BEHAVIOURAL ADAPTATION TO FATIGUE WARNING SYSTEMS

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ABSTRACT

Driver impairment due to fatigue induced drowsiness is a significant cause of vehicle collisions. One countermeasure that is currently being implemented is Fatigue Warning Systems (FWS) to alert drivers that are drowsy. Behavioural adaptation of drivers to a FWS was evaluated in a closed track study. Thirty-two drivers completed two lengthy overnight drives, separated by one week, with half the drivers completing the second drive with an active FWS. During the drives, drivers voluntarily took breaks for as long as they liked. Behavioural results demonstrate that the FWS had no impact on objective and subjective driver fatigue, on driving time, on the number of breaks or on break duration. Results also demonstrate that 30 minute breaks are an ineffective drowsiness countermeasure . These findings suggest that a FWS as currently conceived may not contribute to reduce fatigue induced collisions.

INTRODUCTION

One important cause of single and multiple vehicle collisions is driver impairment due to drowsiness (Wierwille et al., 1994). Fatigue related impairment has been estimated to be a contributing factor in 30% to 40% of heavy truck collisions (AAA Foundation for Traffic Safety, 1985; National Transportation Safety Board, 1990) and causes approximately 6% of single vehicle roadway departure crashes (Knipling, personal communication, 1996). Drowsiness and inattention may contribute to approximately one million collisions annually in the U.S. which represent one-sixth of reported collisions (National Sleep Foundation, 1996). The incidence of driver drowsiness is underestimated in police reported crashes due to the difficulty in determining unequivocally that drowsiness was the primary cause of a specific collision. It has also been reported that 31% of drivers who experienced drowsiness were initially unaware of its onset (Skipper & Wierwille, 1986). The United States Department of Transportation and Federal Highway Administration have identified driver fatigue as a priority road safety issue.

Studies investigating the effects of driver fatigue on driving have typically implemented vehicle control and psychophysiological measures as indices of driver drowsiness. Generally, studies have found that time of day has a larger impact on driver fatigue than time on task (Brown, 1994; Gillberg, Kecklund, & Åkerstedt, 1996; Mitler, Miller, Lipsitz, Walsh & Wylie, 1997; Wylie, Shultz, Miller, Mitler, & Mackie, 1996).

Fatigue warning systems (FWS) have been proposed as specific countermeasures to reduce collisions associated with driver fatigue. These devices employ a variety of techniques for detecting driver drowsiness while operating a vehicle and signal a driver when critical drowsiness levels are reached. However, the detection of driver fatigue using valid, unobtrusive, and objective measures remains a significant challenge. Detection techniques use lane departure, steering wheel activity and ocular and facial characteristics.

Brown (1994) views fatigue as the subjective experience of tiredness combined with a disinclination to continue performing a task. He argued that countermeasures against fatigue will be successful to the extent that they correlate with the driver's subjective experiences of fatigue. This contention stands in sharp contrast to current approaches to fatigue warning systems (FWS) that attempt to develop objective measures of fatigue to warn the driver at the earliest possible moment of fatigue. Systems presently under development use vehicle control measures or video analysis of drivers' facial and ocular features. Several types of measures have been investigated that fall into three broad categories: physiological measures, vehicle control measures, and subjective driver evaluation measures. This study investigated behavioural responses to FWS. In particular, the focus was behavioural adaptation and the effectiveness of breaks in reducing drowsy driving.

Behavioural Adaptation

Assuming that the technology for detecting drowsiness can be perfected, there remains a concern that drivers may use such systems as an 'alarm clock' to keep them awake and allow them to continue driving even when extremely drowsy. There is anecdotal evidence that heavy truck drivers use unpaved shoulders in such a way (rumble strips also have a similar effect). Such unintended use of FWS is an instance of behavioural adaptation.

The Organisation for Economic Cooperation and Development (OECD, 1990) defined behavioural adaptation as follows: "Behavioural adaptations are those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change (OECD, 1990; p.23)."

The OECD report concluded that road users adapt their behaviour to changes made to the road transport system (road, vehicle and road user) to increase their mobility and thereby reduce the safety impact of the change. This phenomenon may be a widespread response to improvements in safety (Janssen, 1994; Wilde, 1994).

Research performed by the Ergonomics Division of Transport Canada has demonstrated that behavioural adaptation may diminish the benefits of Antilock Brake Systems (ABS) present in vehicles following a drivers' exposure to ABS (Grant & Smiley, 1993). A recent study by Sagberg, Fosser and Saetermo (1997) reported that taxi drivers with ABS showed significantly reduced headways. However, airbags were not found to be associated with changes in driving behaviour. Certain personality traits (e.g., sensation seeking, extroversion-introversion) may exacerbate behavioural adaptation and thereby further reduce the impact on safety for such individuals. Given that behavioural adaptation has been shown to influence the effectiveness of countermeasures, the question arises, to what extent do such effects extend to FWS. To date, no study has reported on the impact of behavioural adaptation to FWS.

The purpose of the present study was to assess the extent to which behavioural adaptation can occur in response to the FWS. It is possible that driving performance will improve in the presence of a FWS if the system decreases driver drowsiness. Behavioural adaptation was investigated by recording changes in driver performance (e.g., lane deviation, driving speed, steering wheel changes) and behaviour (e.g., number of breaks, break duration, subjective fatigue level, eye-closure frequency, objective fatigue level).

The primary behaviours of interest are the occurrence of breaks and measures of fatigue. Subjective fatigue, being a sensitive measure demonstrated to correlate with EEG and driving performance measures will also be evaluated. One group of drivers were subjected to the FWS while a second group drove without the system. It should be noted that our goal is to investigate FWS in general and not to assess the effectiveness of particular implementations of such systems. Given the limitations of current technologies to reliably detect drowsiness we have decided to use the most sensitive fatigue detector available: a human observer. The observer triggered the FWS when certain specified fatigue criteria were met.

Drowsiness Measures - Numerous measures have been used in an attempt to detect sleep onset. These include increased slow rolling eye-movements, decreases in behavioural response to stimulation, delayed response time to a vigilance task and shallow respiration (Ogilvie et al., 1985; Ogilvie et al, 1989). Ogilvie and colleagues also report that the change from wakefulness to Stage 1 sleep is associated with a significant increase in *Stanford Sleepiness Scale (SSS)* values. The SSS was developed by Hoddes et al. (1973) on sleep deprived individuals. The scale is a simple 7-point Likert rating scale designed to assess sleepiness. The physiological concomitants of sleepiness, as measured by EEG, were found to correlate with SSS scores. It may therefore be possible to use behavioural measures such as slow rolling eye-movements or fatigue scales instead of more complex EEG measures.

O'Hanlon and Kelley (1977) were able to discriminate between good and poor drivers, during a long duration nighttime driving task, using measures such as speed variability near the end of the drive, rate of large steering wheel movements (greater than 10 degrees) and lane deviation. The differences were amplified during later trip segments. Drivers' self ratings of fatigue and alertness did not reflect differences in performance, though good drivers rated their alertness higher and their fatigue lower than poor drivers. However, vehicle control measures were not as sensitive to group differences as were heart rate and EEG measures.

Riemersma et al. (1977) measured reaction time to a vigilance task, vehicle control measures and heart rate during an eight hour overnight drive. The results of the subsidiary reaction time task showed decrements in performance during the drive. Lane position variability and speed variability increased with driving time. Heart rate and heart rate variability decreased primarily in the first part of the drive. Subsidiary reaction time tasks and vehicle control measures were both sensitive to the effects of fatigue. However, the authors interpreted the decreases in heart rate and heart rate variability as being associated with habituating to driving rather than indexing increases in fatigue.

Khardi and Vallet (1994) developed a ratio derived from EEG theta activity relative to alpha activity and found it to reflect a decrease in driver vigilance. They then compared changes in the ratio to changes in steering wheel activity associated with decreased vigilance as determined with EEG criteria. The authors found that small magnitude steering wheel movements decreased in frequency while large magnitude steering wheel movement increased in frequency with drive time. The threshold derived for small magnitude steering wheel movements was between 0.5 and 2 degrees while for large magnitude steering wheel movements it was 7.2 degrees. These steering thresholds derived from EEG criteria may be useful in detecting decreased driver vigilance.

