions.

Every second the computer recorded the elapsed time from the start of the experiment and the distance of the target from the centre of the screen. Subjects were instructed to centre the square over the white line to the immediate right of the lane in which the vehicle was travelling.

A number of modifications were made to the monitors to allow for recording of their output. A sensor was attached to the alarm mechanism of the commercial head
nodding monitor (Dozer's Alarm) to allow computer logging of the times at which the alarm sounded. The Onguard eye monitor incorporated a custom microchip which led to difficulties in transferring information about alarm times to the computer. To allow this transfer of information the electronic processing module of the Onguard device was removed and the signal sent to the computer. The computer was programmed to emit a tone when an eye closure of longer than 500 msec was detected. The commercially available Roadguard device is designed for installation in trucks and so not suited to laboratory testing. To counter this, a model of the device was built from the manufacturer's specifications. The warning light was mounted on top of the dashboard and one foot switch was provided for responding (the commercial device has one foot switch and two touch contacts on the steering wheel).

3.4 Procedure

Subjects began by reading the instructions and signing a consent form (see Appendix 2).

All subjects were tested individually in the MUARC fatigue laboratory. Each subject sat in a "simulator" comprised of part of a Volvo 200 series sedan. The car was cut in front of the firewall and behind the front seats. A computer mouse was attached to the (modified) end of the steering column to allow movements of the steering wheel to be recorded by the computer. Steering wheel movements resulted in movements of the tracking stimulus on the video screen immediately in front of the dashboard. Operation of other vehicle controls did not have any effect.

Each session comprised the 10-minute reaction time task, device testing for four hours, followed by the 10-minute reaction time task.

At the end of testing subjects in the three experimental conditions completed a questionnaire relating to the perceived usefulness and intrusiveness of the monitor tested. Copies of the questionnaire may be found in Appendix 3.

Subjects were transported to and from the University by taxi for safety reasons.

3.4.1 10-minute reaction time task

The 10-minute reaction time task developed by Lisper and his colleagues (Lisper and Kjellberg, 1972; Lisper, Tornros and van Loon, 1981) was used in this experiment. The auditory stimulus was presented at random intervals of between 2.5 and 5 seconds, which the subject was required to "turn off" by pressing a foot switch. Testing was conducted for 11 minutes and reaction times from the first minute of testing were discarded as practice data. The mean reaction times for each minute were calculated.

3.4.2 Test of Onguard eye monitor

The subject tracked the stimulus while wearing the eye monitor. However, when an eye closure of greater than 500 msec was detected the computer emitted a tone. The computer recorded eye closures and tracking error.

3.4.3 Test of head nodding monitor

The subject tracked the stimulus on the television screen while wearing the head nodding monitor and eye monitor. The computer recorded the times when the alarm sounded in addition to eye closures and tracking error. The sensitivity adjustment at the rear of the head nodding monitor was set at half-way between the minimum and maximum positions.
3.4.4 Test of Roadguard device

The subject tracked the stimulus on the television screen and responded to the Roadguard stimulus while wearing the eye monitor. The computer recorded the reaction times to each Roadguard stimulus in addition to eye closures and tracking error. The eye monitor was adjusted such that the subject could look at the Roadguard light without the downward glance being recorded as an eye closure.

3.4.5 Control condition

The subject tracked the stimulus while wearing the eye monitor. No alarms occurred to alert the subject unless the computer did not register a tracking response for 2 minutes (the default value). The computer recorded eye closures and tracking error.
4 RESULTS

There were two ways in which the performance of the fatigue monitors was evaluated from the laboratory data. The first method was the straightforward traditional comparison of performance of subjects in the three experimental conditions and one control condition. These analyses sought to answer the questions:

- Was the monitor able to detect the onset of fatigue?
- Did use of the monitor allow the subject to drive for longer without falling asleep?
- Did use of the monitor result in less deterioration in performance?

The second method was an analysis of critical incidents, focussing on performance just before and just after warning signals were presented and investigating the immediate effect of the warning. The results of both methods of analysis are presented here.

It should be noted that the performance of the modified Onguard device was less than optimum. An audible warning was not reliably emitted each time that the duration of eye closure was greater than 500 msec. Thus, while the system recorded that a warning had been presented, it was not always heard. For this reason, no firm conclusions could be drawn about the effectiveness of the commercial device.

4.1 Comparison of experimental and control groups

4.1.1 Completion rates

Nine of the 24 subjects tested fell asleep during the experiment. These subjects were awakened and asked to perform the 10-minute reaction time task before being driven home.

The numbers of subjects who completed four hours of testing and the mean duration of testing for each group are presented in Table 2. Neither quantity appeared to have been affected by the fatigue warning device used. However, the number of subjects in each group was probably too small for these crude measures to distinguish between conditions.

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<tr>
<th>Group</th>
<th>No. of subjects</th>
<th>Mean duration of testing (hours:minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onguard</td>
<td>3</td>
<td>3:14</td>
</tr>
<tr>
<td>Head nodding</td>
<td>4</td>
<td>3:21</td>
</tr>
<tr>
<td>Roadguard</td>
<td>4</td>
<td>3:28</td>
</tr>
<tr>
<td>Control</td>
<td>4</td>
<td>3:15</td>
</tr>
</tbody>
</table>
Analyses of results for the four-hour device tests were complicated by subjects being unable to complete the session. The means across subjects may be misleading because of early discontinuation by subjects who were likely to be more fatigued than those who continued. Nevertheless, these means are presented and interpretations are suggested by reference to the individual subject data.

