Fatigue neurophysiology in professional and non-professional drivers

Saroj KL Lal and Ashley Craig
University of Technology, Health Science, Floor 14, Broadway, 2007, Sydney, NSW, Australia.

Abstract

To date, no study has investigated different phases of fatigue (transitional: early, transitional to post-transitional: medium and post-transitional: extreme) between professional and non-professional drivers. Therefore, the aim was to compare electroencephalography (EEG) changes during fatigue in twenty professional and twenty non-professional drivers during a driver simulator task. EEG delta increased during early fatigue in professionals more so than in non-professionals. Theta and alpha increased in professionals only. During medium fatigue, theta increased in both groups. Alpha increased in professional drivers in both the medium and extreme phases and in non-professionals in the extreme phase, while beta increased most in the medium phase. The results are discussed in light of driver fatigue management and developing a fatigue countermeasure device.

Introduction

Recently, the authors (Lal & Craig, 2001a, 2001b) have comprehensively reviewed the effect of driver fatigue in road safety. The review identified driver related fatigue as a significant cause of traffic accidents and an area of great socio-economic concern. A recent inquiry into managing fatigue by policing authorities identified that fatigue-related road accidents alone cost billions of dollars every year with fatigue related heavy vehicle accidents contributing to a major proportion of this cost (The Parliament of the Commonwealth of Australia, 2000). Fatigue is responsible for up to 20-30% of road fatalities (The Parliament of the Commonwealth of Australia, 2000). Recently, in a review from the International consensus meeting on fatigue and risk of traffic accidents, Åkerstedt and Haraldsson (2001) identified disturbed sleep, working at the low of the circadian rhythm and sleep apnea as some of the factors associated with fatigue related accidents. Åkerstedt and his group have pioneered some important investigations into fatigue and sleepiness and identified the detrimental consequences of shiftwork and night driving on fatigue and its effects in professional drivers (Åkerstedt, Kecklund, & Knutsson, 1991; Kecklund & Åkerstedt, 1993; Torsvall & Åkerstedt, 1987). Analyses of accident data suggest that fatigue is implicated in road accidents, particularly at night (Haworth, Heffernan, & Horne, 1989; Mackie & Miller, 1978). Professional drivers know that they endanger themselves and others when they ignore the feelings of fatigue where the natural progression will lead to falling asleep (Arnold, Hartley, Corry, Hochstadt, & Penna, 1997; Idogawa, 1991). Growing evidence suggests that professional drivers present an increasing problem for road safety (Brown, 1994; Miller & Mackie, 1980). Fatigue occurs commonly among long distance truck drivers and can provoke serious consequences for both the fatigued driver and other road users (Haworth et al., 1989; Haworth, Triggs, & Grey, 1988).

Drivers cannot maintain a high level of consciousness when they are engaged in a monotonous task and consequently can become mentally fatigued. Hence measures of brain wave activity or electroencephalography (EEG) can provide evidence for the development of fatigue and also provide a measure for levels of consciousness (Lal & Craig, 2001a, 2001b, 2001c). It follows that to understand the influence of fatigue in professional drivers, it is important to study their brain wave activity. From a review of the relevant literature, it is evident that EEG effects of fatigue are prominent in professional drivers. However, to date no studies have compared the physiological effects during fatigue in professional and non-professional drivers. Furthermore, no study has yet compared the different phases of fatigue such as transitional phase (early fatigue), transitional-post-transitional phase (medium levels) and the post-transitional phase (extreme levels) (Lal & Craig, 2001b, 2002) in these two groups of drivers. Therefore, the aim of this research was to examine the neurophysiological effects during fatigue whilst performing a driver simulator task in both professional and non-professional drivers. The research aimed to clarify any differences in physiological response to fatigue between professional drivers and non-professional drivers. In considering the human contribution to fatigue associated accidents, it seems necessary to make a distinction between professional drivers and non-professional drivers due to the differing amounts of driving times, habits and environments. This paper also explores implications of the results for the development of a fatigue countermeasure device.

Methods

Subjects

A total of forty male subjects, 20 professional truck drivers aged 44 ± 11 (mean ± SD) years and 20 non-professional drivers aged 34 ± 9 years, were randomly recruited for the study from the local community and by advertisements in the local newspaper. All subjects held a current driver's licence. Subjects, all of whom were healthy and medication free, gave written consent for the study, which was approved by the institutional ethics committee and carried out in accordance with the institution's guidelines. All the truck drivers were shift-workers and routinely drove interstate. To qualify for the study, subjects had to have no medical contraindications such as severe concomitant disease, alcoholism, drug abuse and psychological or intellectual problems likely to limit compliance with the study. This was determined during the initial interview on a separate day prior to the study.