Åkerstedt and Gillberg (1990) found that subjective sleepiness was associated with increased energy levels in the alpha and theta bands of the EEG signal. The EEG changes did not appear until subjective sleepiness was considerable. Slow eye-movements were also correlated with subjective sleepiness.

Siegmund, King and colleagues (King, Siegmund & Montgomery 1994; Siegmund, King, & Mumford, 1995; Siegmund, King, & Mumford, 1996) have investigated three types of measures to determine the best measure to evaluate driver fatigue in 17 heavy truck drivers on a closed track. The physiological measures investigated were EEG and heart rate. The vehicle control measures recorded were vehicle speed and distance, steering wheel angle and angular velocity, accelerator pedal angle, accelerator pedal angular velocity and pace-vehicle following distance. The behavioural measure of drowsiness was a rating of video images using facial and ocular features, as developed by Ellsworth and Wierwille (1994). The rating scale was a five point Likert scale: Not Drowsy, Slightly Drowsy, Moderately Drowsy, Very Drowsy, and Extremely Drowsy. The correlations for interrater and test-retest reliability were both greater than 0.8.

Drivers completed a driving task under normal sleep conditions and under sleep deprivation. The authors then correlated all measures to determine which would best index fatigue related changes in driver behaviour. A positive correlation was uncovered between EEG and the subjective evaluation of drowsiness for 10 of 17 drivers tested. EEG and steering behaviour were significantly correlated for 8 of the 17 drivers. Correlation between lane keeping and EEG was stronger than correlations involving steering activity and EEG.

Heart rate correlated well, for five of 11 drivers with reliable data, with the vehicle control measures. The subjective measure of drowsiness correlated most strongly with vehicle based measures. Steering angle standard deviation and large steering reversals correlated most strongly with the subjective measure of fatigue. Lane control measures, particularly centerline deviation, also correlated quite well with the subjective measure.

The authors confirmed that since the lateral position maintenance of the vehicle inside the lane is the highest-order continuous task performed by a driver, this measure was most sensitive to driver fatigue. This is based on the view that the subjective evaluation of drowsiness was the standard measure of fatigue against which other measures would be evaluated (Siegmund et al, 1995).

Skipper, Wierwille and Hardee (1984) studied sleep deprived drivers performing a 1.5 hour driving task. They report that performance measures such as lane deviation and steering velocity were highly correlated with eyelid closures.

Skipper and Wierwille (1986) investigated several dependent measures to discriminate between drowsy and alert drivers. Measures included percent eyelid closure, low velocity steering reversals, and standard deviation of lane position. Two driving control measures were highly weighted within the discriminant function: standard deviation of low steering velocity and standard deviation of lane position. False alarms for alert drivers was approximately 37% while for drowsy drivers it was approximately 15%. In a subsequent study, Wierwille et al. (1994) found that a linear combination of an eye closure measure, two EEG measures and two heart rate measures can provide a good predictor of cognitive task performance in sleep deprived individuals.

In summary, several studies have demonstrated significant correlations between changes in vehicle control measures and physiological (EEG) and subjective indices of drowsiness. This has led to interest in developing vehicle control-based measures to assess driver drowsiness to replace more difficult to measure and interpret physiological indices of driver drowsiness. Given that no single measure emerged from the literature as an unequivocal index of drowsiness in drivers, the present study used criteria based on physiologically relevant eye-closure duration and vehicle lateral control to trigger the FWS.

Impact of Breaks On Fatigue - Drivers employ different coping strategies in dealing with drowsiness while driving. Drivers may stop, stretch or ingest coffee when they are drowsy. However, little research has been performed on the effects of break frequency and duration on driving performance. Drory (1985) studied truck operators performing a seven-hour simulated overnight driving task divided into 21 blocks of 15 minutes. In addition to driving, some drivers were required to complete a vigilance task or a voice communication task.

The design provided two rest conditions: normal rest (6 minutes following each block) representing the time it took to unload and extra rest (30 additional minutes with drivers showering and ingesting coffee following three hours of task time). Driving performance measures included reaction time to simulated brake lights, number of brake responses, and steering wheel reversals. Voice communication was associated with shorter brake reaction time and fewer steering reversals relative to driving alone. The voice task was also associated with the highest reported subjective fatigue level. The extra rest reduced subjective fatigue level but failed to significantly impact the driving performance measures. Consequently, longer breaks may not provide any additional benefits in decreasing objective indices of drowsiness.

Lisper and Eriksson (1980) reported on the effects on subsidiary reaction time performance of a 15 minute versus a 60 minute break with or without food halfway through an eight hour driving task. They found that breaks without food did not impede deterioration in performance regardless of break duration. However, eating was found to reduce deterioration in performance.

Lisper, Laurell, and van Loon (1986) investigated the time for drivers to fall asleep while driving on a closed track and the effect of breaks. On average, drivers' first bout of falling asleep occurred in the last third of a 12 hour drive. The time between the first time drivers fell asleep behind the wheel and two subsequent instances of sleep epochs averaged 24 minutes with a range covering 5 to 60 minutes. The time to falling asleep behind the wheel following a brisk walk averaged 23 minutes. Consequently, breaks did not seem to prevent the onset of sleep while driving but acted to delay sleep onset.

Recently, Nilsson, Nelson, and Carlson (1996) showed that multiple rests delayed fatigue onset to a greater extent relative to long breaks. Gillberg, Kecklund and Åkerstedt (1996) required professional drivers to complete a simulated driving task during day and night. The day drive consisted of three 30-minute task blocks. The night drive consisted of the middle driving block being replaced with a break or a nap. Mean speed was found to be higher during the day drive. Lane position varied significantly less during the day drive. Subjective and objective drowsiness was higher during night driving and increased with task time. Neither the break nor the nap was found to have any impact on drowsiness or driving performance in this limited study.

In summary, most studies have reported little benefit of breaks in reducing drowsiness levels in drivers. However, in the natural driving situation breaks are voluntary and last for as long as the driver feels is necessary. This latter type of break may be more effective in reducing driver fatigue compared to a fixed break regimen. No one to our knowledge has studied the effectiveness of self-initiated breaks.

METHOD

Drivers

Thirty two drivers (seven females and 25 males) between the ages of 17 and 38 years (median age 22 years) participated in the study. All drivers were recruited from two universities in proximity to the testing facilities and were paid a fixed sum of $150 for their time at the end of the second test session. No driver had previous experience participating in a driving study and all had a valid driver's license. Each driver participated in two sessions each on separate nights.

Experimental Design

The design was a 2X2 mixed design. Drivers were randomly assigned to one of two groups: the Fatigue Warning System (FWS) group and the Control group. The within-subjects factor was session with two levels (Baseline, Test). Generally, when no warning system was present we expected no differences in behaviour between the two groups of drivers. Also, all drivers completed the Zuckerman Sensation Seeking Scale Form V (Zuckerman, 1979). The scores on the scale vary from 0 to 40, with a high score indicating increased propensity towards sensation seeking. A median split was performed to classify drivers as high and low sensation seekers which comprised an additional nested two level factor: Trait (high and low). The median score for sensation seeking was 20 for all drivers tested. Student's t-test indicated a significant difference between high and low sensation seekers on the Zuckerman scale [$t(31)=5.77$, $p<0.001$; Means: Low=17.81, High=25.5]. See Jonah, Thiessen, and Vincent (1997) for results contrasting low and high sensation seekers.

Apparatus - A four door 1992 Cutlass Ciera was instrumented to collect and record the following parameters:

- video of driver's ocular and facial features
- vehicle speed and distance
- steering wheel angle
- vehicle lane position

A Panasonic microcamera, installed underneath the rear-view mirror, recorded changes in the driver's ocular and facial features. Two matrices of infrared LEDs were used to increase the brightness of the video images during night driving. No light was perceivable by the vehicle occupants. A speed pulse transducer installed on the rear wheel recorded vehicle speed and distance. A potentiometer encoder was mounted on the steering column to record steering wheel angular position. To record lane deviation, a Human Factors Research corporation lane tracker was mounted on the trunk of the vehicle pointed at the lane line. All signals were sampled at a rate of 10 Hz and were recorded using a laptop computer.