4.1.2 10-minute reaction time test

Figure 3 shows the mean reaction times measured each minute before and after simulated driving. The only effects to be found significant in the analysis of variance were the main effect of minutes of testing ($F(9,180)=2.74, p<.01$) and the interaction of before/after and minutes of testing ($F(9,180)=3.07, p<.01$). There was no significant main effect of condition ($F<1$) or of before/after testing ($F<1$). Neither was the interaction of these factors significant ($F<1$). The interaction of minutes of testing and condition ($F<1$) and the triple interaction of before/after, minutes of testing and condition ($F<1$) were both not significant.

The complex nature of the effect of minutes of testing was revealed by the trend analysis. It showed significant quartic and quintic effects of minutes of testing ($F(1,20)=8.97, p<.01$ and $F(1,20)=5.58, p<.05$). None of the lower level components were significant.

The effect of before/after on the linear component of the minutes of testing main effect was significant ($F(1,20)=15.30, p<.01$).

![Figure 3. Mean reaction times in the 10-minute test administered at the beginning and end of the experimental session.](image-url)
4.1.3 Eye closures

The mean number of long (greater than 500 msec) eye closures in each 30 minute period is presented for each of the conditions in Figure 4. The graph suggests a general increase in the frequency of long eye closures with time on task. The increase appeared to be smaller for the Roadguard condition than for the other conditions.

![Figure 4. Mean number of long (>500 msec) eye closures in each 30-minute period for subjects in each condition.](image)

The graphs of individual subjects' eye closures in Appendix 4 provide a check as to whether the means were distorted by subjects dropping out. The data from individual subjects in the Roadguard group confirm that there were relatively few long closures in the first two hours compared with other groups. The high mean frequency of long eye closures for the head nodding group may reflect the data of one subject who had a very large number of long eye closures and completed the session. The other subjects in the head nodding group showed an increase in the numbers of long closures in the first hour but no clear pattern after that.

Because of subject attrition, the analysis of variance of frequencies of eye closures was restricted to the first three hours of testing. This limitation of the data is likely to have reduced the likelihood of demonstrating a difference due to the fatigue monitor used. One would expect such differences to be less apparent in the early part of the session than later in the session.

Analysis over three hours (after removing the data of those subjects who did not complete the first three hours) showed an effect of time on task, \( F(5,65)=6.42, p<.001 \). Neither the effect of condition (\( F<1 \)) nor the interaction with time on task (\( F<1 \)) were significant.
Total time closed was the second measure of eye closure which was analysed. It is a measure which should be related to the risk of having a crash - the more time the driver's eyes are closed, the greater is the probability of missing a crucial event.

The total time closed in each 30-minute period is shown in Figure 5. The graph suggests that the greatest increase in total time closed was shown by subjects in the Head nodding group. In the last hour, particularly, subjects in the Onguard and Head nodding groups seemed to have their eyes closed for more of the time than subjects in the Roadguard and Control groups.

Inspection of the data for individual subjects (Appendix 4) shows that the large increase with time on task for subject 6 in the Head nodding group may have contributed to the large increase apparent in the mean for the group. The increase with time on task was more consistently evident in the Onguard group.

Unfortunately, analysis of variance had to be limited to data from the first three hours. Analysis of variance of data from the first three hours of testing failed to find any effect of condition, $F<1$, or any interaction of time on task and condition, $F(15,65)=1.03$, $p>.05$. A significant effect of time on task was demonstrated, $F(5,65)=5.83$, $p<.001$.

In summary, none of the devices used resulted in fewer or shorter periods of eye closure than when no device was used.

Figure 5. The total time closed in each 30-minute period.
4.1.4 Tracking errors

The mean tracking errors are presented in Figure 6. There appeared to be a general increase in tracking error with time on task. A large increase is evident in the Roadguard condition between 90 and 120 minutes. The individual subject data in Appendix 4 show that this resulted from the data of one subject only (R6) who had fallen asleep and so had an extremely large error.

Tracking errors on an individual basis seemed to show less fluctuation than, for example, number of long eye closures. The tracking errors per 30 seconds in Table 4 show much greater variability, however, suggesting that the stability in the graphs in Appendix 5 may not result from stable performance, but rather that each point represents 900 observations.

An analysis of variance of tracking errors in the first six 30-minute periods of the sessions showed no significant effect of condition, F<1. A significant effect of time on task was observed (F(5,70)=9.78, p<.001) but there was no interaction of time on task and condition (F<1).

In summary, while tracking errors increased with time on task, none of the devices used resulted in fewer tracking errors than when no device was used.

![Figure 6. Mean tracking errors in millimetres.](image)

4.2 Roadguard reaction times

The mean reaction times to signals emitted by the Roadguard device are shown in Figure 7. Subject R1 appeared often to fail to attend to the red light and to later respond to the bell. For the rest of the group reaction times appeared to increase somewhat during the session.
Analysis of variance was conducted on the data of five subjects during the first three hours of testing (data of subject R1 was excluded). The effect of time on task was significant, $F(5,20) = 3.85, p < .05$.

![Mean reaction time graph](image)

**Figure 7.** Mean reaction times for each 30-minute period.

### 4.3 Analysis of critical incidents

The presentation of warning signals by fatigue monitors should occur in response to detection of instances of poor performance. We have termed these occurrences, critical incidents.

