Experimental Studies of Driver Sleepiness in Young Adults

by

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ABSTRACT

The transport industries are particularly vulnerable to problems caused by sleepiness, since they are safety-critical, and involve extensive vigilance which rapidly becomes monotonous under non-stimulating conditions and following reduced or disturbed sleep. This is most clearly seen in road transport, the investigation of which has led to the now widely recognised terms 'driver sleepiness' and 'falling asleep at the wheel.' Somewhere between 10-20% of road accidents in the UK are thought to be due to sleepiness, and most are serious or fatal due to the lack of avoiding action taken by the sleepy driver. Since this sector may also involve hazardous cargoes such as chemicals (or indeed, passengers) through the involvement of haulage and coach companies, the consequences of a large scale accident could be devastating economically, environmentally and socially. The extent of the problem has been examined with *survey* data and studies of accident statistics in the UK, USA, Australia and across Europe, and is a universal one. *Experimental* work using driving simulation has examined the processes involved in falling asleep whilst driving, and attempted some evaluation of practical countermeasures beyond the popular 'Take a Break' concept used to encourage motorists to rest. Research has also examined technological countermeasures, designed to detect increasing sleepiness, before alerting the driver that it is time to stop. Motorists are slowly becoming aware that they are legally and morally responsible for ensuring that they are fully rested and not at risk from sleepiness when driving, while vehicle manufacturers continue to attempt to find failsafe warning systems. What further practical and theoretical advice can we give to drivers in order to reduce sleepiness-related accidents? Are technological countermeasures a viable alternative? Can we further predict the types of people who are most at risk by examining individual differences? This thesis outlines a series of experimental studies to investigate possible answers to these questions, and discusses the philosophy behind them.

The aim of the first experimental study (described in chapter 3.0), was to examine a fixed-base driving simulator as a tool for measuring driver sleepiness and evaluating potential countermeasures. An established laboratory protocol was replicated in a closed road circuit study, using an instrumented car to validate the simulator and determine the feasibility of the more realistic alternative. The remaining four experimental studies aimed to evaluate different countermeasures, and examine individual differences using the driving simulator. Chapter 4.0 examines the technological race, in a study investigating the effectiveness of a secondary task device designed to detect and warn of increasing sleepiness using reaction time, whereby participants responded during driving by pressing a steering-wheel mounted microswitch. Chapter 5.0 follows the practical approach, by examining the efficacy of two different doses of a 'functional energy drink' containing standard amounts (80 and 160mg) of caffeine, during a 30 minute break from driving. Chapter 6.0 assesses the extent to which we could use medical screening to identify problems before accidents occur. Using a larger

sample size, the study aimed to find a relationship between general, 'trait' sleepiness (as measured by the Epworth Sleepiness Scale) and the standard measurements of the driving simulator. As a result of continued observations throughout these experimental studies, together with the literature on accident statistics, chapter 7.0 outlines an additional study to investigate sex differences, again using a more robust sample of drivers.

The findings of the first study demonstrated the validity of the driving simulator as a tool for investigating driver sleepiness and the effectiveness of potential countermeasures. It also demonstrated the problems associated with closed road circuit testing, the most restrictive being cost, and complex logistics. The remaining studies were therefore conducted using the simulator. Secondary task reaction time as measured in chapter 4.0, proved not to be sensitive to increasing sleepiness. This was related to other such studies which have showed that RT is problematic in the context of driving, and the dynamic nature of driving means that the 'spare capacity' it measures is intermittently required by the driving task. Some of the general prospects for the technological approach to countermeasures are also discussed. Practical countermeasures seem to be more promising at this stage, and the two studies outlined in chapter 5.0 showed clear effects of the energy drink for subjective, EEG and performance measures during driving for both dosage levels. The key element of a standard amount of caffeine is discussed with regard to the implications for advice to sleepy motorists. The study described in chapter 6.0 showed a trend for some power in the method of prediction of performance from trait sleepiness although the driver sample could be altered to include those outside the normal range of the ESS to achieve more interesting findings. The potential changes in sleep problems associated with ageing could well have an effect here and some investigation of appropriate medical screening for professional drivers is discussed. Interestingly, the study outlined in chapter 7.0 showed that females were significantly more sleepy subjectively, and there was a slight trend for this to be the case for the EEG. Driving performance was also worse following sleep restriction in females than males. This is surprising since males are largely over-represented in SRVA statistics. The implications of this and other findings are discussed, and suggestions are given for improvements to the existing protocol, in order to investigate more closely the most relevant questions for future work.

There are now important issues to be investigated, relating to the process of falling asleep at the wheel, in particular drivers' awareness of and attitudes to increasing sleepiness, a key issue being *how* they decide whether or not to take a break, and *why* many drivers ignore sleepiness and continue. As we have seen recently, this has massive legal implications. Education to raise awareness, informed by research into practical countermeasures, is concluded to be more effective, and more rapidly successful than the troubled, technological approach. In particular, awareness campaigns should target male drivers, and address the importance of recognising their own limitations when driving.

KEYWORDS:

Driver Sleepiness, Accidents, Countermeasures, Performance, Driving, Individual Differences, Caffeine.

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'the flame trees will blind the weary driver'

Don Walker, 1986

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BAC	Blood-Alcohol Concentration
BMI	Body Mass Index
CPAP	Continuous Positive Airway Pressure
cm	Centimetres
Df	Degrees of Freedom
DMS	Difficulty Maintaining Sleep
EDS	Excessive Daytime Sleepiness
EEG	Electroencephalogram
EOG	Electrooculogram
ESS	Epworth Sleepiness Scale
FED	Functional Energy Drink
HGV	Heavy Goods Vehicle
Hrs	Hours
Hz	Hertz
kg	Kilograms
kΩ	Kilohms
KSS	Karolinska Sleepiness Scale
LHoFA	Likelihood of Falling Asleep (Scale)
m	Metres
mg	Milligrams
Min	Minutes
ml	Millilitres
mm	Millimetres
Mph	Miles per hour
Ms	Milliseconds
MSLT	Multiple Sleep Latency Test
OSA	Obstructive Sleep Apnoea
RT	Reaction Time
RTA	Road Traffic Accident
SRVA	Sleep Related Vehicle Accident
SSS	Stanford Sleepiness Scale
Sec	Seconds
SWS	Slow Wave Sleep
TST	Total Sleep Time

DEFINITION OF TERMS

The literature on driver sleepiness demonstrates some disparity in the terms used to define it. This can be problematic, and it is therefore necessary to clarify exactly what is meant by terms such as 'Fatigue' and 'Sleepiness' in the context of driving.

'Fatigue' as defined by Bartlett (1953) and Broadbent (1953) is: *'the deterioration which occurs in activity as a result of being engaged in that activity.'* This suggests that time-on-task is a key issue, evident in early research on 'driver fatigue.' Bartley & Chute (1947) categorised 'impairment' as the: 'physiological effects of prolonged activity,' and the 'remaining psychological effects and performance decrements' as 'fatigue.' Brown (1994) notes that the literature struggles to define what 'fatigue' actually refers to. Articles tend to concentrate on *consequence* rather than *cause*, leading to problems of interpretation. His preferred definition is stated as: *'a subjectively experienced disinclination to continue performing the task in hand because of perceived reductions in efficiency'* (Brown, 1995).

These definitions are not sufficient to cover the phenomenon described as 'driver sleepiness,' which is highly dangerous whether the driver decides to cease driving or not.

Dinges (1995) states that *sleepiness* has a 'more precise definition' than *fatigue,* which has numerous other meanings, and is avoided by sleep experts, although still used extensively in industry and by the public. Dinges uses both terms synonymously to refer to 'sleepiness resulting from the neurobiological processes regulating circadian rhythms and the drive to sleep.'

Sleepiness can be best defined as the complex transition between wakefulness and sleep, which is not straightforward and involves some overlap between the two states. This is associated with performance decrement, reductions in awareness, potential errors of judgement and displacement of reactions. Sleepiness may be caused by the circadian rhythms of sleepiness and/or the increasing drive to sleep resulting from reduced sleep length/quality.

Within the scope of this thesis I shall use the terms 'sleepiness,' and in particular, 'driver sleepiness,' to encompass these ideas, although elsewhere they may well be defined as 'driver fatigue,' (Australia), or 'drowsy driving' (USA).

SUMMARY	Cause	Consequence
Fatigue	Time on task	Feeling of tiredness, inclination to cease activity
Sleepiness	Time of day, prior sleep length/quality	Feeling of drowsiness, impairment, errors

1.0 GENERAL INTRODUCTION

Driver Sleepiness

1.1 SLEEPINESS AND ACCIDENTS

Since the late 1980s it has become well documented that several high-profile, large scale accidents have been (at least in part) caused by sleepiness. The Three Mile Island, Chernobyl and Space Shuttle Challenger accidents all involved some element of sleepiness, usually caused by long work hours, or work through the night (Mitler et al., 1988; Dinges, 1995; Harrison & Horne, 2000). These and other incidents in different industries have meant that sleepiness has slowly become an important *public safety issue*. Research has grown out of the need to guard against potential catastrophes, which could impact great social, economic and environmental costs. It is generally accepted also that since near misses and smaller scale accidents are not always recorded, or may be attributed to causes other than sleepiness, the problem may be more widespread than is obvious.

All of this is a symptom of our technological advances, reliance on automation and transition towards a 24 hour society, pushing against our physiological limitations. The 'value of time' has increased greatly and more and more people are expected to work longer hours, and more importantly, be alert and on duty at times when they would usually be asleep (Dinges, 1995).

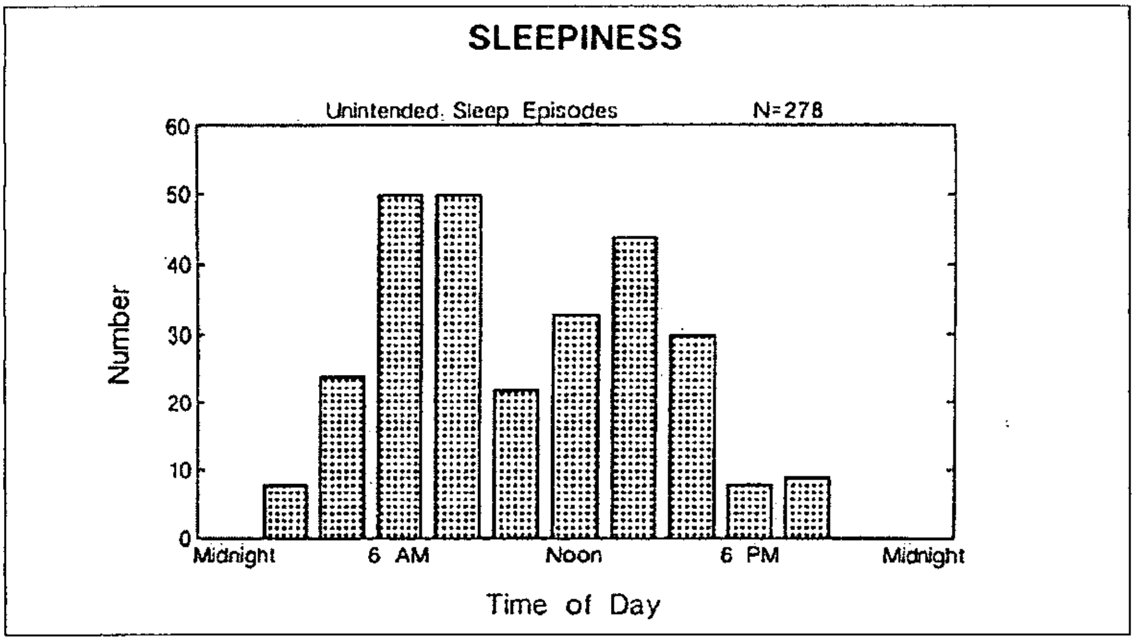

Figure 1.1

24 hour temporal distribution of unplanned sleep periods (Carskadon et al., 1985). Reproduced from Mitler et al. (1988).