The FWS was operated by a 'fatigue observer' seated in the backseat of the vehicle. The fatigue observer was responsible for detecting driver drowsiness and activating a warning tone. The observer used two sources of information to determine driver drowsiness; lane position and eyelid closure based on a technique developed by Wierwille (see Wierwille & Ellsworth, 1994) and applied in real-time using the video image of the driver's facial features. Two independent criteria were used to activate the signal. A tone was presented to the driver whenever the eyelids closed for longer than two seconds. The second criteria incorporated lane tracking standard deviation. The computer was programmed to signal the fatigue observer whenever lane position standard deviation exceeded 0.45m (1.5 feet). The fatigue observer activated the FWS signal when a lane deviation signal was followed within the next minute by the driver's eyelids closing for more than one second.

Procedure

Participants were requested to complete two night driving sessions of approximately five hours, each one week apart, on a closed test track. The test track used consisted of a two-lane oval covering a distance of 6.9 km. Prior to the first (Baseline) session drivers were sent: i) a copy of the consent form to review, ii) a list of caffeinated items to avoid the day of the drive, iii) a sleep log to be completed for each of two days prior to testing.

Drivers were instructed to stay awake on the day of the session from 0700 h until the start of the drive at approximately 2200 h. and to abstain from alcohol and caffeinated items on the day of each drive. Drivers were escorted to the testing facilities by 2115 h. Upon arrival they were asked to complete the consent form, the sensation seeking scale, the Stanford Sleepiness scale, a fatigue-alertness adjective checklist and a breathalyzer test. Any driver with a blood alcohol concentration (BAC) greater than zero would have been discarded from further testing. No driver was discarded due to a non-zero BAC.

Prior to the start of the drive, drivers were informed that two passengers would be in the vehicle throughout the drive. The first was a safety observer in the passenger seat. This observer would activate a secondary brake coupled to an engine shut/off system if an unsafe situation arose. Drivers were informed that the safety observer could ask to be relieved when tired. The second was a fatigue observer, seated in the rear who started the equipment, checked data acquisition throughout the drive and activated the fatigue signal. Drivers were not informed that the observer activated the FWS.

At approximately 2200 h, the driver was instructed to enter the vehicle and adjust the seat/mirrors and prepare to complete two practice laps. Approximately 15 minutes were required to complete two practice laps. Drivers wore headphones to receive the warning signals. Drivers were informed that they could not hold a conversation with the passengers, that they could not use the radio or air conditioning. They were permitted to open the driver's side window.

Drivers were instructed on how to enter their subjective level of fatigue using a microswitch interfaced to a LED display. The digital display allowed values to be entered ranging from 0 to 99. The display automatically reset to zero three seconds after a value was entered. The value 1 represented the state that 'I can continue driving without any problems' and 99 represented 'I definitely need a break'. Drivers were instructed to enter a value every two laps and just before stopping for a break.

For the Test laps, the drivers were instructed to drive 350 km at a speed of 70 km/h. However, drivers were told that if they felt they could not complete the session they could withdraw at any time. Cones were placed at 200 m intervals along the test track just on the other side of the median lane line. Drivers were informed that the cones along the track were to be avoided and if any cone was touched a 15 minute break (i.e., penalty) would be imposed.

Immediately after the practice period, drivers were instructed to commence the drive. Depending on break frequency and duration, the experimental session took between five and six hours to complete. The duration of each session varied for each individual driver.

Drivers were informed that during the drive they were free to take as many pauses as they wished for as long as they wished but they were not permitted to nap. When drivers requested a pause, they were asked to enter their subjective fatigue level and to estimate their sleepiness with the Stanford scale. During the break, drivers were provided with juice, water, and a place to rest. Prior to the restart of the drive, drivers were instructed to enter their subjective fatigue level and to complete the Stanford scale. Drivers who terminated the drive because they felt incapable of safely continuing were asked to complete the Stanford scale within the vehicle and then debriefed.

During the practice laps prior to the start of the Test session, drivers in the FWS group were provided with the opportunity to experience the effects of a FWS. They were informed that the instrumented vehicle contained specialized equipment to detect and signal fatigue to the driver. Drivers were informed that the system assessed numerous aspects of driving performance and behaviour to detect fatigue. Drivers were instructed that the system would alert them using a tone presented through the headphones. They then received direct experience with the system. Drivers were asked to complete two practice laps around the track and at specified points during the laps were presented with the auditory signal. The control group of subjects during the test received the equivalent amount of driving practice but without the FWS. In other words, the baseline protocol was repeated.

RESULTS

Analysis

Two types of response measures were recorded during the test sessions: behavioural and primary task performance. These measures were recorded to determine the effect of driver fatigue on driving with and without a FWS and to assess the impact of behavioural adaptation to the FWS. Behavioural measures included: number of breaks, duration of breaks, the number of warning tones received by FWS drivers, reported levels of subjective fatigue, and objective fatigue levels using a modified PERCLOS method and eye-closure frequency. The PERCLOS method consisted of off-line video analysis to determine the extent of eye-closure for given periods of time. Primary task measures included: lane position, the number of cone collisions, driving speed and steering wheel changes. The present report documents only the results derived from behavioural data.

Summary Information - Tables 1 and 2 present summary data for each driver during each test session for the Control group and the FWS group respectively. Statistical tests were performed to determine if the groups differed in behaviour between sessions but within groups, and within sessions but between groups. Mixed design analysis of variance (ANOVA) tests were performed separately on the measures presented in tables 1 and 2. The ANOVAs included Group (Control, FWS) as a between-subjects factor and Session (Baseline, Test) as a within-subjects factor.

The ANOVAs for distance completed, session duration, and break duration did not uncover any significant effect of Group, Session or their interaction. The values as a function of each driver are presented in tables 1 and 2.

An ANOVA was performed on sleep duration. The ANOVA for reported sleep duration two days before a test session did uncover a significant main effect of Session [$F(1,30)=6.32$, $p<0.02$]. Drivers reported on average longer sleep duration prior to the Baseline session (8.28 hours) relative to the Test session (7.33 hours). No other effect was significant. A similar test performed on reported sleep duration one day prior to testing, uncovered a marginally significant Group by Session interaction [$F(1,30)=3.83$, $p<0.06$]. Drivers in the Control group reported significantly less sleep one day prior to the Baseline session (6.26 hours) relative to the Test session (7.09 hours). No main effects were significant. Parallel effects were not uncovered in reported quality of sleep two days and one day prior to testing. However, moderate positive Pearson correlations were found between quantity and quality of sleep within both groups (Control 2 days, $r=0.52$; 1 day, $r=0.30$; FWS 2 days, $r=0.40$; 1 day $r=0.60$). In summary, the control and FWS drivers do not differ to a large degree on the parameters presented in tables 1 and 2.

Impact of FWS and Breaks On Behaviour - Three measures were used to determine the level of drowsiness. One measure was the subjective ratings provided by the drivers themselves. The two objective drowsiness measures were derived through video analysis. These were the PERCLOS method and frequency of eye-closures. The results from these measures are presented graphically to allow for comparative evaluations in their ability to detect changes in driver drowsiness levels throughout the drive and around breaks. The control group and FWS driver data are presented in figures 1and 2.

Figure 1 presents changes in mean eye closure frequency around breaks, from seven minutes prior to the break to 12.5 minutes following the end of a break. These time values were derived by determining where most changes occurred for most drivers. Information for all breaks for all drivers were averaged for the Control and FWS drivers for the Baseline and Test sessions. For the Control group drivers (full circle and open triangle) there was a decrease in eye-closure frequency especially during the Test session which then returned within minutes to pre-break levels. For drivers in the FWS group (full square and open diamond), there was a slight decrease in eye-closure frequency following breaks. The impact of breaks on drowsiness assessed by eye-closure behaviour are minimal and highly variable.

Figure 2 presents changes in drowsiness derived through video analysis by applying the PERCLOS method. The curves show that drivers in the Control group, within both sessions, show moderate drowsiness levels and that this level decreases markedly following a break. Following the end of a break, drowsiness level increased monotonically and returned to pre-break levels after about 12.5 minutes. This result also holds for FWS drivers during the baseline session. However, the pattern of results is different for FWS drivers within the Test session. From the data in Figure 2, we see that the open diamond curve is higher than the other curves prior to the break. The FWS drivers during the test session demonstrated significantly higher levels of objective drowsiness just prior to the break relative to their baseline levels (FWS-Test vs. FWS-Baseline; $t(4)=2.96$, $p<0.04$) and relative to drivers in the control group (FWS-Test vs. Control-Test: $t(4)=2.56$, $p<0.06$; FWS-Test vs. Control-Baseline: $t(4)=3.24$,$p<0.03$).