It was hypothesised that the presentation of a warning signal could have two kinds of effects on driver performance:

1. An improvement in alertness and vehicle control behaviour following the warning signal. The improvement should be evident for an extended time period (at least five minutes).

2. A startle response to the warning signal. This would be likely to result in a very short-term deterioration in vehicle control behaviour (of less than one minute in duration).

Intuitively, a startle response might be followed by an improvement in alertness and vehicle control behaviour. Our concern with startle responses was that they may be the basis of steering overcorrections upon natural wakening which have been implicated in some single-vehicle run-off-road crashes.
4.3.1 Numbers of warning signals presented

As Table 3 shows, the number of times a warning signal was presented varied considerably between subjects as well as between monitor types. Generally the head nodding monitor (Dozer's Alarm) presented fewest signals. There is some evidence that the Roadguard device gave more warning signals later in the session (when subjects were more fatigued) than earlier in the session.

Table 3. Number of times monitor emitted a warning signal.

<table>
<thead>
<tr>
<th>Time Period (mins)</th>
<th>Roadguard</th>
<th>Onguard</th>
<th>Headnod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject No.</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>0 to 30</td>
<td>12</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>30 to 60</td>
<td>15</td>
<td>19</td>
<td>42</td>
</tr>
<tr>
<td>60 to 90</td>
<td>43</td>
<td>30</td>
<td>56</td>
</tr>
<tr>
<td>90 to 120</td>
<td>80</td>
<td>64</td>
<td>86</td>
</tr>
<tr>
<td>120 to 150</td>
<td>59</td>
<td>13</td>
<td>101</td>
</tr>
<tr>
<td>150 to 180</td>
<td>64</td>
<td>74</td>
<td>89</td>
</tr>
<tr>
<td>180 to 210</td>
<td>59</td>
<td>148</td>
<td>37</td>
</tr>
<tr>
<td>210 to 240</td>
<td>74</td>
<td>97</td>
<td>69</td>
</tr>
<tr>
<td>Total</td>
<td>406</td>
<td>375</td>
<td>373</td>
</tr>
</tbody>
</table>

It should be recalled that the modified Onguard monitor did not reliably present signals each time an eye closure of longer than 500 milliseconds was detected. The number of signals recorded in the Table greatly overestimates the number heard by the subject and so should be treated with caution. There are two reasons for this:

1. If the modified device functioned correctly, the number of signals may have been lower because of an alerting effect.

2. In addition, the commercial monitor does not respond to long closures which occur within one or two minutes after the presentation of a warning signal. If this feature had been available in the experiment, the total number of signals which were presented would have been reduced.

4.3.2 Performance before and after a warning signal

In order to analyse the effects of a warning signal a time window was created for each signal. This window (or block of data) extended from 2.5 minutes prior to the presentation of signal to 2.5 minutes after the signal. The aim was to compare measurements before the presentation of the signal with those after the signal. Unfortunately the occurrence of signals close together in time meant that windows overlapped: the after period of a signal sometimes included part of the before period of the next signal. For this reason straightforward statistical analyses of the data were not possible. Instead, conclusions were drawn from inspection of the data for a sample of windows.
Data from a large number of windows were plotted, portraying the relationship of occurrences of eye closure and tracking error before and after the presentation of the signal. In addition, graphs for Roadguard subjects included reaction times. Examples of graphs for Subject 1 in the Onguard condition, Subject 2 in the head nodding group and Subject 3 in the Roadguard condition are presented in Appendix 6.

In general, performance after the warning signal was not markedly different to before. After a warning signal tracking improved a little in the head nodding group and reaction times appeared to be shorter in the Roadguard group. It is of interest that the head nodding monitor sometimes gave a signal when no long eye closure had been detected in the previous 30 seconds. This is surprising because head nodding is commonly considered to occur while the eyes are closed.

4.3.3 Startle responses

To investigate whether the audible alarm gave rise to startle responses, tracking errors for the 30 seconds after the alarm (30 seconds after the presentation of the light in Roadguard condition) were examined. It was considered that startle responses should occur during that time period and would possibly be of very short duration.

The mean tracking error for the entire 30 second period might hide a fast startle response and so the mean errors per second were examined. (This is the most raw level of the tracking data available.) The number of errors which were greater than 80 mm during the 30 seconds following presentation of the alarm was counted. Eighty mm was chosen as the threshold value because it was larger than any of the mean errors for the 15 minute periods and it was equivalent to the stimulus appearing halfway across the lane on the video presentation. Zero error was represented as the stimulus superimposed on the lane line.

The number of large tracking errors in the 30 seconds after presentation gives an indication of the likelihood of a startle response occurring but a comparison with the number of such errors which occurred outside of this time window is necessary. Table 4 shows the mean number of large errors per warning signal. It should be noted that double counting of large tracking errors occurred when time windows for adjacent warning signals overlapped.

Numbers of large errors were generally lower for the head nodding group. The number of large tracking errors was greater in the 30 seconds following a signal than in the preceding 30 seconds for 7/18 subjects. This is likely to have occurred by chance.

In summary, there was no evidence of a startle response to the presentation of an auditory warning signal by Onguard, Dozer's Alarm or Roadguard.

4.4 Questionnaire results

At the conclusion of the experiment, subjects in the three experimental conditions were asked to indicate their answers to the following questions by placing a mark on a line with ends labelled "Not at all" and "Very":

1. How effective do you consider the monitor would be in preventing crashes from drivers falling asleep?
2. How annoying (or uncomfortable) do you consider the monitor to be?
3. How willing would you be to use such a device on long trips?
4. How willing would you be to pay $20 to purchase such a device?