Research on human circadian rhythms has shown clearly the pattern of sleepiness and alertness across the 24 hour period, as governed by the biological clock. Figure 1.1

illustrates the binomial nature of this pattern, with alertness at its highest during mid-morning and early evening, and sleepiness most noticeable in the early morning and mid-afternoon (Mitler et al., 1988). Of course, this has effects on human performance, and many studies have demonstrated the link to the 24 hour temporal distribution of *accidents* with errors more likely when we are least alert. Peaks in accidents occur early in the morning (between 0200-0600) when we are usually asleep and alertness is lowest. There is also a second, smaller peak between 1400-1600 in the early afternoon where there is a less pronounced dip in alertness (Mitler et al., 1988).

A classic example of this is a Swedish shiftwork study into the 24 hour distribution of meter reading errors over a 20 year period (see figure 1.2) in a gas works. Again, there is a major peak between 0200-0600 and a smaller peak between 1400-1600 (Bjerner et al., 1955).

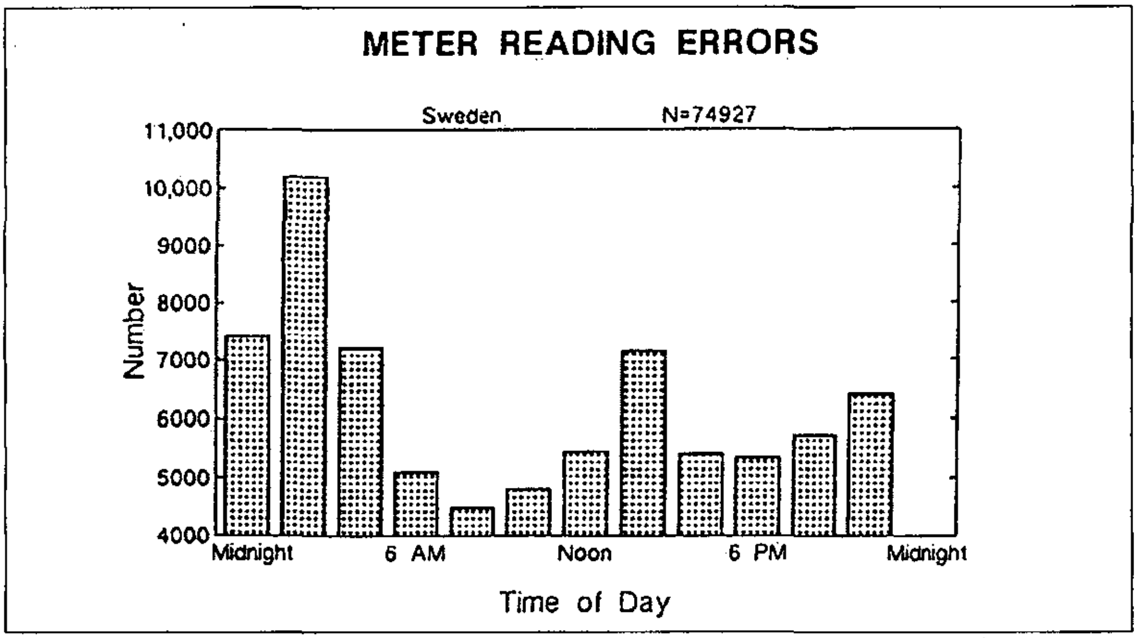

Figure 1.2
24 hour temporal distribution of work errors (Bjerner et al., 1955).
Reproduced from Mitler et al. (1988).

These studies demonstrate our susceptibility to early morning and afternoon sleepiness, and highlight the implications for performance at work.

1.2 SLEEPINESS AND TRANSPORT

This pattern has been replicated in various different areas of work, particularly for the transport industries, which seem to suffer from failing alertness at characteristic 'Black Times' (Folkard, 1997). Transport is particularly at risk due to the hazardous cargoes or large numbers of passengers which may be carried. Research has examined the incidence and role of sleepiness in accidents for rail (e.g. Edkins & Pollock, 1997), air (e.g. Gander et al., 1993; Samel et al., 1995) and maritime (e.g. Brown, 1996; Sanquist et al., 1997) areas of the transport industry. This has even been extended into space travel (Samel & Gander, 1995) as we look further to the future (the first commercial space flights are now beginning to become available).

This vulnerability to sleepiness-related accidents comes from the essentially safety-critical nature of transport, since control has moved further towards simple vigilance with the advance of technology. Automation has reduced the roles of pilots and drivers to basic monitoring, which is more vulnerable to lapses in attention of the kind characterising sleepiness. This is particularly problematic under monotonous conditions such as routine train journeys, long haul flights, or sailing for long periods in open seas. Indeed, many shipping accidents may be related to sleepiness: the oil tanker *Exxon Valdez* is noted to have grounded shortly after midnight, and the incident linked to 'work-hour induced sleepiness' (Dinges, 1995; Åkerstedt, 1995); the *Herald of Free Enterprise* sank at Zeebrugge when the Assistant Boatswain failed to close the bow doors – asleep in his cabin when the ship put to sea (Crainer, 1993); and the *Peacock* grounded on the Great Barrier Reef when the pilot fell asleep shortly before 0200 hours (MIIU, 1996). These are just a few better known examples of such accidents. Accidents in air- and rail-transport have been less apparent, but the industries *are* aware of potential problems and are addressing this internationally through the support of relevant research programs, and forums for discussion (e.g. International Conference on Fatigue in Transportation, Fremantle, Australia – 1994; 1996; 1998; 2000).

There is scope for research into sleepiness and accidents in all areas of transport, but some are much less accessible. The complex hierarchy and international nature of shipping means that while investigation of the problem is possible (Brown, 1996; Sanquist et al., 1997; Folkard, 1997; Reyner & Baulk, 1998), it is difficult to straightforwardly capture a meaningful cross-section of the industry.

Road transport is far simpler to examine. Its more defined, domestic nature enables governments to research and legislate against the problem. Driving is characterised by vigilance-type monitoring which becomes monotonous under certain conditions, and is therefore highly susceptible to sleepiness. It demands 'sustained attention' and a constant readiness to react to the changing environment (Brown, 1994). Several high profile road traffic accidents (RTAs) in the UK have been caused by sleepiness, and although this is often difficult to prove in the investigations that follow, awareness is slowly increasing. Research in the UK, USA, Australia and parts of Europe has examined the links between sleepiness and car crashes, looking at causes and consequences. 'Driver sleepiness' work has revealed many important findings, and this introduction will outline them and identify interesting areas for experimental investigation.

1.3 DRIVER SLEEPINESS

'Fatigue' is a difficult concept to define (see definition of terms, p.12), and recent research has tended to describe this area in terms of *driver sleepiness*. However, early research to examine 'driver fatigue' took a human factors approach, and at first focussed on the effects of time-on-task (Crawford, 1961; Brown, 1967; Lisper et al, 1971; Laurell & Lisper, 1976). Forty years ago, Crawford (1961) outlined the problem of 'driver fatigue,' noting these problems of definition. He discussed various potential measurements, such as EEG, muscle spikes, and secondary tasks designed to measure 'spare capacity.' These methodologies have since been tested extensively, and many are used in current experimental work. Crawford focussed on the roles of stress and emotional arousal, and provided a starting point by concluding that research was needed due to a "lack of knowledge both about driving and about fatigue" (Crawford, 1961). These ideas were developed by Brown et al. (1967) making the distinction between effects of *sleep loss* and *fatigue*. This was related to the implications for legislation on *consecutive hours of rest* rather than just *work hours,* an important issue in commercial sector research concerning truck drivers (e.g. Williamson et al., 1996; Arnold et al., 1997).

High profile accidents caused by sleepiness, and a growing awareness of potential problems have led to an ever increasing body of research in this area. In the last 10-15 years, experimental work has developed to examine the incidence, causes and consequences of what has been termed 'driver sleepiness,' 'drowsy driving' and 'falling asleep at the wheel.' New technologies in data collection and the simulation of driving scenarios have meant that more in-depth, realistic experimental work is now possible, which will continue to improve allowing even greater control and flexibility. Taking a psychophysiological approach, using methodologies from basic and clinical sleep research, and even sleep deprivation, we can examine the sleepy driver in terms of process, behaviour and countermeasures. Changes to accident investigation methods have also made possible epidemiological work using accident records to examine the incidence of crashes related to sleepiness – which would have previously have been attributed to non-specific causes such as 'driver inattention'. Research has addressed separately the issue of commercial drivers, particularly those driving heavy goods vehicles (HGVs) or trucks (Kecklund & Åkerstedt, 1993; Hartley et al., 1994; Williamson et al., 1996; Gillberg et al., 1996; Maycock, 1997; Feyer et al., 1997; Arnold et al., 1997; Häkkänen & Summala, 2000), to highlight issues of work scheduling and hours of rest. Serious sleepiness-related accidents leading to lengthy court cases have also highlighted the need for drivers to take moral and legal responsibility and ensure that they are fit (i.e.

sufficiently alert) to drive. This has been illustrated recently following the Selby Rail Crash (see Case Study below).

CASE STUDY – The Selby Rail Crash

On Wednesday 28th February 2001, the 0445 Newcastle to London Express Passenger Train crashed on the East Coast main line at Great Heck, near Selby, North Yorkshire at approximately 0612hrs. Of the 100 passengers on board, 10 were killed and over 70 injured. The train had been travelling at about 125mph, and had become derailed before colliding with an oncoming freight train travelling at 75mph and carrying 1000 tonnes of coal.

The accident was caused when Gary Hart fell asleep at the wheel and drifted off the M62. His land rover, also towing a trailer carrying another car, ran down the motorway embankment and came to a stop on the railway line.

In the resulting trial, a jury heard that Gary Hart had not slept at all the previous night, instead spending his time talking to a woman on the phone/internet. He had at first told police that he had slept for 2-3 hours. It was concluded that he fell asleep at the wheel, and he was convicted of 10 charges of death by dangerous driving. He was sentenced to 5 years in Jail in January 2002.

Gary Hart described his own life as '1000 miles per hour.' He told police that he often skipped breakfast and lunch, and went without sleep for 36 hrs. He said he was not a person who needed a lot of sleep, and regularly pushed himself to the limit.

Source: BBC News (http://www.bbc.co.uk/news)

As a result of all this, the problem is accepted as a universal one, and research on driver sleepiness is conducted internationally, focussing on several different elements:

1.4 ACCIDENT RATES: The Afternoon Peak

Studies of accident data typically involve examination of police databases (STATS 19 in the UK) to determine those attributable to sleepiness (see section 1.5) as a percentage of all RTAs, and also examine other factors such as their temporal and seasonal distribution, and the representation of different groups within the data (Reyner, Flatley & Horne, 2001).

There is some variation in estimates of the number of RTAs which are due to sleepiness. This has been as low as 1-3% in the US (Lyznicki et al., 1998), rising to 23% in the UK (Horne & Reyner, 1995), and 25% in Germany (Zulley et al., 1994) depending on the type of road.

Accidents of this type are more likely to occur on dull and monotonous roads, although recent work has also examined urban areas (Fell & Black, 1997). These data do not include near misses, or unreported accidents. Some of the lower estimates here have been attributed to a lack of training or awareness on sleepiness in investigative officers (eg. Dinges, 1995). Therefore it is safe to assume that the higher estimates (Zulley et al., 1994; Maycock, 1996) may be more realistic. In any case, the serious nature of the accidents means we must tackle all aspects of the problem.