In summary, for drivers in both groups, across both driving sessions tested, breaks had virtually no impact on drowsiness when measured by eye-closure frequency. The impact of breaks in reducing objective drowsiness level, when measured by the PERCLOS method is evident for drivers in both groups within both test sessions. Drowsiness levels were noticeably higher prior to a break for FWS drivers during the test session when measured using the PERCLOS method. The beneficial effects of breaks on drowsiness level appears to have lasted approximately 12 minutes.

The effects of the signal produced by the FWS on drowsiness levels was assessed with all measures. Within close proximity in time surrounding FWS signal presentation there were no changes in drowsiness levels in any of the subjective of objective measures of driver fatigue.

A different level of analysis of the impact of FWS on break taking behaviour and on objective and subjective measures of drowsiness is possible by studying individual behaviour patterns. As expected for the Control group of drivers, in the absence of FWS, drowsiness levels and break taking behaviour were similar within both sessions. For FWS drivers, observed behaviour within the Test session can be classified into three categories: drivers receiving no drowsiness signals, drivers receiving a moderate number of signals, and drivers receiving a high number of signals. Given this variability, only individual comparisons within each category may be possible to determine the similarities and differences in behaviour within the same experimental condition associated with similar levels of FWS frequency. Consequently, to provide the full range of behavior plots of drivers from each category will be presented.

Within the FWS group, three drivers did not receive a warning signal, although the system was active. During the test session, these drivers did not meet the necessary criteria for signal presentation. Figures 3, 4 and 5 present subjective and objective drowsiness data for three drivers who did not meet the criteria for activating the FWS during the test drive. There was a slight increase in objective drowsiness level as a function of increased drive time with breaks associated with decreased objective drowsiness levels. Early breaks were associated with smaller magnitude decreases in the PERCLOS drowsiness values while breaks taken later in the drive were associated with a larger impact on objective drowsiness. This pattern is apparently independent of the number of breaks taken.

Similarly subjective drowsiness scores exhibited a monotonic increase in drowsiness level as a function of drive time. For these drivers, breaks had only a comparatively small impact on decreasing reported drowsiness level that lasted for a few minutes.

Figures 6 to 10 show the frequency of FWS signals as a function of time as well as the PERCLOS drowsiness ratings. Blank rectangles indicate voluntary breaks while filled rectangles indicate cone hit induced breaks. In figures 6 and 7 the distribution of drowsiness signals is flat indicating that the frequency of signals does not increase with time on task. Data from the driver in figure 6 show PERCLOS scores increased early in the drive and then remained at a relatively stable level which mirrors the drowsiness signal distribution. There is a noticeable decrease in PERCLOS values following the end of each break. In figure 7, the subjective drowsiness values increased gradually throughout the drive and breaks had only a minor impact in decreasing subjective drowsiness levels. Data from a second driver are presented in figure 8 where PERCLOS drowsiness values increased in discrete steps that tend to follow the drowsiness signal pattern. From data in figure 9, there was a marked increase in subjective drowsiness level following approximately one hour of driving. This was followed by a cone hit. Subjective levels of drowsiness remained stable throughout the remainder of the drive.

Figure 10 presents objective drowsiness levels derived using PERCLOS method for subject 12. The changes in objective drowsiness level paralleled changes in the frequency of warning signals. Sudden increases in PERCLOS values were followed closely in time by either a cone-hit induced break or by a voluntary break.

In summary, voluntary breaks had only a minor effect on reducing subjective and objective levels of drowsiness in drivers during night time driving. Whatever effect there was lasted approximately 12 minutes. Analysis of individual warning signal patterns demonstrate that the FWS did not impact drowsiness levels or induce drivers to take a break. A rapid rise in objective drowsiness seen with the PERCLOS method was usually followed by a voluntary or an imposed break.

DISCUSSION

The results do not provide unequivocal evidence for behavioural adaptation to FWS. A more accurate description of the results would be that FWS signals were disregarded by almost all drivers. However, one intriguing result was that drivers in the presence of an active FWS show higher objective fatigue levels just prior to a break. Such a result is consistent with behavioral adaptation to FWS. However, FWS signals were not found to have an impact on driving time, on the propensity for drivers to take breaks, on the number of breaks taken, or on break duration. Additionally, the results demonstrate that breaks were an ineffective countermeasure in decreasing driver fatigue. Breaks had a minor impact on driver fatigue which lasted only a few minutes. However, voluntary and involuntary breaks appeared to be consistently preceded by sharp increases in objective fatigue levels assessed using the PERCLOS method. Each finding is discussed in turn below.

Warning signals were not found to impact objective and subjective fatigue levels or break taking behaviour. It should be stressed that there were large individual differences in the distribution of warning signals presented. Four drivers (a quarter of the sample) failed to meet the established criteria to receive a warning signal. Most of the remaining drivers received a moderate number of warning signals and a few drivers received both frequent and numerous warning signals. Evidently drivers demonstrated large individual differences with respect to fatigue reaction under the same driving conditions. The FWS signals failed to prevent the incidence of cone strikes. Driver number 12 struck five cones during the test with the FWS active. In this instance the driver may have used the FWS to continue driving.

Both voluntary and involuntary breaks were associated with minor decreases in objective and subjective fatigue levels. What changes there were lasted only approximately 12 minutes. This finding is consistent with results from published studies reporting the general ineffectiveness of breaks. Voluntary breaks appear to be no more effective than prescribed breaks. Consequently, it is important to inform drivers that breaks, varying in duration within the range seen in the present study, are ineffective in counteracting the effects of fatigue.

Eye-closure frequency has been used in numerous studies to objectively quantify fatigue levels. In the present study it was not found to be a reliable indicator of fatigue level changes in drivers while completing an overnight driving task on a closed track. However, objective fatigue as determined by the PERCLOS method did seem to be at least as reliable and valid as subjective measures of fatigue. Breaks were shown to be regularly preceded by sharp increases in the PERCLOS ratings. No corresponding sharp increases in subjective fatigue levels were seen. Subjective fatigue levels increased monotonically and gradually with time on task. The PERCLOS method of fatigue assessment seems to tap into changes in driver drowsiness levels that may require intervention. It is necessary to determine the mechanism underlying the different relations between subjective fatigue level and time on task and the PERCLOS method and phasic changes in driver fatigue. Is it the case that there is one absolute threshold beyond which drivers are very likely to stop? Or, is it the magnitude of the relative change from baseline that triggers the behaviour? Furthermore, does the knowledge that an FWS is active, increase the change needed to trigger a stop? Speculatively, the large individual differences reported may indicate that relative change appears to be more important than absolute level in the subjective assessment of individual driver fatigue. Consequently, what may be necessary is the development of a process to establish a baseline for each driver, and to intervene when a specified percentage change is reached. For example, values derived using The PERCLOS method may be a possible candidate measure.

Although drivers may not be consciously aware of the sharp increase in objective fatigue level, it does seem to be associated with break taking a break or striking a cone. It may therefore be superfluous to have drivers receive signals without apparent meaning, since the physiologically based changes represented by the driver's ocular and facial features seem to be more closely related to break taking behaviour. It may be necessary to render the process by which an objective assessment of fatigue is made more explicit to the driver, to make them aware sooner that they may need to stop driving. For example, if drivers can be made explicitly aware that their eyes are closing for prolonged periods of time while driving, rather than only presenting a signal, may be a necessary step in the decision process to stop driving (see Brown, 1994).

SUMMARY & CONCLUSION

In summary, the results demonstrate the ineffectiveness of FWS in changing overt driver behaviour. Drivers generally ignored the FWS signals received. The physical aspect of the warning signals used in the present study had no impact on driver fatigue levels. Voluntary rest stops, lasting on average 30 minutes, had a minor impact on decreasing driver fatigue and the effects were short lived. Therefore, voluntary breaks appear to be ineffective in substantially counteracting the effects of fatigue associated with prolonged night time driving. With respect to the dependent measures used in assessing fatigue, eye-closure frequency was not clearly associated with changes in driver fatigue levels. Subjective fatigue values were associated with tonic (e.g., slow) changes in fatigue levels, whereas values derived using the PERCLOS method were associated with phasic (e.g., quick) changes in fatigue levels. The latter fatigue assessment method seems more promising as an on-line index of critical fatigue levels in drivers requiring intervention.