The distances from the left end of the line ("Not at all") were measured and means and standard deviations for each condition were calculated. These data are presented in Table 5.

Table 4. Mean number of tracking errors greater than 80 millimetres in time period surrounding the presentation of a warning signal. The time (relative to the warning signal) at the start of the 30-second period is cited.

<table>
<thead>
<tr>
<th>Time Period(mins)</th>
<th>-2.5</th>
<th>-2.0</th>
<th>-1.5</th>
<th>-1.0</th>
<th>-0.5</th>
<th>0.0</th>
<th>0.5</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onguard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.71</td>
<td>3.33</td>
<td>3.59</td>
<td>3.41</td>
<td>3.78</td>
<td>4.98</td>
<td>3.43</td>
<td>3.39</td>
<td>3.20</td>
<td>3.21</td>
</tr>
<tr>
<td>2</td>
<td>2.80</td>
<td>3.17</td>
<td>2.90</td>
<td>3.75</td>
<td>3.58</td>
<td>3.86</td>
<td>3.77</td>
<td>3.80</td>
<td>3.88</td>
<td>3.78</td>
</tr>
<tr>
<td>3</td>
<td>3.66</td>
<td>3.38</td>
<td>3.36</td>
<td>3.45</td>
<td>3.83</td>
<td>4.66</td>
<td>3.59</td>
<td>3.61</td>
<td>3.29</td>
<td>3.41</td>
</tr>
<tr>
<td>4</td>
<td>2.96</td>
<td>3.12</td>
<td>3.65</td>
<td>3.06</td>
<td>2.12</td>
<td>2.77</td>
<td>3.58</td>
<td>4.44</td>
<td>4.21</td>
<td>4.05</td>
</tr>
<tr>
<td>5</td>
<td>0.33</td>
<td>0.53</td>
<td>0.42</td>
<td>0.59</td>
<td>0.61</td>
<td>0.58</td>
<td>0.55</td>
<td>0.66</td>
<td>0.50</td>
<td>0.63</td>
</tr>
<tr>
<td>6</td>
<td>1.23</td>
<td>1.26</td>
<td>1.27</td>
<td>1.22</td>
<td>1.38</td>
<td>1.25</td>
<td>1.25</td>
<td>1.13</td>
<td>1.32</td>
<td>1.40</td>
</tr>
<tr>
<td>MEAN</td>
<td>2.45</td>
<td>2.47</td>
<td>2.53</td>
<td>2.58</td>
<td>2.55</td>
<td>3.02</td>
<td>2.70</td>
<td>2.84</td>
<td>2.73</td>
<td>2.75</td>
</tr>
</tbody>
</table>

| Head nodding      |      |      |      |      |      |      |      |      |      |      |
| 1                 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2                 | 0.00 | 0.58 | 1.25 | 0.08 | 0.67 | 0.00 | 2.25 | 0.00 | 0.92 | 0.75 |
| 3                 | 0.59 | 0.00 | 0.00 | 0.12 | 0.29 | 0.06 | 1.76 | 1.00 | 0.06 | 0.24 |
| 4                 | 1.15 | 0.40 | 1.50 | 0.05 | 0.55 | 0.45 | 1.50 | 0.45 | 0.50 | 0.35 |
| 5                 | 2.00 | 1.99 | 1.37 | 1.81 | 1.37 | 1.18 | 1.13 | 2.01 | 2.28 | 1.70 |
| 6                 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 |
| MEAN              | 0.62 | 0.50 | 0.69 | 0.34 | 0.48 | 0.34 | 1.11 | 0.58 | 0.63 | 0.51 |

| Roadguard         |      |      |      |      |      |      |      |      |      |      |
| 1                 | 9.34 | 9.69 | 10.02 | 9.85 | 10.39 | 10.40 | 10.00 | 9.78 | 9.88 | 10.18 |
| 2                 | 0.00 | 0.00 | 0.50 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3                 | 0.06 | 0.11 | 0.28 | 3.50 | 8.50 | 7.11 | 3.22 | 0.83 | 0.00 | 0.33 |
| 4                 | 2.94 | 4.71 | 4.44 | 4.17 | 5.21 | 4.85 | 3.50 | 4.41 | 3.62 | 3.26 |
| 5                 | 7.11 | 7.93 | 8.06 | 8.53 | 8.56 | 9.69 | 10.27 | 8.87 | 9.41 | 8.98 |
| 6                 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| MEAN              | 3.24 | 3.47 | 3.88 | 4.36 | 5.44 | 5.34 | 4.50 | 3.98 | 3.82 | 3.79 |

The head nodding monitor (Dozer’s Alarm) was rated as the least annoying device and subjects considered it to be the most effective. Subjects were more willing to use and purchase the head nodding monitor than the other two devices. One way analyses of variance were conducted to test whether any of the ratings differed between the experimental groups. There were no significant effects (Effectiveness: F(2,14)=1.31, p>0.05, Annoyance/interference: F(2,14)=1.78, p>0.05, Willingness to use: F(2,14)=1.29, p>0.05, Willingness to purchase: F(2,14)<1). The clear pattern of results in Table 5 suggests that the lack of significant effects may have been due to the small number of subjects in each group.
The popularity of the head nodding monitor is at odds with the objective measures: the eye closure measures suggested that subjects in the head nodding group were more fatigued towards the end of the session than those using other monitors.