Study protocol

The study was conducted in a temperature-controlled laboratory in which subjects performed a sensory motor driver simulator task. The driver simulator equipment consisted of a car frame with an in-built steering wheel, brakes, accelerator, gears, and speedometer with a video display (Lal & Craig, 2002). Caffeine, tea and food intake was restricted for four hours and alcohol for 24 hours before the study. The night before the study subjects reported similar sleep periods of 6 ± 1 hours in non-professional drivers and 4 ± 1 hours in professional drivers. This was not a sleep deprivation study so subjects were not sleep deprived prior to the study. Refer to Lal and Craig, 2002 for further justification and detail of the method. The study was conducted at the same time of the day (noon period) for all participants. The initial driving task consisted of 10-15 minutes of driving to familiarize the subject with the driver simulator, followed by a 5-minute break. Following this, subjects performed stage 1 (baseline) of the experimental task which constituted 10-15 minutes of 'active' driving with regular road stimuli at various speeds. This was followed by stage 2, which involved up to two hours of monotonous driving (very few road stimuli, speed < 80 km/hr) or until the subjects showed physical signs of fatigue. The 'active' Stage 1 consisted of regular road stimuli such as presence of other cars, pedestrians, road signs etc. Stage 2 did not have road signs and depicted monotonous long-distance freeway driving.

Simultaneous physiological measures were obtained during the driving task. These consisted of EEG and electro-oculogram (EOG). Nineteen channel EEG was recorded according to the International 10-20 system (Fisch, 1991). A monopolar montage was used, that is, EEG activity was recorded in relation to a linked-ear reference. Left eye EOG was obtained with electrodes (Red dot, Ag/AgCl, Health Care, Germany) positioned above and below the eye with a ground on the masseter. The EOG signal was used to identify blink artifact in the EEG data as well as changes in blink types such as the small and slow blinks that characterize fatigue. Physical signs of fatigue were identified using a video image of the driver's face, linked in real time with the physiological measures. The video analysis served as an independent variable for fatigue assessment. The study was concluded when specific fatigue signs (such as nodding, yawning, small fast blinks etc.) appeared on the video. The identification of these physical signs of fatigue from the video has been shown to have excellent reliability (Lal & Craig, 2001b, 2002).

Data acquisition and analysis

The EEG and EOG data were acquired using a 24 channel physiological monitor (Neurosearch-24, Lexicor, USA). A fast Fourier transform (FFT) was performed on the EEG data using a spectral analysis package (Exporter, Lexicor, USA). A 4-term Blackman-Harris window and a 2 Hz cut-off high-pass filter was used which significantly reduced low frequency artifact as low frequency signals are attenuated. The EEG was defined in terms of four frequency bands: delta (0-4 Hz), theta (4-8 Hz), alpha (8-13 Hz) and beta (13-20 Hz) (Fisch, 1991). For each band the average EEG magnitude (μV) was computed as an average of the nineteen channels (representative of the entire head). The EEG of drowsiness/fatigue was classified into the first appearance of transitional phase (between awake and absence of alpha, early fatigue levels), transitional to post-transitional phase (which has characteristics of both phases, medium fatigue levels) and post-transitional phase (early Stage 1 of sleep, extreme fatigue levels) followed by an arousal phase (emergence from drowsiness) (Santamaria & Chiappa, 1987). For each phase, thirty successive EEG spectra were generated using FFT which were averaged to form 30 second means to derive the EEG magnitude in the four EEG bands. Previous studies have reported reliable changes during fatigue and brain functional states from EEG data spanning 15 seconds to 1 minute (Gillberg, Kecklund & Åkerstedt, 1996; Torsvall & Åkerstedt, 1987). These phases were classified according to the simultaneous video analysis of the facial features and the EEG activity that are believed to be specific to each phase (Santamaria &Chiappa, 1987). The EEG data in the fatigue phases (Stage 2 of the driving task) was then compared to the EEG data in the alert baseline (Stage 1 of the driving task).