Future research needs to address what mechanism induces subjects to take breaks and ignore warning signals. One hypothesis is that drivers consider the signal redundant. Also, given that drivers perceive only slight decreases in their fatigue level that last a few minutes following a break, drivers are not inclined to stop and prolong the drive (cost) for a minimal improvement (benefit) in their state. This may have been a greater factor in the present study given the presence of a safety observer. Such factors reduce the effectiveness of FWS. Given the present findings, more research into the consequences of implementing FWS in vehicles is necessary prior to their general implementation.

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REFERENCES

AAA Foundation for Traffic Safety, "A report on the determination and evaluation of fatigue in heavy truck accidents". 1985.

Åkerstedt, T., & Gillberg, M., "Subjective and objective sleepiness in the active individual". International Journal of Neuroscience. 1990, 52, 29-37.

Brown, I. D., "Driver fatigue". Ergonomics, 1994, 36, 298-314.

Drory, A., "Effects of rest and secondary task on simulated truck-driving task performance". Human Factors, 1985, 27, 201-207.

Gillberg, M., Kecklund, G., & Åkerstedt, T, "Sleepiness and performance of professional drivers in a truck simulator-comparison between day and night driving". Journal of Sleep Research, 1996, 5, 12-15.

Grant, B. A., & Smiley, A., "Driver response to antilock brakes: A demonstration of behavioural adaptation". Proceedings of the Canadian Multidisciplinary Road Safety Conference VIII, 1993, 211-220.

Hoddes, E., Zarcone, V., Smythe, H., Phillips, R., & Dement, W. C., "Quantification of sleepiness: A new approach". Psychophysiology, 1973, 10, 431-436.

Janssen, W., "Seat-belt wearing and driving behaviour: an instrumented-vehicle study". Accident Analysis and Prevention, 1994, 26, 249-261.

Jonah, B. A., Thiessen, R., & Vincent, A., "Sensation seeking, risky driving and behavioural adaptation". Proceedings of the Canadian Multidisciplinary Road Safety Conference X, 1997, 1-10.

Khardi, S. & Vallet, M., "Drowsiness of the driver: EEG and vehicle parameters interaction". Proceedings from the 14th International Technical Conference on the Enhanced Safety of Vehicles, 1994, Paper No, 94-S3-O-06.

King, D. J., Siegmund, G. P., & Montgomery, D. T., "Outfitting a Freightliner tractor for measuring driver fatigue and vehicle kinematics during closed track testing". Society for Automotive Engineers Technical Report # 942326, 1994.

Lisper, H-O, & Eriksson, B., "Effects of the length of a rest break and food intake on subsidiary reaction time performance in an 8-hour driving task". Journal of Applied Psychology, 1980, 65, 117-122.

Lisper, H-O, Laurell, H., & van Loon, J., "Relation between time to falling asleep behind the wheel on a closed track and changes in subsidiary reaction time during prolonged driving on a motorway". Ergonomics, 1986, 29, 445-453.

Mitler, M. M., Miller, J. C., Lipsitz, J. J., Walsh, J. K. & Wylie, C. D., "The sleep of long-haul truck drivers". The New England Journal of Medicine, 1997, 337, 755-761.

Nilsson, T., Nelson, T. M., & Carlson, D., "Development of fatigue symptoms during simulated driving". Proceedings of the second international conference on fatigue and transportation: engineering, enforcement and education solutions, 1996, 403-441.

OECD Scientific Expert Group, "Behavioural adaptation to changes in the road transport system". 1990, Paris: OECD.

Ogilvie, R. D., McDonagh, D. M., Stone, S. N., & Wilkinson, R. T., "Eye movements and the detection of sleep onset". Psychophysiology, 1985, 25, 81-91.

Ogilvie, R. D., Wilkinson, R. T., & Allison, S., "The detection of sleep onset: Behavioural, physiological, and subjective convergence". Sleep, 1989, 12, 458-474.

O'Hanlon, J. F., & Kelley, G. R., "Comparison of performance and physiological changes between drivers who perform well and poorly during prolonged vehicular operation". In R. M. Mackie (Ed.), Vigilance: theory, operational performance, and physiological correlates (pp. 87-109). 1977, New York: Plenum Press.

Riemersma, J. B. J., Sanders, A. F., Wildervanck, C., & Gaillard, A. W., "Performance decrement during prolonged night driving". In R. M. Mackie (Ed.), Vigilance: theory, operational performance, and physiological correlates (pp. 41-58). 1977, New York: Plenum Press.

Sagberg, F., Fosser, S., & Saetermo, I-A. F., "An investigation of behavioural adaptation to airbags and antilock brakes among taxi drivers". Accident Analysis and Prevention, 1997, 3, 293-302.

Siegmund, G. P. , King, D. J., & Mumford, D. K., "Correlation of heavy-truck driver fatigue with vehicle-based control measures". Society for Automotive Engineers Technical Report # 952594, 1995.

Siegmund, G. P., King, D. J., & Mumford, D. K., "Correlation of steering behaviour with heavy-truck driver fatigue". Society for Automotive Engineers Technical Report # *961683*, 1996.

Skipper, J. & Wierwille, W., "Drowsy driver detection using discriminant analysis". Human Factors, 1986, 28, 527-540.

Stern, J. A., Boyer, D., & Schroeder, D. J., "Blink rate as a measure of fatigue: A review". Office of Aviation Medicine, Federal Aviation Administration, Washington, D.C., Report No. DOT/FAA/AM-94/17, 1994.

Wierwille, W. W., & Ellsworth, L. A., "Evaluation of driver drowsiness by trained raters". Accident Analysis and Prevention, 1994, 26, 571-581.

Wierwille, W. W., Wreggit, S. S., Kirn, C. L., Ellsworth, L. A., & Fairbanks, R. J., "Research on vehicle-based driver Status/performance monitoring; development, validation, and refinement of algorithms for detection of driver drowsiness". Virginia Polytechnic Institute and State University, Blacksburg, VA: Department of Industrial and Systems Engineering, Report No. DOT HS 808-247, 1994.

Wilde, G. J. S., "Target risk: dealing with the danger of death, disease and damage in everyday decisions". 1994, Toronto: PDE Publications.

Wylie, C. D., Shultz, T, Miller, J. C., Mitler, M. M., & Mackie, R. R., "Commercial motor vehicle driver fatigue and alertness study". Federal Highway Administration, Report No. FHWA-MC-97-001, 1996.

Zuckerman, M., "Sensation seeking: Beyond the optimal level of arousal". 1979, Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Table1
Summary Information for Drivers in Control Group

Subject	Session	Distance Driven (km)	Test Duration (min.)	Driving Time (min.)	Hours Slept	Sleep Quality
1	Base	332.2	297.9	284.6	7.3	85
	Test	351.1	320.0	313.0	8.0	90
2	Base	331	321.2	279.6	7.0	75
	Test	344.8	356.2	288.8	7.0	90
3	Base	234.3	336.1	279.5	7.3	85
	Test	292.8	358.5	278.1	6.3	50
4	Base	350.3	297.8	275.1	3.8	60
	Test	314.5	292.3	266.0	6.8	40
5	Base	347.5	329.4	306.5	4.8	75
	Test	248.4	325.0	---	7.5	75
6	Base	262	242.3	225.8	4.5	95
	Test	296.8	278.0	258.0	7.5	90
7	Base	345.6	308.0	292.4	8.5	80
	Test	351.7	336.2	305.5	9.0	90
8	Base	344.6	304.0	304.0	6.5	90
	Test	302.7	337.3	337.3	7.3	90
	Base	344.6	285.9	285.9	7.0	70
	Test	180.2	175.0	155.0	6.3	60
10	Base	234.5	231.0	209.1	6.8	70
	Test	283	268.5	252.4	6.0	55
11	Base	344.9	328.6	298.1	7.5	95
	Test	344.9	309.4	294.8	5.0	90
12	Base	344.5	330.0	293.9	5.5	70
	Test	296.4	335.2	295.8	8.0	85
13	Base	297.9	364.0	249.3	3.3	60
	Test	352.6	353.9	301.0	6.5	80
14	Base	345.5	321.4	321.4	7.3	70
	Test	345.9	334.4	328.8	7.0	70
15	Base	350.7	335.0	315.0	6.5	95
	Test	350.8	317.0	298.4	8.0	---
16	Base	332	354.7	316.3	6.5	55
	Test	351.2	368.0	335.5	7.3	65

Note: High sensation seekers are shaded.