Table 5. Subjects' responses to questionnaire about monitor. The mean scale value is presented with the standard deviation in brackets.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Effective</th>
<th>Annoying</th>
<th>Willing to use</th>
<th>Willing to purchase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onguard</td>
<td>48.7 (46.2)</td>
<td>52.8 (31.4)</td>
<td>49.7 (38.3)</td>
<td>54.0 (38.9)</td>
</tr>
<tr>
<td>Head nodding</td>
<td>84.0 (28.1)</td>
<td>25.2 (17.6)</td>
<td>86.0 (35.1)</td>
<td>71.2 (45.4)</td>
</tr>
<tr>
<td>Roadguard</td>
<td>59.0 (31.9)</td>
<td>54.3 (31.8)</td>
<td>66.3 (38.1)</td>
<td>51.2 (35.6)</td>
</tr>
</tbody>
</table>

Correlational analyses were carried out on all subjects who used a monitor and then separately for each group. The matrices of correlation coefficients are presented in detail in Appendix 5.

The overall analysis showed that subjects' ratings of the effectiveness of a monitor were significantly positively correlated with their rated willingness to use the monitor ($r=.65$, $p<.01$) and their rated willingness to purchase the monitor ($r=.58$, $p<.05$). Not surprisingly, there was a significant positive correlation between subjects' willingness to buy and willingness to use ($r=.76$, $p<.01$). There was a significant negative relationship between ratings of annoyance/interference and willingness to purchase ($r=-.60$, $p<.05$).

The correlation between ratings of effectiveness and willingness to use the monitor was significant only in the Roadguard group ($r=.84$, $p<.05$) and in no group was the overall relationship between ratings of effectiveness and willingness to purchase statistically significant. The negative relationship between ratings of annoyance/interference was significant only for subjects who used the head nodding monitor ($r=-.97$, $p<.01$). The relationship between willingness to use and willingness to purchase was not found for subjects in the head nodding group ($r=.53$, $p>.05$).

Did the perceived effectiveness or the perceived annoyance depend on the number of times the device gave a warning? It is interesting to note that the monitor which received the most positive ratings from subjects was the one which presented fewest warning signals.

None of the responses to questionnaire items correlated significantly with number of warning signals when analyses were conducted on the entire sample of subjects. Subjects in the head nodding group who received more warning signals rated the monitor as less effective ($r=-.89$, $p<.05$). The same group of subjects showed a significant negative correlation between the number of warning signals and rated willingness to use the monitor ($r=-.89$, $p<.05$). Surprisingly, there was a negative
relationship between the number of warning signals presented by the Roadguard device and subjects' judgements of the annoyance/interference of that device.

It is interesting that the perceived annoyance of Roadguard and Onguard is similar. This suggests that the necessity to press footpedal did not cause as much irritation as expected. In addition, the modified Onguard monitor rarely gave an audible warning signal and so the Roadguard alarm cannot have been considered very annoying by subjects.

4.5 Informal observations

4.5.1 Onguard

The Onguard monitor tended to become out of alignment because of spectacles slipping on the nose. We secured spectacles with surgical tape in order to avoid this problem. Commercially available elastic straps to secure spectacles were tried but found inadequate to prevent slippage.

The Onguard monitor requires that spectacles be worn but it cannot be attached to very thick frames or lenses. The manufacturer states that the device will not work with lenses with reflective coatings but performance did not seem to be affected by tinted glasses. Onguard appeared to work with drivers who were wearing contact lenses in addition to the clear glass spectacles to which the device was attached.

Onguard gave some false warning signals with sudden changes in illumination when driving. This occurred when driving in patches of intermittent shade along tree-lined roads.

When a modified form of Onguard was used in experimentation on a test track for another project (Haworth, Vulcan, Triggs and Fildes, 1989) it was observed that performance of the device was sometimes impaired at sunrise and sunset. This resulted from subjects squinting when driving into the sun.

4.5.2 Head nodding monitor

One subject could not be tested in this condition because the device slipped off his ears. Thus Dozer's Alarm may not be suitable for persons with small ears, particularly those who wear glasses (all of our subjects were required to do so to enable measurement of eye closures).

4.5.3 Roadguard

The optimum position on the dashboard of the Roadguard lamp depended on the driver's eye height. The lamp needed to be repositioned to avoid being eclipsed by the steering wheel.
5 DISCUSSION AND CONCLUSIONS

This report presents an evaluation of the effectiveness of three commercially available fatigue monitors:

- the Onguard eye closure monitor
- a head nodding monitor (Dozer's Alarm)
- the Roadguard reaction time monitor.

The laboratory experiment sought to determine how well the monitors performed by comparing the performance of subjects with and without monitors and by examining the short-term effects of presenting warning signals to drivers. The experiment also allowed collection of more qualitative information about the reliability, criterion level (or threshold) and degree of intrusiveness of the monitors.

5.1 Summary of experimental findings

The fatigue monitors were evaluated first by comparing the performance of subjects using the monitors with those in the control condition. The three questions addressed were:

Was the monitor able to detect the onset of fatigue?

This question was addressed by analysing the performance of subjects immediately preceding presentation of warning signals. In other words, an assessment was made of whether warning signals were presented at appropriate times.