The statistical analysis package Statistica (for Windows, V 5.5, 1999, StatSoft, USA) was used for data analysis. A sample size calculation using the EEG changes in all frequency bands provided a statistical power ($1-\beta$) of >0.9 based upon an effect size of >0.9. A 2x5 repeated measures ANOVA (professional versus non-professional drivers by alert, transitional, transitional-post transitional, post transitional and the arousal phase) was used for each frequency band separately, to make within and between group comparisons of EEG activity in the two groups of drivers. Post hoc analyses were conducted to determine specifically where differences existed in the comparison of the means for the five phases in the two groups of drivers. The significance level was set at $p<0.05$ for all analysis performed. Results are reported as mean and standard deviation of differences.

Results

All 40 subjects (20 truck and 20 non-professional drivers) completed the study. The average time to the first visible signs of fatigue (transitional phase), identified from the simultaneous EEG and video analysis, was 66 ± 2.3 minutes in the professional drivers and after 65 ± 2.8 minutes in the non-professional drivers (not significantly different). This was usually followed by subjects entering the transitional to post-transitional and post-transitional phases of fatigue. It should be noted that the subjects moved through a number of these micro sleep cycles i.e. the different fatigue phases, until the study was terminated after approximately two hours (2 hrs ± 30 minutes) of driving. The subjects remained in each of the fatigue phases for 2-3 minutes on average.

A comparison of the EEG response in the five phases between the professional drivers and non-professional drivers using a 2 x 5 repeated measures ANOVA revealed an overall difference in the means of the two groups. The EEG magnitude in all frequency bands was significantly higher in the non-professional drivers compared to the professional drivers. The effects were: delta (F=206.8, df=9, 162, $p<0.0001$), theta (F=110.3, df=9, 162, $p<0.0001$), alpha (F=365.1, df=9, 162, $p<0.0001$) and beta (F=65.5, df=9, 162, $p<0.0001$). There was a significant interaction between group and fatigue phase ($p<0.0001$). The 2 x5 ANOVA also revealed an overall difference in the means for the five phases tested. The effects were: delta (F=206.8, df=9, 162, $p<0.0001$), theta (F=110.3, df=9, 162, $p<0.0001$), alpha (F=365.1, df=9, 162, $p<0.0001$) and beta (F=65.5, df=9, 162, $p<0.0001$). There was a significant interaction between group and fatigue phase for all of the delta, theta, alpha and beta bands ($p<0.0001$ for all).

EEG activity compared to the alert phase

Table 1 summarises the EEG response in the two groups of drivers. A repeated measures ANOVA conducted on the magnitude data revealed overall differences in EEG magnitude between the five phases tested for the two groups of drivers separately. The effects for the professional drivers were: delta (F=78.4, df=4, 72, $p<0.0001$), theta (F=135.4, df=4, 72, $p<0.0001$), alpha (F=127.4, df=4, 72, $p<0.0001$) and beta (F=84.5, df=4, 72, $p<0.0001$). The effects for the non-professional drivers were: delta (F=157, df=4, 72, $p<0.0001$), theta (F=142, df=4, 72, $p<0.0001$), alpha (F=85, df=4, 72, $p<0.0001$) and beta (F=77, df=4, 72, $p<0.0001$). The Post hoc Scheffé analyses identified where differences existed in the comparison of the means of the various phases to the alert baseline (refer to Table 1 for the change in magnitude from the alert baseline in delta, theta, alpha and beta).

Table 1 The average changes in EEG magnitude (µV) during fatigue compared to an alert baseline

EEG Band	**Transition to Fatigue**	**Transitional to post-transitional**	**Post-Transitional**	**Arousal**
Magnitude (µV)				
Delta (np)	10.1 ± 12.80*	3.7 ± 10.39*	21.1 ± 7.17*	2.6 ± 10.49*
Delta (p)	**3.8 ± 4.49****	**6.2 ± 4.94****	**6.3 ± 5.94****	**1.1 ± 4.01**
Theta (np)	3.0 ± 4.23*	0.9 ± 3.57*	3.1 ± 3.92*	-0.9 ± 3.37*
Theta (p)	**0.1 ± 1.89**	**0.9 ± 1.33****	**1.2 ± 2.16****	**-0.4 ± 1.94****
Alpha (np)	0.6 ± 1.34*	0.4 ± 1.22*	1.4 ± 1.25*	-0.6 ± 1.26*
Alpha (p)	**0.2 ± 0.67**	**1.3 ± 0.79****	**1.3 ± 0.75****	**0.1 ± 0.60**
Beta (np)	0.2 ± 0.69	0.9 ± 0.63*	0.6 ± 0.67*	-1.2 ± 0.60*
Beta (p)	**-0.1 ± 0.86**	**1.2 ± 0.84****	**0.3 ± 0.81***	**-0.1 ± 0.81**