Table 2
Summary Information for Fatigue Warning System Group Drivers

Subject	Session	Distance Driven (km)	Test Duration (min.)	Driving Time (min.)	Hours Slept	Sleep Quality
1	Base	352	325.5	317.3	1.8	40
	Test	345.5	309.9	277.5	3.8	50
2	Base	352	317.3	304.8	7.8	65
	Test	344.8	336.5	299.1	6.3	75
3	Base	344.6	293.2	293.2	8.0	80
	Test	344.7	320.2	307.3	8.0	70
4	Base	332.3	328.3	---	7.7	85
	Test	198.7	321.6	301.7	7.3	70
5	Base	349.9	311.4	306.1	8.8	60
	Test	352.2	341.4	316.3	6.8	50
6	Base	338.9	393.0	283.9	6.8	50
	Test	226.7	288.2	193.6	6.3	70
7	Base	351.4	348.0	313.1	5.5	70
	Test	351.9	326.5	318.7	5.3	65
8	Base	342.3	332.7	310.3	8.0	95
	Test	352.2	351.7	317.5	8.0	75
9	Base	346	308.0	265.0	8.0	90
	Test	350	305.0	270.0	7.3	90
10	Base	345.2	316.3	313.5	7.3	70
	Test	345	294.2	286.2	6.8	70
11	Base	221.2	305.3	191.0	5.0	50
	Test	344.3	376.3	295.9	7.8	90
12	Base	239.9	315.1	267.0	6.3	70
	Test	303	357.5	271.9	6.5	80
13	Base	351	317.7	306.5	6.5	90
	Test	352	315.0	304.0	6.0	80
14	Base	349.5	327.5	313.6	4.5	39
	Test	347.7	336.3	309.0	5.0	45
15	Base	348.2	313.4	298.0	8.3	85
	Test	351.8	309.8	303.1	8.5	90
16	Base	311.2	335.0	297.1	11.0	70
	Test	351.4	356.7	327.1	7.8	70

Note: High sensation seekers are shaded.

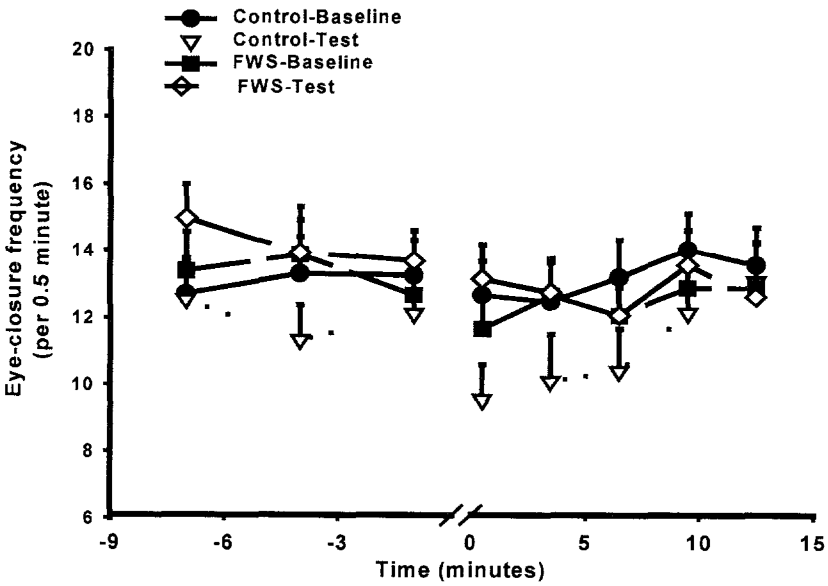

Figure 1. Mean eye-closure frequency as a function of time pre and post break for control and FWS drivers within Baseline and Test Sessions.

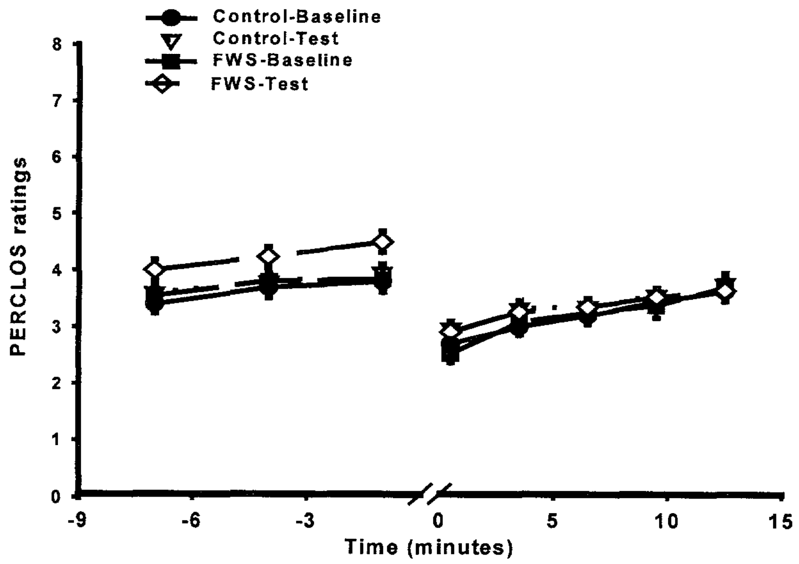

Figure 2. Mean PERCLOS ratings as a function of time pre and post break for control and FWS drivers within Baseline and Test Sessions.

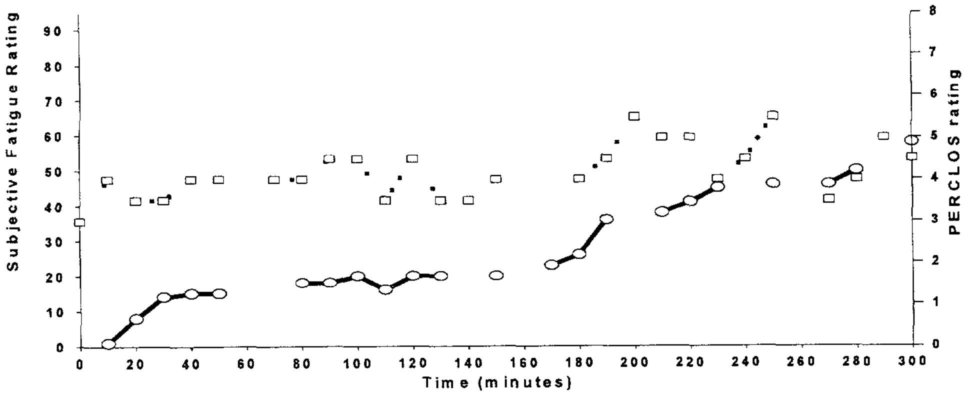

Figure 3. Fatigue ratings using PERCLOS method (dotted curve) and subjective levels (line) as a function of time on task for FWS driver #4 (Test Session).

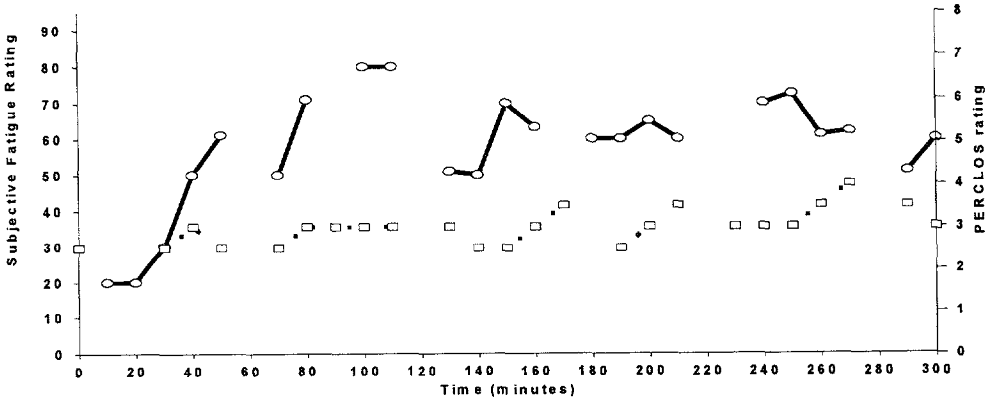

Figure 4. Fatigue ratings using PERCLOS method (dotted curve) and subjective levels (line) as a function of time on task for FWS driver #5 (Test Session).