Literature is more consistent regarding the 24 hour temporal distribution of sleepiness-related vehicle accidents (SRVAs), which follows a similar pattern to that of circadian alertness (figure 1.1), with more accidents occurring at the low points between 0200-0600 hrs and 1400-1600 hrs.

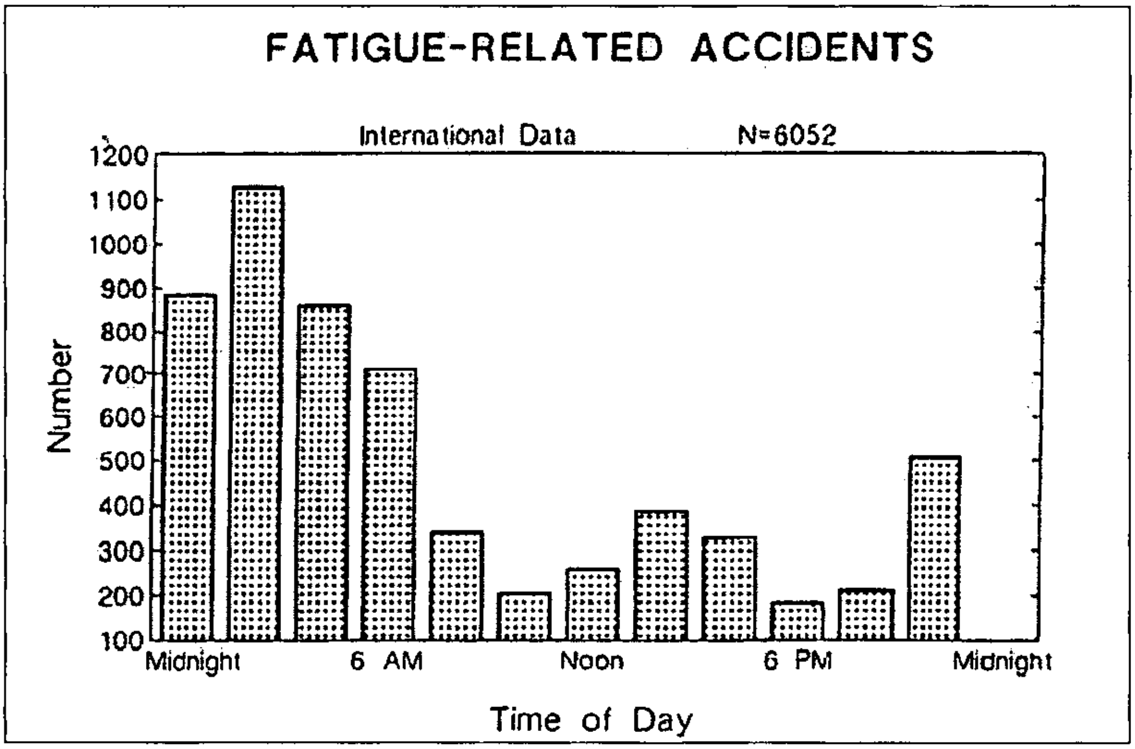

Figure 1.3

Temporal distribution of sleepiness related vehicle accidents (Mitler et al., 1988).

This pattern was noted by Mitler et al. (1988) in summation of data from Israel, Texas and New York (see fig. 1.3), and has been replicated in the UK (see fig 1.4), Israel (Zomer & Lavie, 1990), Germany (Zulley et al., 1994), Sweden (Åkerstedt et al., 1994), the USA (Pack et al., 1995), France (Philip et al., 1996), and most recently, Italy (Garbarino, 2001). Clearly, accidents tend to occur more often at peak traffic flow times (0700-0900 hrs and 1600-1800 hrs), and data has typically been adjusted for this to demonstrate the higher probability of drivers falling asleep at certain times (see figure 1.5; Garbarino, 2001; Folkard, 1997).

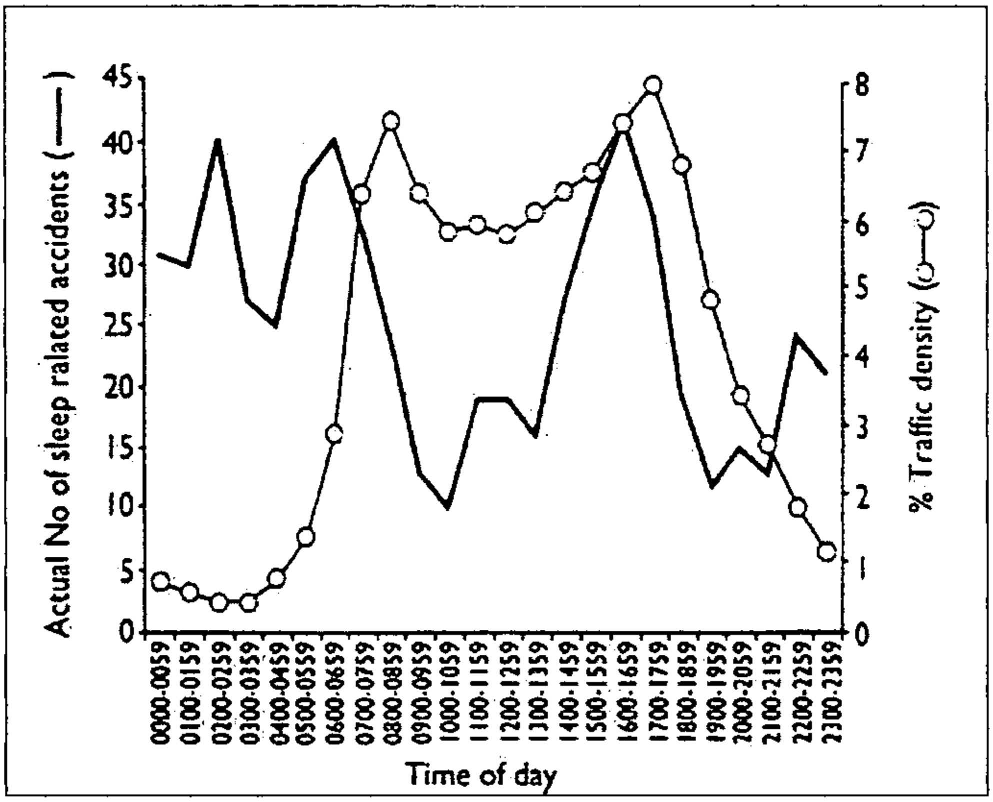

Figure 1.4
Temporal distribution of SRVAs (N=606) and hourly traffic density in Devon & Cornwall (Horne & Reyner, 1995a).

As the data shows, drivers are 10 times more likely to be involved in a SRVA at 0200 than at 1000 hrs due to the effect of the primary circadian dip in the early morning. The effects of the afternoon circadian dip in alertness can also be seen (inset graph), showing that drivers are about 3-4 times more likely to be involved in a sleepiness-related accident between about 1400 and 1600 hrs.

As these findings are slowly replicated across the Western world, awareness of the problem increases, leading us to questions of causes and countermeasures. Examination of accidents themselves is particularly important, in order to identify the processes involved for experimental examination.

1.5 CAUSES & CHARACTERISTICS

Studies of accident data show that SRVAs are typified by certain characteristics, defined in a set of criteria used by Horne & Reyner (1995a; 1995b) to identify SRVAs on motorways and trunk roads:

1. Breathalyser Alcohol levels below the legal driving limit.
2. The vehicle either ran off the road or into the back of another vehicle.
3. No signs of the brakes being applied beforehand (no skid marks).
4. No mechanical defect in the vehicle, no tyre blow-out.
5. Good weather and clear visibility.
6. Elimination of 'speeding' and 'driving too close to the vehicle in front.'
7. Police officer(s) at the scene suspected sleepiness as the prime cause.
8. For several seconds immediately prior to the accident the driver could have seen clearly the point of run-off or the vehicle hit (implying prolonged inattention).
9. The driver may or may not have admitted falling asleep.

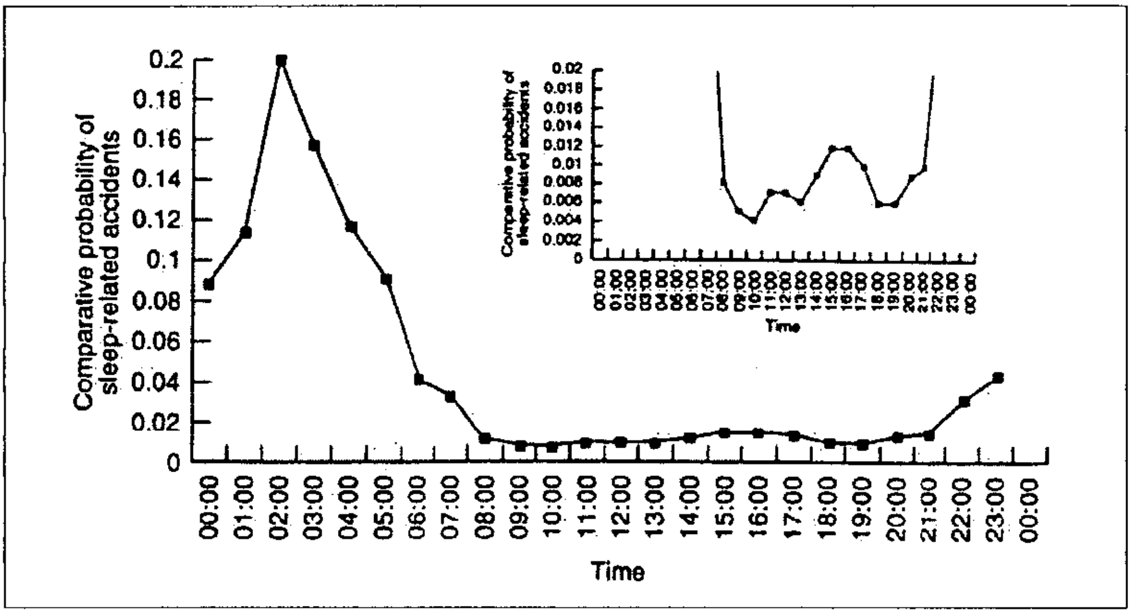

Figure 1.5

Temporal distribution of SRVA probability (Horne & Reyner, 1995b).

Insert shows detail of the afternoon circadian 'dip.'

Similar criteria have been used in other studies internationally (e.g. Pack et al.,1995; Garbarino, 2001) to replicate findings. The required absence of other causes such as alcohol or drugs when using this method, means that they may mask sleepiness if they are involved. For this reason, again, we can perhaps assume that the problem is worse than is apparent. These accidents are usually serious or fatal due to the high speed of impact and lack of avoidance manoeuvres (Zomer & Lavie, 1990; Horne & Reyner, 1995a), this being one reason why some urgency is required in raising awareness to the level achieved by campaigns on speed and alcohol as killers on the road.

The characteristics of SRVAs offer some insight into the processes involved in falling asleep at the wheel, and inform suggestions for its measurement in experimental studies. For example, driving performance measurement must encompass lane drifting (2). Similarly, an objective measure of sleepiness is required to take into account the last point (9). Experimental measures are discussed in section 1.8.