The number of times a warning signal was presented varied considerably between subjects as well as between monitor types. Generally the head nodding monitor (Dozer's Alarm) presented very few signals, even when performance was quite poor. There was some evidence that the Roadguard device gave more warning signals later in the session (when subjects were more fatigued) than earlier in the session. However, Roadguard could not be said to be a totally reliable detector of driver fatigue because long eye closures occurred without a warning being given by Roadguard (see Appendix 6 Figure 3, Graphs 2, 4, 5 and 6). But it should be noted that large tracking errors did not accompany these long eye closures. For this reason it is somewhat difficult to extrapolate the results of this study to on-road performance.

Did use of the monitor allow the subject to drive for longer without falling asleep?

Subjects who used the Onguard, Head nodding or Roadguard devices did not drive for longer without falling asleep. The lack of clear trends in the four groups of six subjects used in this study suggests that the results would not have differed if a larger group of subjects was tested.

Did use of the monitor result in less deterioration in performance?

There was little evidence that use of any of the monitors led to less deterioration in performance. While reaction times before and after testing and eye closure and tracking measures showed that performance deteriorated during simulated driving, there were no significant differences in the amount of deterioration occurring when the eye closure monitor, head nodding monitor, Roadguard reaction time monitor or no monitor was used.

There were some patterns in the data which failed to reach statistical significance, however. The number of long eye closures showed some evidence that subjects using
the Roadguard reaction time monitor were less fatigued than subjects using the other two monitors. However, the Roadguard subjects were not less fatigued than the Control subjects. Similar results were found when the total time closed was examined. After three hours of driving performance seemed to be poorest for subjects using the Head nodding monitor but this was not supported by the statistical analyses.

In summary, the answer to the first question was generally "yes" for the Roadguard device and "sometimes" for the other two devices. The answers to the second and third questions were "no".

The fatigue monitors were also evaluated by examining critical incidents. Performance just before and just after warning signals were presented was analysed to clarify the immediate effect of the warning. The analyses looked for evidence of

1. An improvement in alertness and vehicle control behaviour following the warning signal (evident for at least five minutes).
2. A startle response to the warning signal (of less than one minute in duration).

There was mixed evidence of an improvement in alertness and vehicle control behaviour following the warning signal. Tracking errors appeared to be somewhat reduced in the two minutes following presentation of the Head nodding alarm. There appeared to be fewer long eye closures following the presentation of the Roadguard alarm. No corresponding reduction in tracking errors was noted, however.

There were few instances of a startle response to the presentation of an auditory warning signal by Dozer's Alarm or Roadguard. Equipment faults with the modified version of Onguard made it impossible to assess the frequency of startle responses to the alarm.

5.2 Reliability, criterion level (threshold) and intrusiveness

For a fatigue monitor to perform satisfactorily it must be reliable, have an appropriate threshold and not be unduly intrusive. The laboratory test allowed some qualitative observations of the performance of the three monitors tested.

The reliability of Onguard and, to a lesser extent, Dozer's Alarm is reduced by the tendency to slip from the correct position. This shortcoming is not at a conceptual level, however, and could be corrected by redesign or by use of adhesives. Adhesives might increase the intrusiveness of the device, however.

Roadguard should be sensitive to long eye closures because subjects need to see that red light to know to press the button. There was some suggestion that this did not always follow, however. Subjects may get into an automatic pressing mode, pressing about every four seconds without attending to the lamp. This is discouraged by variability in the timing of light presentation (between 4 and 14 seconds) but remains a possibility. This problem could be remedied by redesigning the circuitry to give a warning signal when the button is pressed in the absence of the light. This would act to discourage automatic pressing.

In Chapter 2 the issue of whether the threshold of the Roadguard device is too high was raised. The large number of warning signals emitted by the device during testing suggests that this is not so. In contrast, the threshold may have been too high for head nodding monitor. There were only a small number of warning signals presented by Dozer's Alarm. Whether increasing the sensitivity of the device by making it sound a
warning signal when the angle of the head is less would remove this problem cannot
be said from this study.

Perceived intrusiveness was assessed from responses to the questionnaire item "How
annoying (or uncomfortable) do you consider the monitor to be?". The head nodding
monitor, Dozer's Alarm, received the lowest ratings on the scale from "Not at all
annoying" to "Very annoying". This information is important despite the indications
from performance data that the head nodding monitor may not have detected fatigue
as well as other monitors. The level of perceived intrusiveness is likely to influence
whether subjects will use a fatigue monitor.

The laboratory test allowed a limited evaluation of another aspect of the intrusiveness
of the devices, the degree to which the devices interfered with simulated driving.
While there was no difference in tracking errors between subjects using any of the
monitors and the control group, we have some concern about the need to respond to
the Roadguard device interfering with driving. In another study (not yet reported) we
found that tracking errors of subjects performing a subsidiary reaction time task were
greater than those of subjects not required to perform the reaction time task. Whether
this difference would be evident as less accurate steering in real-life driving remains
to be investigated.

The methodology used did not allow an assessment of another aspect of intrusiveness
of the Onguard eye monitor, the degree to which obscuration of the visual field by the
sensor unit interfered with detection of hazards. This issue would need to be
investigated before widespread use of the monitor was encouraged.

5.3 General conclusions and recommendations

In conclusion, none of the devices tested enabled the subject to drive for longer
without falling asleep or resulted in less deterioration in performance during
prolonged driving. While none of the devices claims that it will keep the driver
awake or improve long-term performance, it is possible that drivers may attempt to
use fatigue monitors for this purpose. For this reason, drivers using these or other
devices should be advised not to rely on them to be able to drive longer distances and
to cease driving once fatigue is detected, rather than take the risk of continuing to
drive.