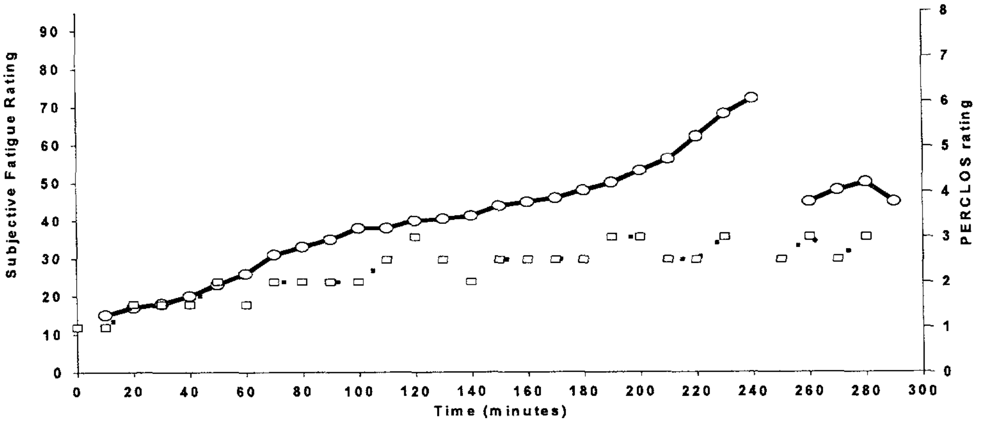

Figure 5. Fatigue ratings using PERCLOS method (dotted curve) and subjective levels (line) as a function of time on task for FWS driver #10 (Test Session).

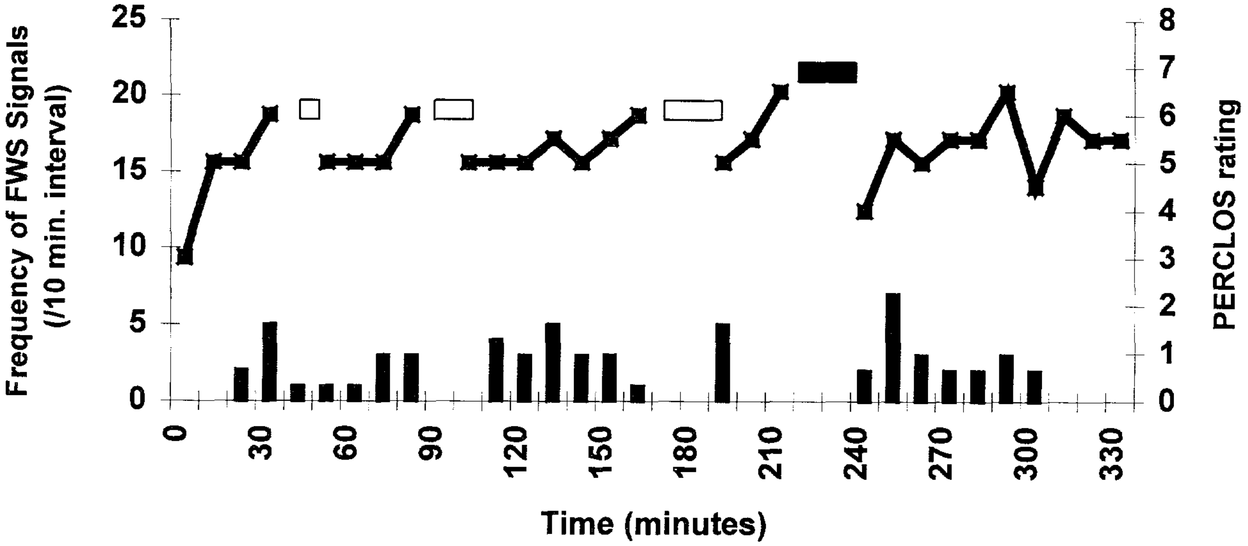

Figure 6. PERCLOS ratings (line) and frequency of FWS signals (bars) as a function of time on task for FWS driver #2 (Test Session).

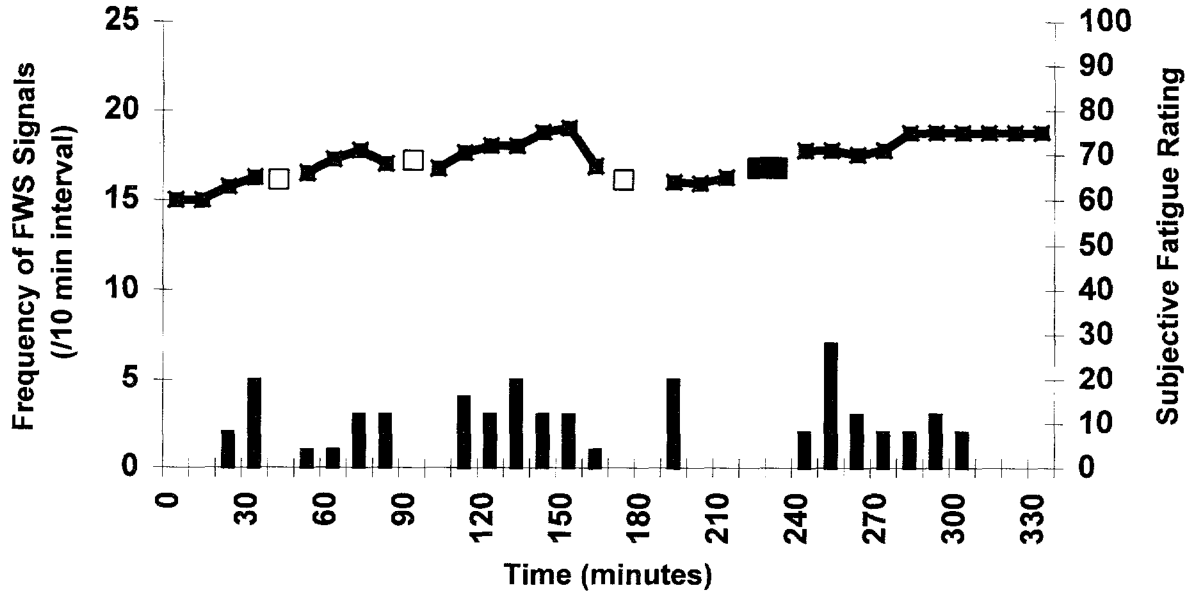

Figure 7. Subjective fatigue ratings (line) and frequency of FWS signals (bars) as a function of time on task for FWS driver #2 (Test Session).