Examination of the incidence of SRVAs, as well as drivers' attitudes and experiences, has led to conclusions about the causes of driver sleepiness, and identification of groups who are particularly at risk. Circadian dips in alertness at certain times of the day, combined with driving long or monotonous journeys (such as commuting), are the main catalysts for the problem. An 'early start' in the morning - even with 8 hours sleep the night before, can still be sufficient to cause significant sleepiness and some impairment to driving performance, due to the effect of the circadian dip (Horne & Reyner, 1996). Clinical causes of sleepiness have been shown to be a factor (see section 1.7), but once identified, drivers are either treated appropriately, or prevented from driving.

Although effective in terms of accidents, and particularly in the case of fatalities, accident work may not capture the entire picture. Surveys of drivers' habits and experiences with sleepiness have also been used to illustrate the importance of non-fatal accidents and near misses, and to assess changes in awareness. Surveys are needed to capture information not covered by accident studies, and calculate accident risk from variables such as age, mileage and gender (Maycock, 1996; 1997). Young men (under 30 years) seem to be most at risk, possibly because they are more likely to be driving during the early hours, while older people are more vulnerable in the afternoon (Horne & Reyner, 1995). Although no investigative work has been conducted on accidents by occupation, it seems likely that people driving at vulnerable hours (shiftworkers, early morning commuters) or who regularly drive long hours (professional drivers, sales representatives, company car drivers) may well be at greater risk of falling asleep at the wheel. In particular, shiftworkers working through the night are at high risk if they drive home afterwards (Horne & Reyner, 1999).

These studies have generally shown that drivers do drive when sleepy, and often actively try to fight sleepiness in order to continue driving. Maycock (1996) conducted a survey of UK car drivers, wherein 29% admitted that they had felt close to falling asleep at the wheel in the previous 12 months. This compares to 55% for the same question in a US telephone survey, which also found that 26% had actually fallen asleep at the wheel in the past (McCartt et al., 1996).

1.6 INDIVIDUAL DIFFERENCES

General Trait Sleepiness

There is a body of clinical work linking sleep disorders of excessive daytime sleepiness (EDS) to SRVAs. This goes some way to explaining possible causes, and therefore directions for countermeasures. Research has examined accident risk in apnoea and narcolepsy patients, as these are the two most common clinical causes of EDS, to show that patients with obstructive sleep apnoea (OSA) had twice the incidence of RTAs compared to controls (George et al., 1987). Survey work has also examined this relationship for undiagnosed sleep problems including snoring (Hanning & Welsh, 1996; Young et al., 1997). Zomer & Lavie's (1990) survey of 3000 sleep laboratory patients in Israel used about 900 with sleep problems resulting in EDS. All were given scores on 'accident proneness' and 'excessive sleepiness,' and the two measures significantly correlated ($r=0.36$, $p<0.0001$). Hanning & Welsh (1996) used insurance company information to examine EDS, snoring, car accidents and 'near misses.' Although snorers were found more likely to experience daytime sleepiness, and also to change their driving habits because of this, there were no significant result for accident rate. Aldrich (1989) reviewed accident data in control subjects and sleep disordered patients, to find that apnoea and narcolepsy patients are more at risk of accidents, but also noted that their *awareness* of sleepiness plays a major role in accident risk.

SRVAs involving heavy goods vehicles (HGVs) have the potential to cause greatest damage, particularly if carrying hazardous substances, or if they collide with other vehicles. Truck drivers are thought to be at greater risk for sleep problems due to obesity, particularly a fat neck (Horne, 1992; Maycock, 1997), now commonly associated with respiratory sleep disorders. If it is possible to identify sleep disorders, or potential sleepiness problems using medical screening, support and guidance can be made available for those concerned. As disorders such as apnoea may well develop during middle age, could this also be used as a re-screening method to identify potential problems ? Ultimately this would encourage employers to take more responsibility for the welfare of their drivers. Methods of identifying pathological sleepiness have traditionally used the Multiple Sleep Latency Test (MSLT – Carskadon & Dement, 1982), although expensive and time-consuming. The Epworth Sleepiness Scale (see fig. 2.1) has been offered as an alternative (Johns, 1991), and could be used to predict whether certain types of people are more at risk from accidents based on general 'trait,' or situation-dependent sleepiness (Johns, 2000). This would have implications for professional drivers and those who drive for long periods on a regular basis.

Sex Differences

Although historical research noted the potential effects of the menstrual cycle on female sleep, little work has directly investigated this since then (Manber & Bootzin, 1997). Women have generally been found to complain more of sleep related problems (Bliwise, 1992), problems associated with shiftwork (Harma, 1993; 1995; Dirkx, 1991), and to have higher levels of recovery sleep following deprivation (Reynolds et al., 1986) particularly SWS (Armitage et al., 2001). There have been documented differences between the sexes also, in driving, with males perceiving less risk (DeJoy, 1992), taking more risks (Jessor, 1987), and rating offences as less serious (Brown & Copeman, 1975). Despite these differences, little research into driver sleepiness has directly addressed the issue. Although difficult to normalise data for exposure, it is generally found that males are involved in far more SRVAs than females (Åkerstedt & Kecklund, 2001; Reyner, Flatley & Horne, 2001), perhaps due to differences in attitudes or in driving behaviour, particularly when sleepy. This is a particularly interesting area for investigation, as it may be that males actually suffer more from sleepiness during driving than females, and perhaps their driving is more impaired by it. On the other hand, their awareness of sleepiness may be less than that of females.

Research Questions for the examination of individual differences:

- Are certain types of people more likely to have sleepiness related accidents ?
- What are the implications for the medical screening of professional drivers ?
- Do men and women perceive sleepiness in the same way while driving ?
- Are there differences between the sexes in performance under restricted sleep ?

1.7 EXPERIMENTAL WORK

Experimental work has used various methodologies to examine more closely the *processes* involved in falling asleep at the wheel, the *behaviour* of drivers when sleepy, and the efficacy of potential *countermeasures*. Physiological, subjective and behavioural measures have typically been combined in driving simulation, to mimic road conditions and investigate the processes of falling asleep at the wheel. Usually this has combined objective and subjective measurements of sleepiness, together with some measure of performance, ranging from acceleration and braking data, steering information and lane drifting to subsidiary tasks such as reaction time (Dureman & Boden, 1972; Horne & Reyner, 1996; Lenné et al., 1997).

Subjective Sleepiness

Subjective measures of sleepiness are used to collect data on the perceptions of participants. This is particularly important in the case of driving since it is drivers' own perceptions which help them to decide whether or not they should stop driving and take a rest. Several scale types have been used for this, but numbered scales are preferred by driving work, since they can be given verbally and recorded without disruption to driving (unlike visual analogue scales which must be marked physically). Two scales of this type used in sleep research are the Stanford Sleepiness Scale (SSS – Hoddes et al., 1973) and the Karolinska Sleepiness Scale (KSS - Åkerstedt & Gillberg, 1990). Only the latter has been validated against EEG however (Åkerstedt & Gillberg, 1990) and the SSS uses arbitrary words which may be difficult to understand, particularly when sleepy (Harrison & Horne, 2000). The SSS has also been questioned in terms of validity, since scores do not correlate with objectively measured sleep onset latency (Johns, 1991; 1998). The KSS is a 9-point scale designed to determine subjects own level of sleepiness (see fig. 2.7) and is used widely in European research. It is generally accepted that subjects should rate themselves at 5 or below on the scale while at work, since errors begin to occur at around 6 and above (Horne & Reyner, 1996; Reyner & Horne, 1998b).

Simulation-based work has showed that the KSS provides a reliable measure of sleepiness in the laboratory (Horne & Reyner, 1998). Drivers generally recognise how sleepy they are and this clearly has implications for legal issues in accidents related to sleepiness (i.e. drivers are at fault if they know they are sleepy but continue to drive). Can we be sure that the progression of subjective sleepiness shown by the KSS in the simulated driving protocol is consistent with levels in real car driving ?

Another issue for subjective sleepiness is the strength of the link between *perception* of sleepiness, and the realisation that this leads to actually falling asleep. In other words, are some individuals aware that they are sleepy, but unaware that they are likely to fall asleep at the wheel ? Are they confident that they can overcome this sleepiness and avoid accidents ? This has been investigated previously (Reyner & Horne, 1998a), but the effect of intervention on the relationship is unknown. The Likelihood of Falling Asleep scale has been used to examine disparities here (see fig. 2.8). It may be interesting to see the pattern of increasing subjective sleepiness in control trials, and if there are any clear changes to this caused by interventions. That is, what are the effects of potential countermeasures on drivers expectancy to actually fall asleep, in addition to their feelings of sleepiness ? This is an interesting issue since it seems many drivers are aware of sleepiness yet they continue to drive.

Although shown to be reliable, subjective methods do not always reflect the complete picture. Drivers may feel over-confident or euphoric when sleepy, or fail to realise how close they are to falling asleep. Therefore a physiological measure may be used to support subjective data and illustrate the effects on the brain.

Electroencephalography

Electroencephalography (EEG) involves the measurement of brainwaves using silver-coated electrodes attached to the scalp, to measure changes in electrical potential. Crawford (1961) identified EEG as a possible physiological measurement in future studies of 'driver fatigue.' Technology has advanced greatly since then, with EEG measurement (and more importantly, analysis), becoming much simpler. While more traditional equipment was able to accurately record EEG, this typically involved paper printouts and manual scoring (Rechtschaffen & Kales, 1968). Modern equipment stores data in paperless electronic systems, using complex software to run spectral analysis and automatic sleep staging. Readings are usually taken at several locations to monitor potentials from different areas of the brain, allowing the breakdown and definition of stages during sleep, the measurement of sleep onset/offset latency, and the identification of different waking states. EEG is a good method for assessing experimental effect in a laboratory environment, and can tell us many things about the state of the brain, in terms of AMPLITUDE (the voltage between the highest and lowest points of a wave, measured in microvolts – uV), and FREQUENCY (the number of cycles per second, expressed as hertz - Hz). The effective range in the human brain is about 0.5-25 Hz, with specific wave-types identifiable in separate frequency bands:

BETA - 15 Hz +, fast waves of low amplitude (<10 uV) occurring when alert/anxious.
ALPHA - 8 - 13 Hz, typical of relaxed wakefulness/when there is little visual input.
THETA - 3.5 - 7.5 Hz, reflecting drowsiness and light sleep.
DELTA - <3.5 Hz, slow waves with the lowest frequency, occurring in deep sleep.

Clearly, delta EEG is not important in measuring driver sleepiness, as it is impossible to continue driving for long enough to reach these stages of sleep without crashing. Rather we are interested in the transitional state from wakefulness to light sleep, typified by increasing slow alpha (8-11 Hz) and then theta (4-7 Hz) activity (see figure 1.6). Some subjects display alpha surges, others show little alpha but much theta (c.f. Kecklund & Åkerstedt, 1993; Rechtschaffen & Kales, 1968). We are therefore interested primarily in alpha and theta activity (4-11Hz), to reflect increasing sleepiness, as well as slow eye movements which also signify increasing drowsiness.

Although the addition of a physiological measure means we can see what is happening in the brain during driving, there are several limitations: the lengthy preparation procedure (skin cleaning etc.) means that subjects are waiting for 20-30 minutes prior to the test drive; complex equipment is required to output the channels online; electrodes can be pulled off accidentally; electrodes can be uncomfortable and intrude on the real life of subjects. EEG is much easier to measure in the driving simulator scenario, as amplifiers and computers can be used to process data and produce a simple visual output. Ambulatory recording (as would be required in closed road-circuit or road testing) requires setting up prior to the start of the experiment, some kind of synchronisation with the start of the drive, and data is collected 'blind,' i.e. the experimenter has no reassurance that data is being successfully collected until it is downloaded later.