Note:
np = the non-professional drivers are represented in normal text
p = the professional truck drivers are represented in bold
The results are reported as mean ± sd, * $p<0.05$ ** $p<0.0001$ compared to the alert baseline

EEG activity in non-professional versus professional drivers

The results of the comparison of the two groups of drivers are shown in Table 2 as the difference in EEG activity and the corresponding p values between similar phases. The largest differences between the two groups can be seen in delta activity with beta showing the smallest difference. The EEG of drowsiness (that is the slow wave activities of delta and theta) was observed to be higher in the non-professional drivers during the different fatigue states. Post hoc Scheffé tests revealed that the differences between EEG magnitudes in the two groups of drivers were significantly different for all frequency bands, except for beta activity in the transitional-post transitional and arousal phases.

Table 2 Showing differences in EEG and the corresponding p values between professional and non-professional drivers for the alert, transitional, transitional-post transitional fatigue phases and the arousal phase

EEG Band Magnitude (µV)	Alert	Transition to fatigue	Transitional to post -transitional	Post-Transitional	Arousal
Delta	12.0 ± 6.61 **<0.0001**	12.9 ± 10.83 **<0.0001**	7.3 ± 8.58 **<0.0001**	27.0 ± 10.86 **<0.0001**	10.6 ± 8.40 **<0.0001**
Theta	1.6 ± 2.62 **<0.0001**	4.2 ± 3.41 **<0.0001**	1.7 ± 2.99 **<0.0001**	3.4 ± 3.41 **<0.0001**	1.1 ± 0.7 **<0.0001**
Alpha	2.6 ± 1.07 **<0.0001**	2.9 ±1.06 **<0.0001**	1.6 ± 0.95 **<0.0001**	2.8 ± 1.02 **<0.0001**	1.7 ± 0.88 **<0.0001**
Beta	0.7 ± 0.73 **0.002**	0.9 ± 0.83 **0.000001**	0.4 ± 0.75 **ns**	1.1 ±0.71 **<0.0001**	-0.4 ± 0.63 **ns**

Note:
The differences were calculated as: (mean EEG magnitude in non-professional drivers) minus (mean EEG magnitude in professional drivers).
p values shown in bold
ns-not significant

Discussion

In the present study the physical signs of fatigue were evident very early, after approximately sixty minutes into the driving task in both groups of drivers. Other studies have also been able to demonstrate sleepiness in relatively short periods of continuous driving for 30 minutes (Gillberg et al., 1996). It may be argued that large effects cannot be expected with task duration as short as 1-2 hours. However, the observation of physical signs of fatigue in approximately one hour in the two different groups of drivers in this study, suggests only a brief time before fatigue occurs during the performance of monotonous, boring tasks such as continuous driving. This has important implications for road safety issues in truck drivers who drive long hours such as 12-14 hour journeys (Arnold et al., 1997). It should also be noted that the professional drivers reported less sleep the night before the study than the non-professional drivers. This suggests that professional drivers may regularly suffer from reduced sleep. Arnold et al. (1997) also found that unregulated truck drivers work in excess of 14 hours in typical working days and get less than 4 hours sleep in one or more of their working days in a week (Arnold et al., 1997). Although hours slept by truck drivers prior to driving cannot be a reliable estimate for adequacy of rest for every driver schedule, they may indicate possible problems for the drivers' recovery from fatigue with resultant adverse consequences. In the present study we did not control for the amount of sleep the night before the driving task, since the effects of sleep deprivation was not being investigated. The effect of monotonous driving on instigating fatigue effects was investigated.

The EEG showed consistent and reliable changes associated with driver fatigue. In the present study, the task *per se* influenced alertness, as indicated by the clear increases in EEG magnitude especially evident in slower frequencies. All drivers showed substantial increases in delta activity during fatigue resulting from driving. Smaller though significant changes also occurred in theta, alpha and beta activity. On arousal from fatigue the EEG activity observed during the alert baseline was generally restored especially for alpha and beta, which are indicative of alertness, arousal and excitement states.