The Roadguard reaction time monitor appeared to be the most reliable detector of
driver fatigue, being able to detect fatigue in most, but not all, cases. Earlier research
suggested that the Onguard eye closure monitor should be effective but equipment
malfunction made it impossible to effectively test Onguard in this study.

To reduce the intrusiveness of Roadguard it could be adapted so that it is only
necessary to use it during night-time or when the driver elects to do so. The use of a
nonintrusive monitor which may be oversensitive to evidence of fatigue as a filter to
determine when Roadguard or a similar device should be activated may be a better
method for monitoring driver fatigue.

This research has not addressed the type of vehicle or driver which would benefit
most from fatigue monitoring. Because of the greater number of kilometres driven,
the more severe consequences of a crash and the greater capital cost of the vehicles,
benefit-cost ratios are likely to be much better in heavy vehicles than in cars.

An additional issue is that of the legal situation if a driver falls asleep and crashes
while using one of the devices. This issue, while outside of our brief, needs to be
investigated.
ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Mr John O'Dempsey of AMP Auto Insurance and Mr Chris Walpole of Bayswater Wreckers for their assistance in providing the car shell which was used in this study. The staff of the Psychology Mechanical Workshop refurbished the shell magnificently. Finally our thanks to all those involved in the difficult business of transporting it into the Fatigue Laboratory.

The research could not have been undertaken without the dedication of our Research Assistants, Belinda Shen and Bruce Stevenson, who worked nightshift to run subjects for this study.

Our thanks must also go to the subjects who persevered at a boring task through the middle of the night. Mr John Doig, President of Clayton Rotaract Club, recruited many of the subjects.
REFERENCES


APPENDIX 1: HEALTH AND DRIVING HISTORY QUESTIONNAIRE

There are a number of factors (long and short term) which could affect your performance in the experiment. The purpose of this questionnaire is to identify whether you are eligible to participate in the experiment.

Health

1. What is your date of birth?
2. Are you an epileptic or have you ever had any seizures or unexplained periods of unconsciousness? YES/NO
3. Are you currently taking medication of any of the following kinds: antidepressants antihistamines (including cough preparations) sedatives or tranquilizers? YES/NO
4. Please state any other form of medication you are taking.
5. Do you smoke? YES/NO

Driving history

1. When did you obtain your driver’s licence?
2. Do you currently have a probationary licence? YES/NO
3. Approximately how many kilometres have you driven in the last year?
APPENDIX 2: INSTRUCTIONS TO SUBJECTS

A2.1 Instructions to subjects in Headnodding condition

INFORMATION FOR SUBJECTS PARTICIPATING IN LABORATORY DRIVING STUDY

Our aim is to create a laboratory driving task which will give similar results to those found in road tests but has the advantages of being safer, cheaper and more convenient.

We are interested in the visual aspect of driving, particularly in how drivers manoeuvre their vehicles in response to changes in what they see while driving.

Reaction time tests will be administered before and after the main experiment.

In the main experiment, on the screen you will be shown a film of the road. It gives a driver’s eye view of the road. You will also see a moving target superimposed on the road scene. Your task is to move the steering wheel to keep the target accurately positioned over the lane line near the centre of the screen.

You will be asked to wear special glasses or have a device attached to your glasses to record eyeblinks while you are performing the task. In addition we would like you to wear a small monitor which will sound an alarm if your head nods forward.

At the end of the experiment refreshments and transport home will be provided.
A2.2 Instructions to subjects in Roadguard condition

INFORMATION FOR SUBJECTS PARTICIPATING IN LABORATORY DRIVING STUDY

Our aim is to create a laboratory driving task which will give similar results to those found in road tests but has the advantages of being safer, cheaper and more convenient.

We are interested in the visual aspect of driving, particularly in how drivers manoeuvre their vehicles in response to changes in what they see while driving.

Reaction time tests will be administered before and after the main experiment.

In the main experiment, on the screen you will be shown a film of the road. It gives a driver's eye view of the road. You will also see a moving target superimposed on the road scene. Your task is to move the steering wheel to keep the target accurately positioned over the lane line near the centre of the screen.

A red light on the dash will come on regularly. When it does, your task is to press the footswitch as quickly as possible. If you take a long time to respond, the computer will emit a beeping sound to remind you to respond. The light and the beep only stop when a response has been made.

You will be asked to wear special glasses or have a device attached to your glasses to record eyeblinks while you are performing the task.

At the end of the experiment refreshments and transport home will be provided.
A2.3 Instructions to subjects in Onguard condition

INFORMATION FOR SUBJECTS PARTICIPATING IN LABORATORY DRIVING STUDY

Our aim is to create a laboratory driving task which will give similar results to those found in road tests but has the advantages of being safer, cheaper and more convenient.

We are interested in the visual aspect of driving, particularly in how drivers manoeuvre their vehicles in response to changes in what they see while driving.

Reaction time tests will be administered before and after the main experiment.

In the main experiment, on the screen you will be shown a film of the road. It gives a driver's eye view of the road. You will also see a moving target superimposed on the road scene. Your task is to move the steering wheel to keep the target accurately positioned over the lane line near the centre of the screen.

You will be asked to wear special glasses or have a device attached to your glasses to record eyeblinks while you are performing the task. The computer will emit a beep to alert you if it judges your eyes have been closed for an extended period of time.

At the end of the experiment refreshments and transport home will be provided.