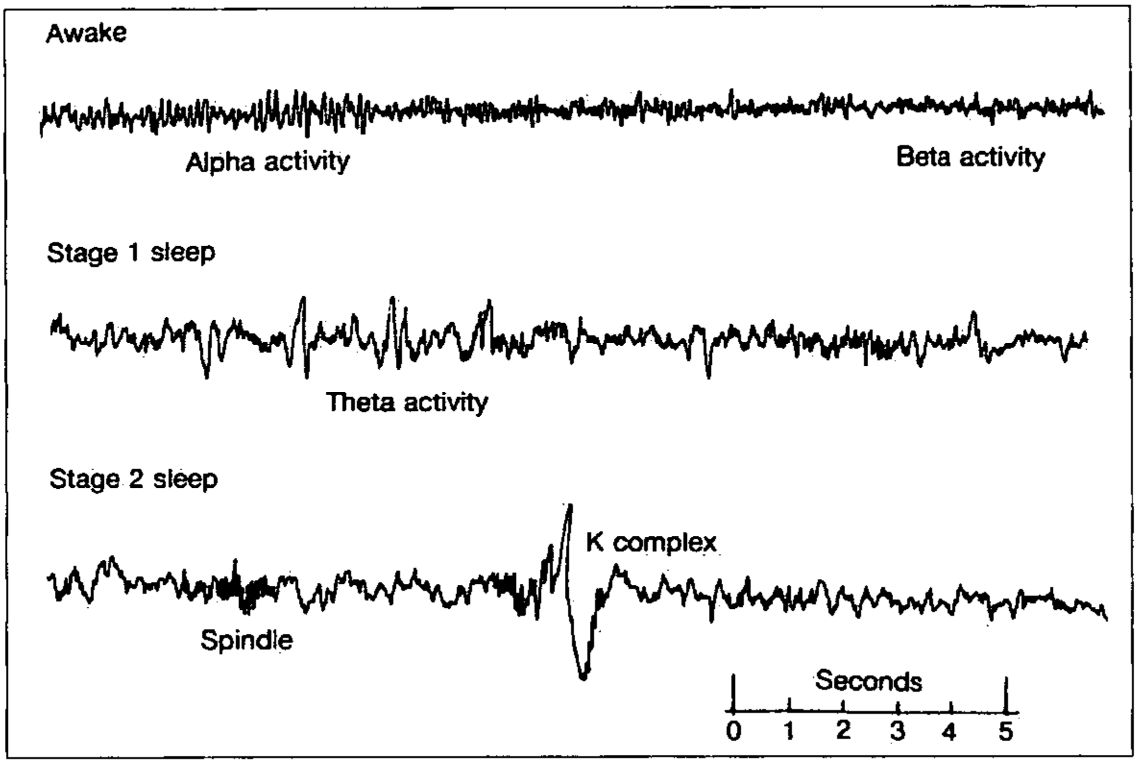

Figure 1.6
Examples of EEG activity, showing wakefulness as well as stages 1 and 2 sleep (reproduced from Horne, 1988)

Driving Performance

The third measurement that is necessary is driving performance, as we need to know how the sleepy driver is affected on the road. This has been measured using a variety of variables including acceleration, braking, following distance, response to another vehicle, ability to maintain a constant speed (Regina et al., 1974), and ability to maintain lateral road position (Summala et al., 1999). Since crashes related to sleepiness are characterised by drivers drifting off the road or into another lane of traffic (Pack et al., 1995; Garbarino, 2001), it seems sensible to use *lane drifting* as the primary measure of driving performance, while accepting that braking, acceleration and other elements may also be negatively affected by sleepiness. Work using an interactive, fixed base driving simulator (eg. Horne & Reyner, 1996; 2001a; Reyner & Horne, 1997; 1998a; 1998b; 2000) has used lane drifting in the measurement of driving performance by manually scoring video data. This would seem a reasonable measure of good or bad driving performance, but it remains to be seen whether this holds up against a real car, as the low stimulus characteristics of the simulated roadway may well create more driving 'incidents' due to its monotonous nature causing drivers to perform worse.

In addition to the measures described above, it may be interesting to measure driving speed. There is some evidence to suggest that drivers relax more when becoming sleepy, and therefore drive more slowly. More importantly, this slowing down could also be due to an increased awareness of sleepiness, drivers actually slowing down to avoid making errors if they know they are sleepy. This is a very important issue since active physical changes to driver behaviour denote this awareness from which follows liability in the event of an accident.

However, the setup of the simulator does make this problematic, since speed is not an easily controllable element for the driver. The simulator does not feature a speedometer, and the only feedback on speed to the driver is the visual graphical display of the moving road. While drivers are free to drive at a comfortable speed, this may mean that without the risk of real injury, realism is lost, and participants will drive at a maximum speed – creating a 'ceiling effect' in the speed data. While this would still to some extent be sufficient to show us some deceleration as a result of increasing sleepiness, any upward variation would be lost.

Research Questions for the evaluation of research methodologies:

- How can we best measure driver sleepiness in the laboratory ?
- Are simulator based findings reliable, valid and applicable to the real world ?
- What is the relationship between subjective sleepiness and driving performance ?

As well as extensive examination of the processes and behaviours involved in falling asleep at the wheel, experimental work has investigated potential countermeasures to driver sleepiness which have been suggested by drivers, motoring organisations and inventors. These fall into several categories, defined differently by various researchers. Education, legislation and environmental methods are all very important in tackling the problem efficiently, through information on the causes, consequences and practical countermeasures, intelligent scheduling, rest breaks for professional drivers, and provision of adequate environmental measures such as rumble strips and suitable rest facilities (Stutts, 2000). It is beyond the scope of this thesis to fully investigate them all. The main focus of experimental work has been on *practical* and *technological* countermeasures:

1.8 PRACTICAL COUNTERMEASURES

The most effective countermeasure to sleepiness is sleep (Horne & Reyner, 1999). Drivers are advised to stop driving as soon as sleepiness becomes apparent, and not to continue with their journeys until they have had adequate sleep to do so safely. However, many drivers persist, the motivation to continue augmented by 'trip momentum,' the desire/need to be somewhere or even work related goals (Fell & Black, 1997). Despite being advised to stop, motorists will push on and drive to their limits, using advice given by motoring organisations, or simply inventing their own methods of fighting sleepiness.

A survey of 4600 UK drivers outlined some of the typical methods adopted by motorists at the onset of sleepiness (Maycock, 1996). They reported winding down the window (68%), stopping for a walk (57%), listening to the car's radiocassette (30%), or a passenger (25%), or drinking coffee (14%). 15% indicated 'other' measures such as: singing, eating, smoking, changing driver, or moving the seat (to an uncomfortable position). Some of the more popular measures have been examined in the laboratory and have not been found to be effective (Reyner & Horne, 1998a), at best only providing drivers with enough time to find a suitable stopping point. This is interesting since drivers are encouraged to take breaks, but simple breaks alone are not found to be greatly beneficial. Research has aimed to identify the best methods drivers can adopt *during* this break in order to refresh themselves and continue to their destination.

Returning to the idea of sleep itself, napping is an effective countermeasure to sleepiness. This has been evaluated in operational settings (Rosekind et al., 1995), to demonstrate that naps of > 20 minutes cause individuals to descend into deeper sleep (Naitoh, 1992), which results in sleep inertia upon awakening. Therefore naps of 15 minutes or less are recommended during breaks from driving (Gillberg et al., 1994; Naitoh, 1992), and this strategy has showed some success (Horne & Reyner, 1996).

Psychostimulants

Another effective method of counteracting sleepiness (and an alternative to napping) is a psychostimulant such as caffeine. Caffeine works by blocking adenosine receptors in the brain, which are thought to promote sleep (Radulovacki, 1995; Porkka-Heiskanen et al., 1997). Experimental work has shown that 150-200mg caffeine significantly improves alertness in sleepy people (e.g. Griffiths et al., 1990; Lorist et al., 1994; Bonnet & Arand, 1994; Muehlbach & Walsh, 1995; Åkerstedt & Ficca, 1997). This has also been demonstrated in the context of driving both in the afternoon (Horne & Reyner, 1996), and in the early morning (Reyner & Horne, 2000). Since caffeine is so widely available, this seems a likely solution to motorists problems. Research has also demonstrated the effectiveness of caffeine in combination with naps (Reyner & Horne, 1997) and this advice has been passed on to motorists in the updated highway code – see figure 1.7 (November 1999).

The Highway Code – FITNESS TO DRIVE

80. Driving when you are tired greatly increases your accident risk. To minimise this risk:

Make sure you are fit to drive. Do not undertake a long journey (longer than an hour) if you feel tired. Avoid undertaking long journeys between midnight and 6am, when natural alertness is at a minimum.

Plan your journey to take sufficient breaks. A minimum break of at least 15 minutes after every two hours of driving is recommended.

If you feel at all sleepy, stop in a safe place. Do not stop on the hard shoulder of a motorway.

The most effective ways to counter sleepiness are to take a short nap (up to 15 minutes) or drink, for example, two cups of strong coffee. Fresh air, exercise or turning up the radio may help for a short time but are **not** as effective.

Figure 1.7
Advice for sleepy drivers - taken from the Highway Code, New Edition 1999. London: The Stationery Office.

It is assumed that this advice to sleepy drivers results in the consumption of coffee, as this is how caffeine is most commonly taken. However, it is not clear how reliable coffee is in its caffeine content, and this may undermine the validity of the advice currently given by the highway code. Alternative sources are tea (about 40mg of caffeine per cup), soft drinks such as colas (again about 40mg), caffeine tablets or functional energy drinks (FEDs) which contain a standard, high dose (circa 80mg), and are readily available without preparation.

Research Questions for the evaluation of psychostimulant countermeasures:

- Are 'functional energy drinks' effective at reducing sleepiness in the context of driving ?
- Are there any sex differences in the effects ?
- What are the implications for advice given to sleepy drivers ?

1.9 TECHNOLOGICAL COUNTERMEASURES

Other recent research has attempted to aid vehicle manufacturers and inventors to use technological 'devices' to somehow monitor drivers in order to detect and/or warn of increasing sleepiness. It is unclear what the output of such a device should be – to warn drivers through alarms, simply advise them of the need to rest, or even stop the vehicle (Richardson, 1995). All these issues have been theoretically discussed, although it is generally accepted that the implementation of an effective device is still at least 10 years away (Brown, 1997). These methods have been continually evaluated and re-designed in an attempt to find a foolproof method to detect and warn of increasing sleepiness. So far limited success has been achieved and it seems that Brown's view of imminent implementation (inside 20 years) is a little optimistic. Research has focussed more on the methods by which detection could be achieved than the output, and there are 3 categories to be examined:

Physiology

Many systems have been designed to use physiological measures from the driver to detect the onset of sleepiness. Typically these have been parameters from the heart and/or eyes. This approach is problematic however, because drivers put more and more effort into staying awake while driving, which is very different to the process of naturally falling asleep (Ogilvie et al., 1989). A typical approach has been to use blink rate (e.g. Stern, 1994). This is problematic though, since individuals can reach states of extreme sleepiness with the eyes open (Miles, 1929), and secondly blink rate is affected by other factors (Horne, 1988). Physiological devices have therefore had limited success, although research continues, using more complex, combined input systems.

Driver Behaviour

Other systems have been geared towards using some direct measurement from the car itself such as steering or braking to monitor changes in association with increasing sleepiness. This may be a promising approach since there is none of the intrusion of physiological methods. Typically, some calibration is needed in order to familiarise the system with each driver's 'normal' level. Most research in this area has focussed on steering control – the basic hypothesis being that increasing sleepiness leads to changes in fine adjustments to steering, resulting in increasing incidence of lane drifting (Riemersma, 1977; Fairclough, 1997).