There was an overall difference between the magnitude of EEG change in the truck and professional drivers. Generally, the EEG activity of drowsiness was greater in the non-professional drivers. The following discussions on EEG activity for the different bands are compared to the alert phase. It was found that delta activity increased significantly during transition to fatigue in professional and in the non-professional drivers. Theta and alpha also increased, but by a smaller degree, in the non-professional drivers. In contrast, theta and alpha activity did not change significantly in the truck drivers. However, peak increases occurred in the truck drivers and non-professional drivers in the post transitional phase. Alpha activity increased the most in truck drivers in both the transitional-post transitional phase and the post-transitional phases and in non-professional drivers in the post transitional phase. During transition to fatigue, beta did not increase at all in both groups.

Slow wave and alpha activity were found to be associated with various stages of drowsiness during the simulated driving task in both groups of drivers. Others have also shown that slow wave activity such as delta and theta has been shown to be prominent during drowsiness in adults (Santamaria & Chiappa, 1987). Deteriorated performance has also been associated with increased theta, changes in alpha and altered beta activity during fatigue (Townsend & Johnson, 1979; Wierwille & Ellsworth, 1994). Makeig and Jung (1996) also found changes in theta and alpha waves related to fatigue. In another study of drivers subjected to monotonous tasks, mean EEG activity in the theta and alpha bands increased and higher theta activity accompanied performance impairment (Horváth, Frantik, Kopriva, & Meissner, 1976). The results from the current study confirm the increases reported in the literature, reflecting the decreased cortical arousal that occurs during long monotonous tasks such as driving. The general trend was for decreased cortical processing during monotonous driving. Others have also reported lowered brain activity during monotonous work (Idogawa, 1991). Another study recorded the EEG of 11 train drivers and showed that alpha activity was clearly the most sensitive to sleepiness with delta and theta increasing by a lesser extent (Torsvall & Åkerstedt, 1987). In contrast, we found that in professional drivers delta increased the most with theta and alpha showing increases of smaller magnitude.

The non-professional drivers showed greater increases in EEG indicators of fatigue than truck drivers when compared in similar stages of fatigue. This suggests that the magnitude of fatigue as measured by EEG was stronger in the non-professional drivers who more than likely do not spend as much time on the road driving and possibly this explains why the fatigue effects were more severe when compared to the truck drivers. Others have also suggested that drowsiness occurs less in professional drivers because of their greater driving experience (Idogawa, 1991). This suggests that drivers who could endure monotonous conditions for longer periods of time with smaller changes in brain wave activity levels have an aptitude for professional driving (Idogawa, 1991). An alternative explanation could be that the truck drivers have long experience as professional drivers as well as of continuous monotonous driving. In support of this is the finding of Lisper and colleagues who reported that experienced drivers were less vulnerable to the negative influences of continuous driving compared to inexperienced non-professional drivers (Lisper, Laurell, & Stening, 1973). Generally, it is difficult to maintain alertness and to drive continuously in monotonous conditions for lengthy periods. However, professional drivers may be able to maintain a higher level of alertness for longer periods than non-professional drivers due to experience attained by spending more time driving. Furthermore, on presentation of an acoustic cue for arousal from fatigue, the truck drivers were more likely to attain the reduced delta activity observed in the initial alert levels. This indicates that professional drivers can quickly ‘snap out’ of their fatigue state and attain alert levels when presented with external alerting stimuli whilst driving. It may be argued that the truck drivers have greater experience than non-professional drivers of working in sleep deprived conditions. In support of this, other research suggests that experienced drivers (such as professional drivers) are less vulnerable to fatigue during continuous driving compared to inexperienced drivers (Lisper et al., 1973) and the results of the present research confirm this finding.

A comparison of the physiology of fatigue such as EEG in professional and non-professional drivers during monotonous driving highlights interesting and important results. The main outcome of this research has been the demonstration of a difference in brain activity between those more experienced in monotonous driving compared to those not so experienced. Non-professional drivers had greater EEG signs of fatigue compared to professional drivers during continuous monotonous driving. The current study therefore has implications for developing EEG-based fatigue countermeasures that can sense fatigue symptoms and present appropriate warnings (Lal & Craig, 2001d, 2002). Furthermore, for fatigue management programs, monitoring EEG could prove to be useful in identifying the driver’s capability for the occupation of a professional driver. Fatigue management, education and objective measures of fatigue appear to be important tools not only for experienced drivers but anyone who drives while fatigued.

Acknowledgement

We thank the National Health and Medical Research Council for Fellowship support (#169309). We also acknowledge support from the University of Technology, Sydney Internal Research Grants Scheme, 2002.