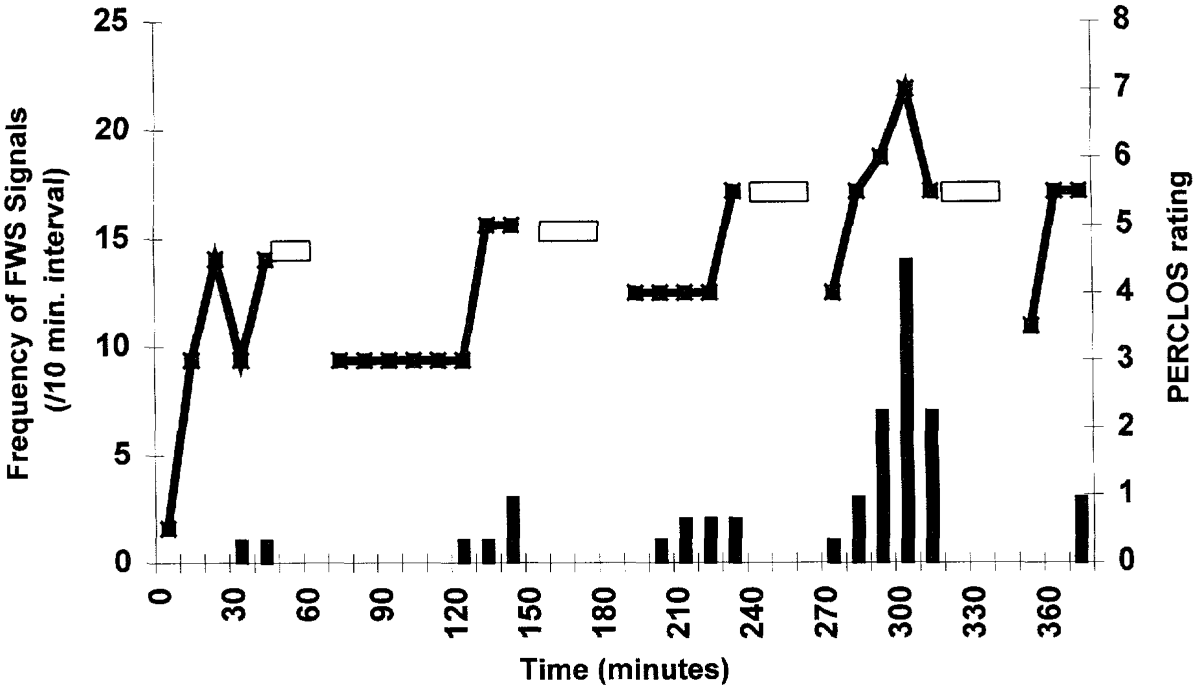

Figure 8. PERCLOS fatigue ratings (line)and frequency of FWS signals (bars) as a function of time on task for FWS driver #11 (Test Session).

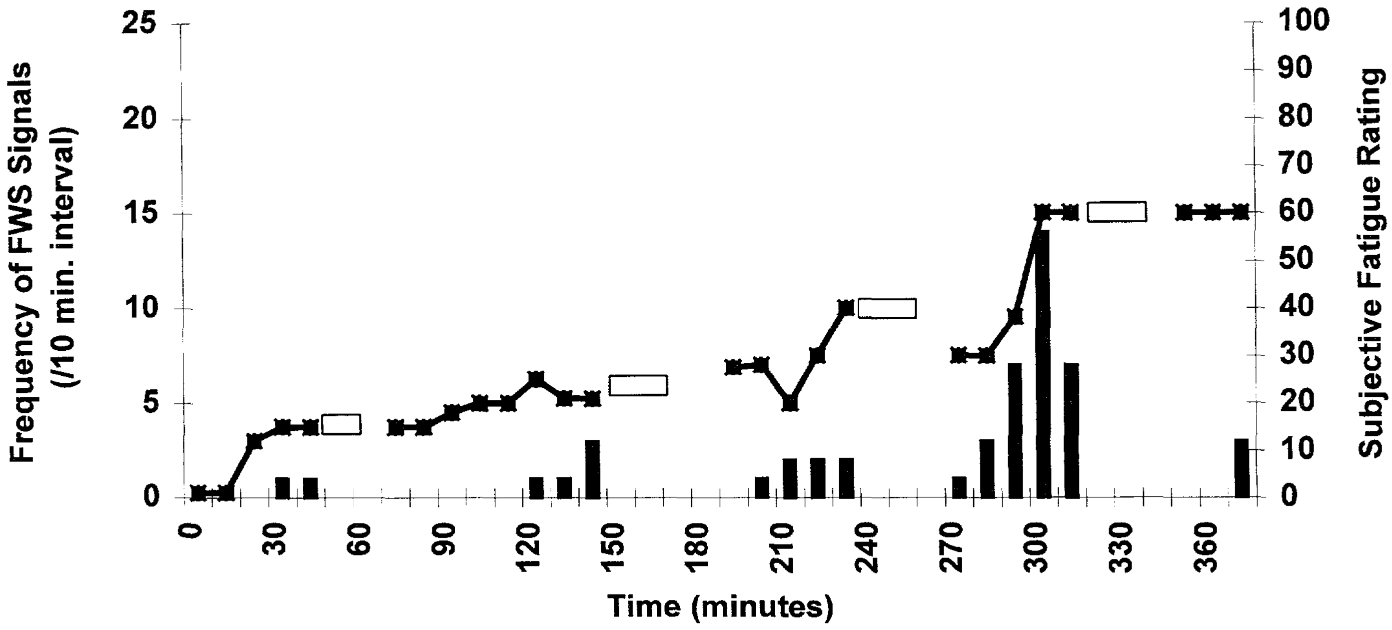

Figure 9. Subjective fatigue ratings (line) and frequency of FWS signals (bars) as a function of time on task for FWS driver #11 (Test Session).

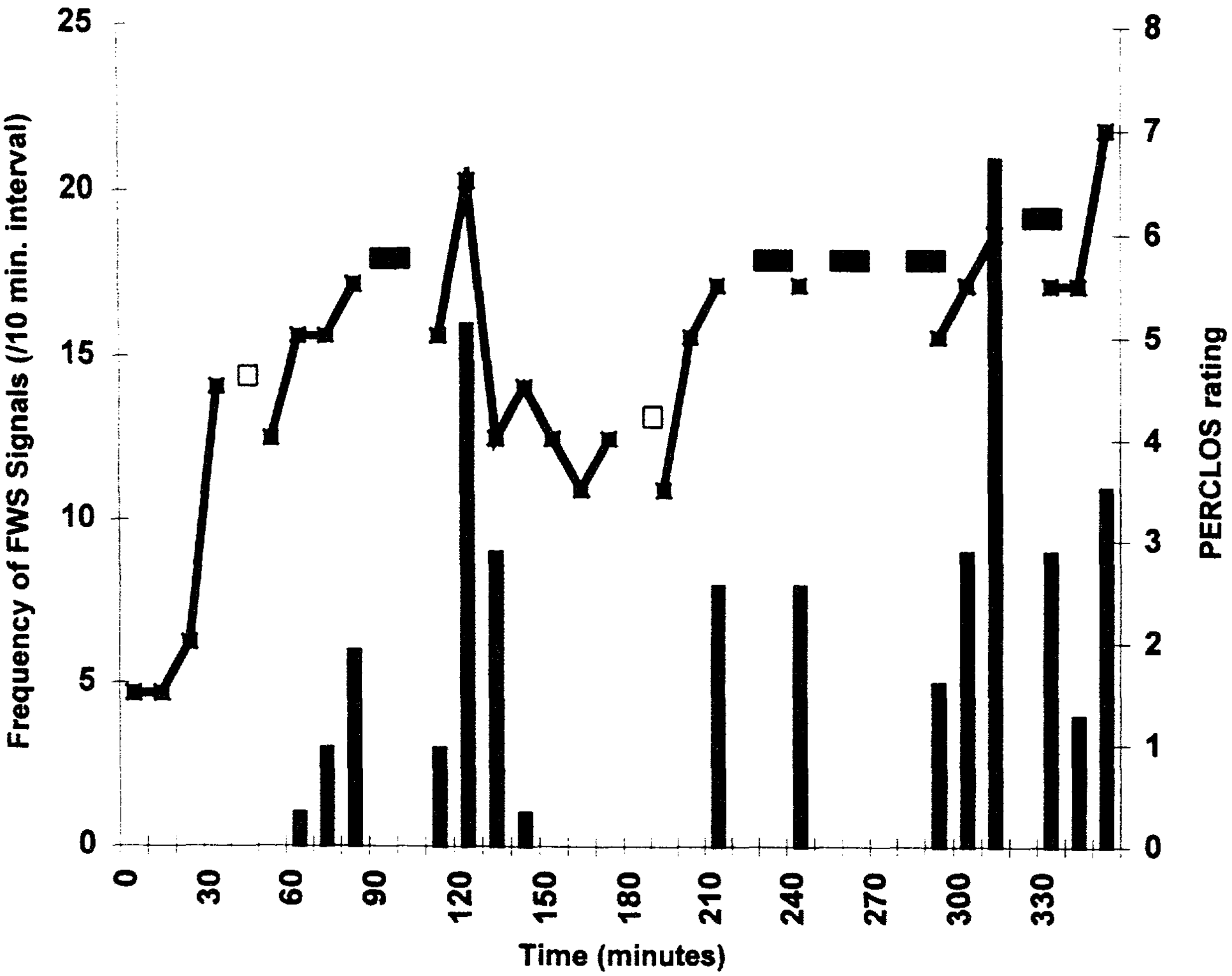

Figure 10. PERCLOS fatigue ratings (line) and frequency of FWS signals (bars) as a function of time on task for FWS driver #12 (Test Session).