Secondary Task

A third approach works by measuring the 'spare capacity' of drivers while driving. This is done using a simultaneous *secondary* task, poor performance at which would indicate increasing sleepiness. However, safety may be compromised if drivers become distracted by the secondary task, and the added stimulation may alert drivers. Typical examples are reaction time devices whereby subjects respond to a light or buzzer from within the car.

Reaction Time

It has been generally assumed that sleepiness impairs drivers, making them respond more slowly to emergency situations, by reacting slower in applying the brakes or making other avoidance manoeuvres. The secondary task approach has attempted to use this principle in the design of a device which measures reaction time while driving using a hand or foot operated switch in response to an auditory or visual signal (Lisper et al., 1971; 1986; Laurell & Lisper, 1976; Riemersma, 1977; Reyner et al., 1999). The device then monitors drivers' responses to give a warning when performance falls below a required level or when signals are missed. This level must somehow be defined mathematically, as well as the frequency of stimuli given to the driver. This is a problematic approach, as stimuli which are too frequent may distract or irritate the driver (making a commercial device potentially unsuccessful), whereas stimuli which do not occur often enough may allow the driver to fall asleep and crash between them. Some investigation of the threshold between these ideas would be helpful, though extremely costly to conduct. Also, since there may well be effects of other factors such as age on reaction time (Wilkinson & Allison, 1989), there is no guarantee of success for all drivers. It should also be noted that several laboratory sleep studies have demonstrated that response to auditory stimuli is still possible during stage 1 sleep (Ogilvie et al, 1989).

Although research has clearly shown the sensitivity of RT to sleep deprived subjects in the laboratory (Dinges, 1994) as well as in the field (Corfitsen, 1993; 1994; 1996), we do not know that this is the case while driving, particularly under more realistic conditions. Research has shown that drivers may either respond normally despite increasing sleepiness, or not respond at all – rather than showing a gradual decline which could be picked up by the mathematical processing of RT responses (Riemersma et al., 1977). In other words, sleepiness displaces RT, rather than simply increasing it (Dinges & Kribbs, 1991). This questions the validity of in-car devices based on reaction time. How does RT progress over time in the driving scenario ? Is this sensitive to sleepiness ? Are drivers alerted by the increase in task load ?

Research Questions for the evaluation of technological countermeasures:

- Is secondary task Reaction Time sensitive to sleepiness ?
- How do changes in Task Load affect sleepiness when driving ?
- What are the prospects for in car devices to detect and warn of increasing driver sleepiness ?

1.10 SUMMARY & RESEARCH QUESTIONS

'Driver Sleepiness' is recognised as the cause of approximately 20% of UK RTAs depending on the type of road. Many of these are serious due to the high speed of vehicles involved and a lack of braking or avoidance manoeuvres, particularly if HGVs are involved. SRVAs show a clear pattern of temporal distribution, in line with the circadian rhythm of sleepiness. Single-vehicle accidents occur predominantly at the circadian nadir in the early morning, and to a lesser extent in the mid afternoon. These findings have been replicated internationally and represent a large portion of accidents previously attributed to 'driver inattention,' or other non-specific causes.

Accidents typically involve a single vehicle running off the road or into the back of another. Young males <30y are particularly at risk, and time of day is as, if not more, important than the length of time driving. Clinical causes exist but are thought to have only a small effect demographically. More effective medical screening could perhaps be a direction for tackling driver sleepiness in the commercial sector. Research has examined driver sleepiness in laboratory simulation, as well as (to a lesser extent) closed road-circuit and road car studies. Countermeasures have been devised, the most important aspect seeming to be education and awareness, but this requires some practical scientific input on steps such as journey planning, regular breaks and the use of psychostimulants. Technological measures have used physiology, driver behaviour and secondary task approaches in an attempt to measure and warn of sleepiness.

As the world advances technologically, and moves further towards a 24 society, the 'value of time' (Dinges, 1995) increases, and long journeys, long work hours and driving at physiologically inappropriate times of day become commonplace. Therefore it is conceivable that the problem may worsen without implementation of sufficient countermeasures. These should come from research into process and behaviour in driver sleepiness for commercial *and* public sectors. The following questions may lead us to identify these:

Research Methodologies to examine Driver Sleepiness

- What is the relationship between subjective sleepiness and driving performance ?
- Are simulator based findings reliable, valid and applicable to the real world ?
- What improvements can be made to the existing driving simulator and protocol ?

Technological Countermeasures to detect/warn of Driver Sleepiness

- Is secondary task Reaction Time sensitive to sleepiness ?
- How do changes in Task Load affect sleepiness when driving ?
- What are the prospects for in-car devices to detect and warn of increasing driver sleepiness ?

Practical Countermeasures to reduce Driver Sleepiness

- Are 'functional energy drinks' effective at reducing sleepiness in the context of driving ?
- Is there any improvement in driving behaviour ?
- What are the implications for advice given to sleepy drivers ?

Individual differences in Driver Sleepiness

- Are certain people more likely to have sleepiness related accidents ?
- Can we identify drivers at risk from SRVAs using measures of trait sleepiness ?
- What are the implications for the medical screening of professional drivers ?

- Are there differences in driving performance/subjective sleepiness/EEG for males and females ?
- Is the relationship between perception of sleepiness/likelihood of falling asleep to driving performance different for males and females ?

This thesis will aim to answer these questions, and evaluate potential countermeasures to driver sleepiness through a programme of research undertaken in the laboratory using a fully interactive driving simulator. It will describe a series of experimental studies, beginning with some validation of the simulator against data from a real car on a closed road circuit. No countermeasure is recommended to excessively prolong driving, and all advice is based on the assumption that the most effective countermeasure to sleepiness is *sleep*, and that drivers should plan journeys (with regular breaks) so as not to experience a level of sleepiness which necessitates 'in-car' methods.

2.0 GENERAL METHODOLOGIES

Investigating Driver Sleepiness

This chapter outlines the methodologies used in the experimental work described by this thesis. More detailed information specific to individual studies, such as descriptive statistics on participants, is given briefly in the chapters that follow.

2.1 Participants

All participants were selected from respondents to recruitment posters at Loughborough University. Volunteers were interviewed using a background information questionnaire (see appendix 1), to highlight any sleep-related problems and ensure suitability. Participants were English speaking, aged 20-30yrs, healthy (medication-free), of normal weight range for height (measured using the Body Mass Index [BMI]: Heyward & Stolarczyk, 1996), and experienced drivers (driving for at least 2 years, and averaging 3 or more hours of driving per week). They were good sleepers, sleeping regular hours and infrequent daytime nappers (less than once a month). None complained of daytime sleepiness, nor indicated potential sleep disorders.

The Epworth Sleepiness Scale

How likely are you to fall asleep or doze off in the following situations, rather than just feeling tired ? This refers to your usual way of life in recent times. Even if you have not done some of these things recently try to work out how they would have affected you. Use the following scale to choose the most appropriate number for each situation.

0 = would *never* doze
1 = *slight* chance of dozing
2 = *moderate* chance of dozing
3 = *high* chance of dozing

Situation	**Chance of dozing**
Sitting and reading	....
Watching TV	....
Sitting inactive in a public place (e.g. theatre/meeting)	....
As a passenger in a car for an hour without a break	....
Lying down in the afternoon when circumstances permit	....
Sitting and talking to someone	....
Sitting quietly after lunch without alcohol	....
In a car, while stopped for a few minutes in the traffic	....
TOTAL	....

Figure 2.1
The Epworth Sleepiness Scale (Johns, 1991)

Their Epworth Sleepiness Scores (see figure 2.1) were within the normal range 0-10 (Johns, 1991). Shiftworkers were excluded. Procedures were fully explained to them (see appendix 2 and 3), they all signed consent forms (see appendix 4), and were paid to participate. Payment was based on a rate of £5.00 per hour, so £15.00 for each 2hr, and £20.00 for each 2.5hr session. Some attempt was made to balance participants equally between the sexes, though this was not always possible. All were given a 20 minute practice drive to familiarise themselves with the simulator's controls, prior to the first test trial. They attended the laboratory briefly on the day prior to testing, in order to collect briefing information (see appendix 2 and 3), sleep logs (see appendix 5) and actiwatches (see below).

All participants were asked not to drive or cycle on the day of the trial and if necessary were brought to the laboratory by taxi. Participants were also asked to refrain from consuming alcohol or caffeine from 2200 hrs the night prior to testing, or at all on the day of the trial (see appendix 2). Eating, smoking or chewing gum were not permitted during driving. Participants were also asked to remove wristwatches and switch off mobile phones during the test sessions. Temperature and humidity were monitored throughout and kept relatively constant.

2.2 Study Design & Protocol

The general protocol was a repeated measures design, whereby participants drove during the mid-afternoon, following a night of sleep restricted to 5 hours (verified by overnight actimetry – see below). Conditions were given at least a week apart, and their order was counterbalanced. Unless otherwise stated, the drive lasted 2 hours, beginning at approximately 1400h.

2.3 Measurements, Materials and Apparatus

Driving Simulator and Roadway

This comprised the front half of a Vauxhall Cavalier with a fixed base (see figure 2.2). A 2.0 metre by 1.5 metre screen was located 2.3 metres from the windscreen, upon which the roadway was displayed from an AV projector (GE Imager LCD36E). An unobtrusive infra-red camera (Panasonic WV-BP500) filmed the driver's face with the aid of an infra-red lamp (Dennard 880). This was recorded with the roadway using a split-screen video display via a Digital AV mixer (Panasonic WJ-AVE55). All mirrors were removed from the car. A small microphone suspended from the car's ceiling recorded participants responses to the experimenter.

Figure 2.2

Interactive Fixed-Base Driving Simulator (side view)

The car's steering, accelerator and brake (right-hand drive) were connected via electronic sensors to a computer (Acorn A5000), which generated the roadway and varied the view position and speed accordingly. This was a daytime, dual carriageway road scene, with hard shoulder, central reservation and auditory "rumble strips" on both sides (see figure 2.3). The roadway ran for a preset time, bending gently to simulate motorway type driving (see figure 2.4). Participants sat in the driving seat and drove at their normal cruising speed within white lane markings. About once per hour, at a fixed time, a slow vehicle was met unexpectedly (facilitating a collision) and had to be avoided, by overtaking and returning to the left hand lane. The laboratory lights were switched off during driving sessions.

Figure 2.3

Interactive Driving Simulator: Visual Display showing dual carriageway road

The roadway picture from the A5000 computer was fed electronically into a video standard converter (Media Scan™ MS120) to transfer the image to video format, this was then split into two signals – one to the projector and the other to the video mixer for recording by the video cassette recorder (Mitsubishi HS-M59), together with the image of the driver's face (see figure 2.5A). This was displayed in the laboratory using a television screen (Mitsubishi CT21M2BM).