A2.4 Instructions to subjects in Control condition

INFORMATION FOR SUBJECTS PARTICIPATING IN LABORATORY DRIVING STUDY

Our aim is to create a laboratory driving task which will give similar results to those found in road tests but has the advantages of being safer, cheaper and more convenient.

We are interested in the visual aspect of driving, particularly in how drivers manoeuvre their vehicles in response to changes in what they see while driving.

Reaction time tests will be administered before and after the main experiment.

In the main experiment, on the screen you will be shown a film of the road. It gives a driver's eye view of the road. You will also see a moving target superimposed on the road scene. Your task is to move the steering wheel to keep the target accurately positioned over the lane line near the centre of the screen.

You will be asked to wear special glasses or have a device attached to your glasses to record eyeblinks while you are performing the task.

At the end of the experiment refreshments and transport home will be provided.
APPENDIX 3: FATIGUE MONITOR QUESTIONNAIRES

HEAD-NODDING MONITOR QUESTIONNAIRE

Place a mark on each line below to indicate your response to each question.

1. How effective do you consider the head-nodding monitor would be in preventing crashes from drivers falling asleep?

   __________________________________________
   Not at all effective                       Very effective

2. How annoying (or uncomfortable) do you consider the monitor to be?

   __________________________________________
   Not at all annoying                        Very annoying

3. How willing would you be to use such a device on long trips?

   __________________________________________
   Not at all willing                         Very willing

4. How willing would you be to pay $20 to purchase such a device?

   __________________________________________
   Not at all willing                         Very willing
REACTION TIME MONITOR QUESTIONNAIRE

Place a mark on each line below to indicate your response to each question.

1. How effective do you consider the reaction time monitor would be in preventing crashes from drivers falling asleep?

Not at all effective                           Very effective

2. How annoying (or uncomfortable) do you consider the monitor to be?

Not at all annoying                           Very annoying

3. How willing would you be to use such a device on long trips?

Not at all willing                           Very willing

4. How willing would you be to pay $20 to purchase such a device?

Not at all willing                           Very willing
EYE CLOSURE MONITOR QUESTIONNAIRE

Place a mark on each line below to indicate your response to each question.

1. How effective do you consider the eye closure monitor would be in preventing crashes from drivers falling asleep?
   
   Not at all effective  Very effective

2. How annoying (or uncomfortable) do you consider the monitor to be?
   
   Not at all annoying  Very annoying

3. How willing would you be to use such a device on long trips?
   
   Not at all willing  Very willing

4. How willing would you be to pay $20 to purchase such a device?
   
   Not at all willing  Very willing
APPENDIX 4: DATA OF INDIVIDUAL SUBJECTS

Mean number of long eye closures
Note: scales differ between conditions.

LONG CLOSURES (ONGUARD)

LONG CLOSURES (HEADNOD)
Total time closed
Note: scales differ between conditions.
Tracking errors
Note: scales differ between conditions
TRACKING (ROADGUARD)

ERROR (MM)

15 MINUTE PERIOD

TRACKING (CONTROL)

ERROR (MM)

15 MINUTE PERIOD
## APPENDIX 5: CORRELATION MATRICES

### Overall

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### Onguard

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### Beadnodding

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### Roadguard

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APPENDIX 6: PERFORMANCE BEFORE AND AFTER WARNING SIGNALS

_Onguard_. Graphs showing the effects of warning signals on the performance of Subject 1 in the Onguard condition are presented in Figure 1. The diamonds represent eye closures and the line graph shows the mean tracking errors in each 30-second interval. Most graphs show more than one warning signal, in some instances within the same 30-second time period. It is possible that this pattern may not have been found if the signal was reliably heard by subjects.

Tracking errors were highly variable. The contiguity of warning signals means it is difficult to assess the effect of the signal on tracking performance.

_Head nodding_. Some examples of graphs for Subject 2 in the head nodding group are presented in Figure 2. In each graph there was at least one long eye closure in the 2.5 minutes prior to the warning signal. However, only in graphs 2 and 5 were there long eye closures in the 30 seconds prior to presentation of the warning signal. This is surprising because head nodding is commonly considered to occur while the eyes are closed.

Mean tracking errors varied greatly in most graphs. In all six graphs the error was less in the 30 seconds after the signal than in the same period before the signal but the magnitude of this effect was not large.

_Roadguard_. The graphs for Subject 3 in the Roadguard condition are presented in Figure 3. Eye closures are represented as short horizontal lines on these graphs. The tracking errors are multiplied by 10 to allow them to be more easily seen.

In several instances there were a number of long reaction times which preceded the response which initiated the warning signal (Graphs 1 and 3). There was rarely a long reaction time in the two minutes following the warning signal. This is evidence of the effectiveness of the Roadguard device in alerting the subject.

In two of the six windows portrayed in Figure 3, warning signals were presented just after long eye closures. Unfortunately there was little evidence that the warning signal led to a reduction in the length of eye closures.

There was little evidence of any improvement in tracking performance associated with presentation of warning signals.
Graph 5

Graph 6

Graph 7

Graph 8
Figure 1. Number of long eye closures and tracking error before and after presentation of warning signal by Onguard eye monitor - Subject 1.
Figure 2. Length of eye closures and tracking error before and after warning from Dozer's Alarm - Subject 2.
Graph 1

Graph 2

Graph 3
Figure 3. Length of reaction times, number of long eye closures and tracking error before and after presentation of warning signal by Roadguard device - Subject 3.