References

Åkerstedt, T., & Haraldsson, P.O. (2001). International consensus meeting on fatigue and the risk of traffic accidents. The significance of fatigue for transportation safety is underestimated. *Lakartidningen,* 98, 3014-3017.

Åkerstedt, T., Kecklund, G., & Knutsson, A. (1991). Manifest sleepiness and the spectral content of the EEG during shift work. *Sleep,* 14, 221-225.

Arnold, P.K., Hartley, L.R., Corry, A., Hochstadt, D., & Penna, F. (1997). Hours of work, and perceptions of fatigue among truck drivers. *Accident Analysis and Prevention*, 29, 471-477.

Brown, I. (1994). Driver fatigue. *Human Factors,* 36, 298-314.

Fisch, B.J. (1991). *Spehlmann's EEG Primer, Second revised and enlarged edition.* Amsterdam, The Netherlands: Elsevier Science B.V.

Gillberg, M., Kecklund, G., & Åkerstedt, T. (1996). Sleepiness and performance of professional drivers in a truck simulator- comparisons betweeen day and night driving. *Journal of Sleep Research,* 5, 12-15.

Haworth, N.L., Heffernan, C.J., & Horne, E.J. (1989). *Fatigue in truck accidents* (Rep No. 3). Australia: Victorian Road Freight Industry Council.

Haworth, N.L., Triggs, T.J., & Grey, E.M. (1988). *Driver fatigue: concepts, measurement and crash countermeasures*. Canberra, Australia: Federal Office of Road Safety.

Horváth, M., Frantik, E., Kopriva, K., & Meissner, J. (1976). EEG theta activity increase coinciding with performance decrement in a monotonous task. *Activitas Nervosa Superior (Prague),* 18, 207-210.

Idogawa, K. (1991). On the brain wave activity of professional drivers during monotonous work. *Behaviormetrika*, 30, 23-34.

Kecklund, G., & Åkerstedt, T. (1993). Sleepiness in long distance truck driving: an ambulatory EEG study of night driving. *Ergonomics,* 36, 1007-1017.

Lal, S. K. L. & Craig, A. (2001a). A critical review of the psychophysiology of driver fatigue. *Biological Psychology,* 55, 173-194.

Lal, S.K.L. & Craig, A. (2001b). Driver Fatigue: Psychological and Electroencephalography assessment. 154-160. Road Safety Research Education and Policing Conference, Australia.

Lal, S.K.L. & Craig, A. (2001c). Electroencephalography activity associated with driver fatigue: implications for a fatigue countermeasure device. *Journal of Psychophysiology*, 15, 183-189.

Lal S.K.L. & Craig A. (2001d). Towards the development of a countermeasure device to detect fatigue in drivers from electroencephalography signals. 161-165. Road Safety Research Education and Policing Conference, Australia.

Lal, S. K. L., & Craig, A. (2002). Driver fatigue: electroencephalography and psychological assessment. *Psychophysiology,* 39, 1-9.

Lisper, H.-O., Laurell, H., & Stening, G. (1973). Effects of experience of the driver on heart rate, respiration rate and subsidiary reaction time in a three hours continuous driving task. *Ergonomics,* 16: 501-506.

Makeig, S., & Jung, T. (1996). Tonic, phasic, and transient EEG correlates of auditory awareness in drowsiness. *Cognitive Brain Research,* 4, 15-25.

Mackie, R.R., & Miller, J.C. (1978). *Effects of hours of service, regularity of schedules and cargo loading on truck and bus driving fatigue* (Rep. No. 1765-F). Coleta, CA: Human Factors Research Inc.

Miller, J. C., & Mackie, R. R. (1980). Effects of irregular schedules and physical work on commercial driver fatigue and performance. In Oborne, D.J. & Levis, J.A. (Eds.), *Human factors in transport research.* (pp. 127-133). New York: Academic Press.

Santamaria, J., & Chiappa, K.H. (1987). *The EEG of drowsiness.* New York: Demos Publications.

The Parliament of the Commonwealth of Australia. (2000). *Beyond the midnight oil: an inquiry into managing fatigue in transport.* Canberra: CanPrint Communications Pty Limited.

Torsvall, L., & Åkerstedt, T. (1987). Sleepiness on the job: continuously measured EEG changes in train drivers. *Electroencephalography and clinical Neurophysiology,* 66, 502-511.

Townsend, R. E., & Johnson, L. C. (1979). Relation of frequency-analyzed EEG to monitoring behavior. *Neurophysiology,* 47, 272-279.

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