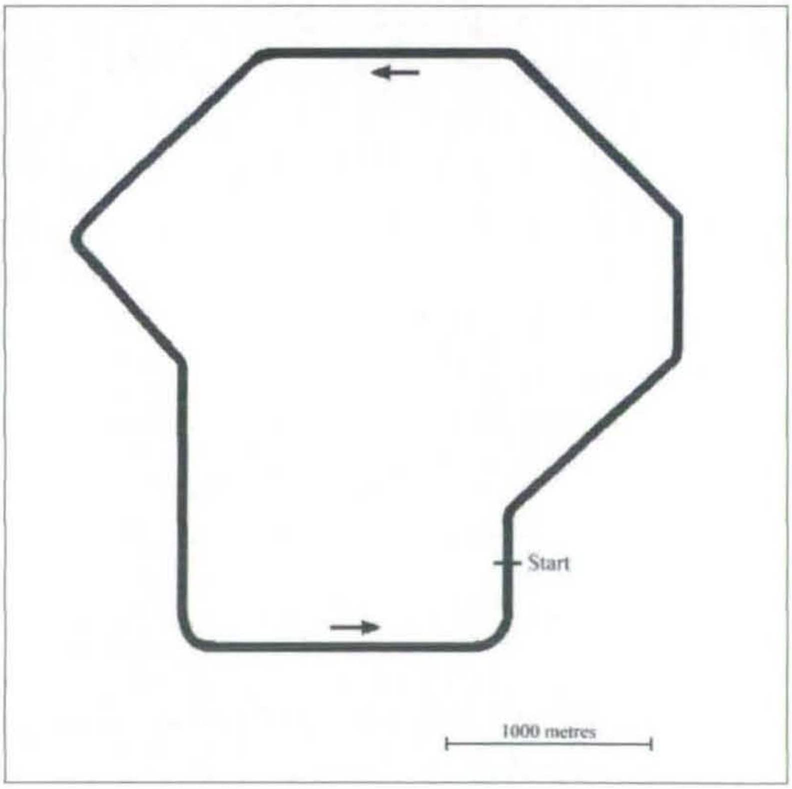

Figure 2.4

Sketch of Driving Simulator Circuit

Road Car and Test Track

The car was a Peugeot 205 (diesel), with dual controls (footbrake and clutch) on the passenger side. Two infra-red, security type cameras were used to record the trials. One was mounted on the dashboard (aimed at the driver's face), and the other fixed to the passenger side sun visor (aimed at the road ahead). A video cassette recorder (Panasonic AG-1070 DC) and mixer (CQ820 Real Time Colour Quad) were carried in the boot of the car, and used to record a composite picture of the two images similar to that recorded in the simulator (see figure 2.5B). The video recorder was also connected to a service monitor (Chugai Boyeki PSM012) placed in the back seat of the car - this displayed an image for observation by the second experimenter. A microphone was suspended from the driver's side sun visor to record participants' subjective responses. The whole system was powered by a 12 volt battery, also carried in the boot. All equipment was unobtrusive and the car appeared normal from the outside.

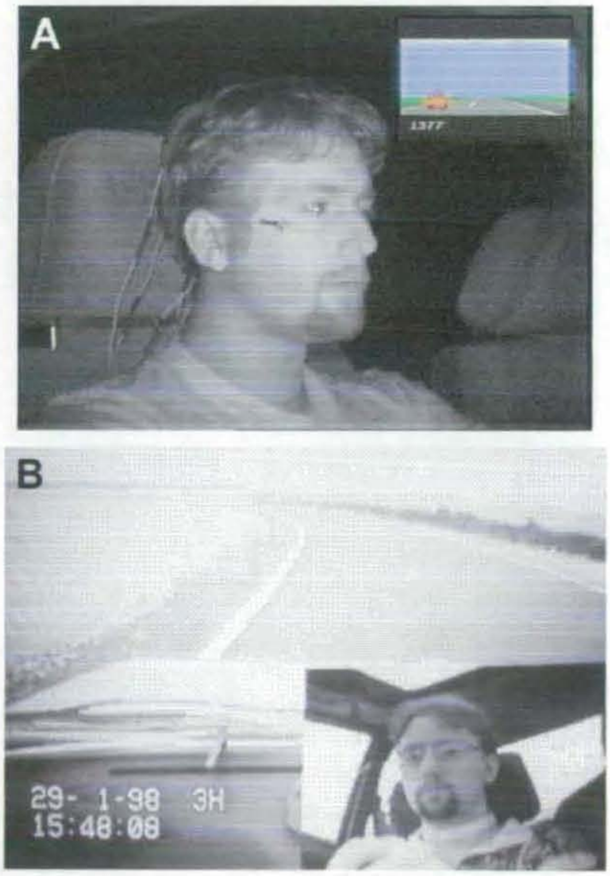

Figure 2.5

Video display showing road and driver's face shots:

(a) Driving Simulator (b) Closed road circuit

The track test trials took place at the Motor Industry Research Association (MIRA) site in Leicestershire. The Dunlop handling circuit (see figure 2.6) was used as it was most freely available, and facilitated exclusive use (i.e. no other vehicles were on the track simultaneously). Cones were placed at irrelevant intersections so that drivers were clear about the route to take around the track.

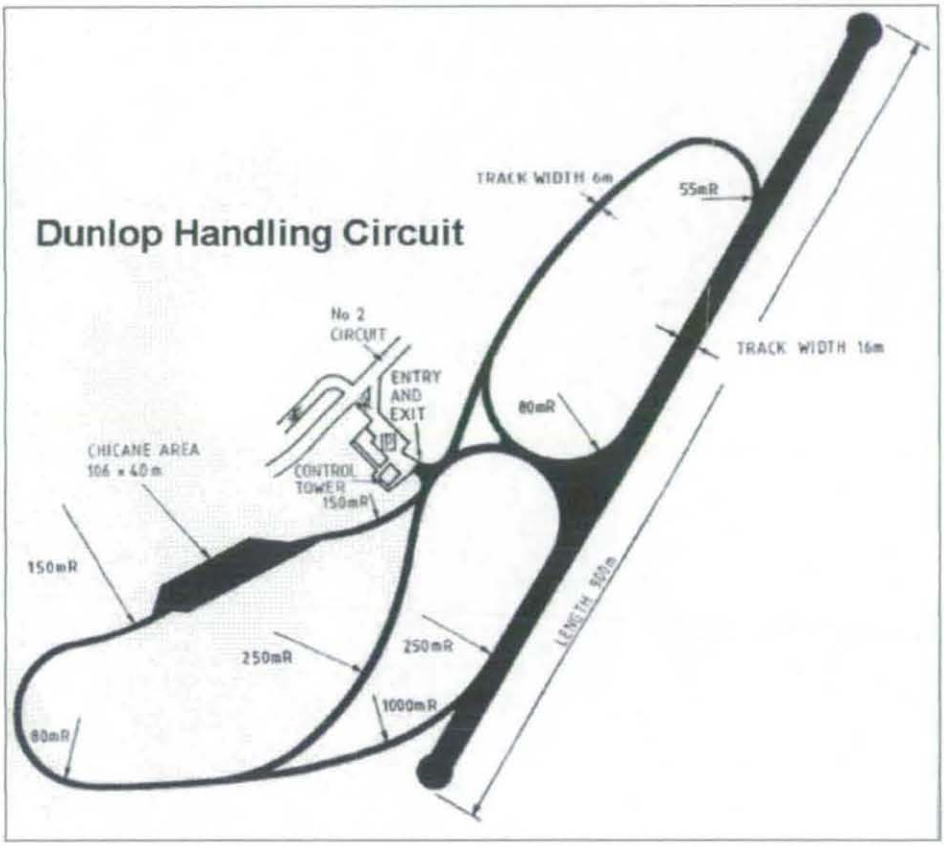

Figure 2.6

Closed Road Circuit: 'Dunlop Handling Circuit' (MIRA)

Driving Performance

Lane drifting is the usual manifestation of sleepy driving, and a car-wheel crossing a lateral lane marking was the criterion for this. This was analysed visually by the experimenter (see appendix 6) and classified as MINOR incidents (one wheel crossing the lane line) and MAJOR incidents (car leaving the lane). All identified 'incidents' were checked to see whether: (i) they were due to driver distraction (looking elsewhere, fidgeting etc.) which were discounted, or (ii) to episodes associated with sleepiness (i.e. accompanied by eye 'rolling,' eyes closed or vacant staring). Additional quality checks were undertaken on these video data by another experimenter "blind" to the findings of the first. These 'minor' and 'major' incidents were totalled for the purposes of analysis.

Subjective Sleepiness

Every 200 seconds, participants rated their subjective sleepiness on the 9-point Karolinska Sleepiness Scale (Åkerstedt & Gillberg, 1990 – see fig 2.7). The scale and descriptors were printed on the dashboard behind the steering wheel, within easy view of the driver, and responses were noted by the experimenter (see appendix 7).

The Karolinska Sleepiness Scale

1. Extremely alert
2. Very alert
3. Alert
4. Rather alert
5. Neither alert nor sleepy
6. Some signs of sleepiness
7. Sleepy, but no effort to keep awake
8. Sleepy, some effort to keep awake
9. Very sleepy, great effort to keep awake, fighting sleep

Figure 2.7
The Karolinska Sleepiness Scale - a 9 point subjective ratings scale
(Åkerstedt & Gillberg, 1990)

In addition to this, participants were asked to rate their likelihood of *actually falling asleep*, during the following 5 minute period. This used a simple 5 point scale (Reyner & Horne, 1998a - see figure 2.8), in order to examine drivers' perceptions of the *possibility* of falling asleep at the wheel.

Likelihood of falling asleep in the next 5 minutes

A Very Unlikely
B Unlikely
C Neither
D Likely
E Very Likely

Figure 2.8
Likelihood of Falling Asleep Scale – a 5 point subjective ratings scale
(Reyner & Horne, 1998a)

Overnight Actimetry

As well as completing an overnight sleep log on the morning of the trial (see appendix 4), each participant also wore a Swiss, Gaewihler-type actiwatch commencing at 1800 hrs the evening prior to testing (see figure 2.9). This measured and logged movement in 30 second epochs. The data was used solely to verify that all participants complied with their 5 hour sleep restriction (see appendix 8 for example data).

Figure 2.9
Swiss, Gaewihler Type Actiwatch – used to log movement

Reaction Time

In the RT condition participants responded to an audible stimulus by pressing a single thumb-activated microswitch mounted in the centre of the steering wheel. Stimuli were randomised with an inter-stimulus range of 50 to 300 seconds, averaging 150 seconds. RT began during the initial 30 min period. This simple form of RT was used in order to minimise practice effects and distraction from driving. RTs longer than 1000 milliseconds were regarded as missed responses. Data was logged as: (i) mean and standard deviation of RTs shorter than 1000 msec, and (ii) missed responses (or 'lapses'). The response button and beeper unit were mounted in the car and connected to a data logger (Strawberry Tree) powered by a Windows 95 PC. The stimulus device was a simple beeping sounder cancelled by the pressing of the microswitch. The software used to run the device was Workbench 5.0 (Datalog GmbH).

Electroencephalography (EEG)

EEG and EOG signals were collected using silver chloride/silver electrodes, which were attached for: one channel of EEG (C3-A1: Rechtschaffen & Kales, 1968), and to identify 'eye-rolling', two channels of EOG (electrodes 1cm lateral to and 1 cm above left outer canthus, and 1 cm lateral to and 1cm below right outer canthus; both referred to the forehead). Electrode resistance was measured using an impedance tester (Oxford XI-1) and was kept <10kΩ for EOG, and <5kΩ for EEG channels. Low and high band-pass filtering of the EEG at >15 Hz and <4 Hz removed slow eye movements and muscle artefact. These electrophysiological signals were amplified using Psylab amplifiers (Contact Precision Instruments, London), and recorded using Labview (version 3.0.1, National Instruments Inc.) at 128Hz. The EEG was spectrally analysed in 1 Hz bins over the theta and alpha ranges (4-11 Hz, i.e. 6 bins), using 'Rhythm' software (Stellate Systems), and in 4 second epochs. Power over these 6 bins was combined and then averaged in 1 min epochs. Each of these epochs was standardised for each participant (to reduce individual differences in mean EEG power levels), before averaging across participants (Horne & Reyner, 1996). Standardisation for each epoch was thus :

$$\text{Standardised epoch} = \frac{\text{Difference from mean of first 30, 1 min EEG epochs}}{\text{Standard deviation of these first 30 EEG epochs}}$$

For the study described in chapter 5.0, data were collected (again at 128Hz) using the Embla ambulatory EEG system (Flaga, Iceland) and spectrally analysed using Somnologica (Version 2.0: Flaga, Iceland) also in 4 second epochs and standardised as shown.

'Energy Drinks'

During the 30 minute break from driving, one of two drinks was administered double blind from a pre-packed plain glass bottle:

1) Functional Energy Drink (250ml)

Ingredients: Carbonated water, sucrose, glucose, citric acid, Taurine (0.4%), glucuronolactone (0.24%), Caffeine (0.03% [80mg]), inositol, vitamins (niacin, pantothenic acid, B6, B12), flavours, colour (caramel, riboflavin).

2) Control Drink (250ml)
The same drink (virtually identical in colour and taste), but without the active ingredients (caffeine, glucuronolactone & taurine).

2.4 General Procedures

Driving Simulator

On an initial adaptation, or 'baseline' day following a normal night's sleep, and a week before experimental testing began, participants underwent a 2 hour afternoon practice drive on the fixed-base driving simulator. They were instructed to drive at a comfortable speed for motorway/dual carriageway type driving, and keep to the left hand lane except for when overtaking other vehicles. Participants were prompted at 200 second intervals by the experimenter saying "sleep check." The experimenter was present in the laboratory at all times, and monitored the equipment while taking notes on participants' performance. Driving sessions were either a 2 hr drive (approximately 1400-1600 hrs) or a 2.5 hr drive (approximately 1400-1430 hrs plus 1500-1700 hrs) depending on the condition. Drivers remained in the car during breaks.

Road Car

Participants were driven to the test circuit by the experimenters in the instrumented car (this took approximately 35 minutes). On arrival at the circuit, cones were put in place to highlight the correct route around the track, and portable radios were obtained to facilitate communication with the control tower in case of emergency. After cones were put in place, participants were given the chance to drive for 2 laps in order to get used to the controls of the car and the route around the track. The size of the circuit was such that speed had to be reduced in order to be relatively constant and enable participants to navigate the turns. Therefore drivers were instructed to drive at approximately 30 mph throughout the trial (see appendix 3). All persons in the car wore seatbelts at all times. Two experimenters were present with the participant throughout the drive, one at the dual controls and one in the back seat with the monitor and stopwatch, and at intervals one of the experimenters would give the 'sleep check' prompt for response to the KSS as described in the simulator scenario. Participants drove anti-clockwise around the outermost extensions of the circuit (see figure 2.5), and were instructed to think of the track as a two lane carriageway, keeping to the left hand lane at all times – as in the driving simulator.

After all trials, participants were either escorted home by the experimenter on foot (in the case of on-campus students), or by taxi.

'Energy Drinks'

These were given at the beginning of the break; allowing adequate time at least for the absorption of caffeine (van der Stelt & Snel, 1993). The absorption and plasma elimination rates of taurine and glucuronolactone are not known. Participants consumed "energy drinks" on an infrequent basis, and as the tastes of the two experimental drinks were almost identical and drinks were given a week apart, participants were unable to distinguish between the two. The drinks were not given in proportion to body weight, but rather a fixed 250ml dose, as the typical driver would consume this drink by the can. All participants were asked if they felt any ill-effects of the caffeine/control drinks both immediately after the trial and 24 hours later. None complained of any such effects.

3.0 VALIDATION OF METHODS

Closed Road Circuit / Simulator Study

3.1 SUMMARY

Experimental work on driver sleepiness has typically used simulated driving tasks to examine performance under conditions of reduced sleep and/or prolonged driving. These studies have shown that realistic levels of sleep restriction, such as a delayed bedtime combined with an 'early start,' can lead to serious deterioration in afternoon driving performance (Horne & Reyner, 1996). They have also shown that drivers *are* aware of increasing sleepiness, prior to actually falling asleep at the wheel (Reyner & Horne, 1998b). Some have also evaluated potential countermeasures as suggested by both drivers (Maycock, 1996) and motoring organisations. Practical methods such as rest breaks, napping and caffeine (Horne & Reyner, 1996), cold air, and listening to the radio (Reyner & Horne, 1998a) have all been tested in the laboratory, as well as technological countermeasures such as blink rate monitors (Stern, 1994) and reaction time devices (Reyner et al., 1999) to measure and warn of increasing sleepiness. Measurements taken by these investigations typically include subjective and physiological measures, as well as some gauge of driving performance. Early 'driving simulators' were based on primitive tracking tasks (e.g. Dureman & Bodén, 1972), and did not offer much flexibility, so closed road-circuit and even road testing methodologies, both using instrumented cars were proposed. These have the advantages of greater realism and generalisability, although they are more complex and costly to conduct. Modern simulators are much more powerful and offer greater control, but it is often said that they over-emphasise the resulting deterioration in performance, since they are monotonous and do not reflect 'real life.' How reliable is driving simulation for the examination of driver sleepiness and potential countermeasures ? Is closed road-circuit testing a viable alternative ?

The aims of this study were to validate data from a simulator-based investigation (Reyner & Horne, 1998b), against that obtained from a real car driving on a test track, and thereby also to determine the feasibility of closed road-circuit testing. Eight participants (4 male and 4 female), with a mean age of 24.9yrs (±3.36yrs) participated in a repeated measures design whereby they were tested objectively and subjectively whilst driving without a break, in both a fully interactive fixed-base driving simulator, on a computer-generated monotonous roadway (for 2hrs), and in a real, dual controlled car on a closed road-circuit (for 1.25hrs), both following a night of sleep restricted to 5hrs (between 0200-0700 – verified by overnight actimetry). Subjective sleepiness data were collected throughout both conditions every 200 seconds using the Karolinska Sleepiness Scale (Åkerstedt & Gillberg, 1990). Driving performance data was collected using video cameras, and analysed manually for lane drifting due to sleepiness. Technical difficulties prevented the comparison of EEG data.

Increased subjective sleepiness and deterioration in driving performance occurred under both conditions, developing over time to reflect the afternoon circadian dip. Changes in subjective sleepiness with both simulator and track were identical, and relative changes in sleepiness-

related driving incidents over time were similar. These findings support the validity of simulator-based research, indicating that laboratory findings are not due to the over-simplified or low-stimulus characteristics of such studies. The logistics of closed road-circuit experimental work are complex however, and conditions are difficult to control relative to simulator studies. Although more realistic, the added cost of closed road-circuit work means that realistic simulation is a much better way to examine driver sleepiness, and evaluate potential practical and technological countermeasures, as shall be attempted in the chapters that follow.

3.2 INTRODUCTION

Experimental work on driver sleepiness has generally focussed on 3 main aspects of the problem. These are the *processes* of falling asleep at the wheel, the *behaviour* of drivers when sleepy, and the evaluation of potential *countermeasures*. This chapter will discuss the available methodologies for doing this, in order to form a reliable protocol for the subsequent experimental studies.

Typically, research has relied on laboratory simulation of the driving task, to examine sleepiness and performance under conditions of reduced sleep, or prolonged driving. This began at a fundamental level, and has advanced rapidly over time to make today's high standards of simulation possible. As with all laboratory based work however, there is the question of realism, and therefore generalisability of findings to the outside world. In addressing this, closed road-circuit, and even on-road studies have been proposed as alternatives to modern laboratory work, leaving 3 possible methodologies with which to examine the efficacy of countermeasures to driver sleepiness. These are summarised below, including the measurements used, beginning with a brief outline of some early work in this area.

Early Driving Tasks

Early research used simple tracking tasks to simulate driving at a fundamental level. Until the 1980s, computer simulation was not possible, so more primitive imitations of the driving task, such as the paper tracking test used by Dureman & Bodén (1972) were used. Volunteers controlled a moving 'car' placed over a moving paper road to give the illusion of 'driving' the car. Interestingly, this study also used electric shocks to heighten the risks attached to driving errors and therefore increase realism. The study involved 4 hours of continuous driving and measurements were taken on: steering errors, braking reaction time, subjective fatigue, pulse rate, respiration, skin resistance, neck muscle tension, and EEG. Results showed increasing levels of 'fatigue' over time, but the study did not investigate time of day, focussing more on the time-on-task aspect. This was typical of early work, investigating 'driver fatigue' rather than sleepiness (see section 1.3). Clearly also, the electric shock element might well raise ethical concerns today.

Another early driving study used a complex system of rotating belts, to generate the visual sensation of driving a car (Regina et al., 1974). Drivers sat in front of a magnified screen so that a small model of a car, and the road behind it, appeared to be full size. While the model car remained stationary, the road, split into lanes by the separate belts, was driven by machinery connected to the accelerator pedal, and moved towards the driver to give the illusion of movement. One of these 'lanes' also included another model car, so the system could mimic an overtaking procedure. Although this setup was ingenious and effective, it had several limitations, the most obvious being the simple straight design of the road (bends were not possible using the belt system).

More Realistic Methodologies

These methods, although primitive, were noted to utilise the same fundamental 'psychological functions' as driving in general (Moskowitz, 1974). However, other researchers have considered practical relevance to be more important, and used more realistic protocols to investigate driving behaviour. For example, Riemersma (1977) conducted a study using an instrumented car on a 56km highway route. Participants drove through the night, accompanied by 2 experimenters, and measurements taken included heart rate, lane position and speed. Most interestingly, the study aimed to examine the converging effects of time-on-task, circadian rhythm, monotony and prolonged wakefulness on driving, thus challenging previous work which focussed on the time-on-task aspect. Results showed clearly that these converging elements caused decrement to performance over time, and the presence of the experimenter(s) was also noted to have some effect on alertness and behaviour. This is an important issue, since safety is paramount for non-laboratory driving studies, and must be carefully considered in the design of field investigations.

Two more recent studies have used similar protocols to examine driving performance in a real car. A Finnish study (Summala et al., 1999), examined the effects of fatigue in overnight driving, using a 1200km route. Interestingly, this study did not include an experimenter in the car, although participants completed the route twice, once as a passenger, and once as the driver (i.e. 2 participants were present at all times). Measurements were taken on blink rate, subjective sleepiness, steering input, and drivers' faces were videotaped. The main focus of the study was possible interventions for driver sleepiness. Changes in blink frequency with time were discussed in terms of potential technological countermeasures, using blink rate as the variable for detection. These ideas will be discussed further in chapter 4.0.

In another study, Reed & Green (1999) compared driving behaviour in both an on-road protocol and a fixed base driving simulator, using a secondary telephone dialling task to examine the validity of the simulator for measuring performance. This study found that lane keeping was more accurate on the road, but in conclusion, noted that despite *absolute* differences, the simulator demonstrated a good level of sensitivity both within and between subjects (i.e. good 'relative validity').

Driving Simulation

Although these field-based methods offer a high degree of realism and therefore practical relevance, they are complex to conduct, and many variables must be considered. *Modern* driving simulation gives us a great deal of *control* over the driving scenario: weather conditions, traffic flow, road characteristics, traffic systems and even specific roads can all be created in a virtual environment by advanced computer programs.

Simulation also varies in complexity however, and systems can be tailor made to account for budget and experimental requirements. Some researchers have used simple, desk mounted, PC based systems, with video-game style interfaces (e.g. Russo et al., 2001). Other laboratories have built more immersive driving simulators, with large visual displays and immobile (fixed-base) cars as the interface (i.e. drivers sit in the car, and steering, brake and accelerator are connected to the simulation program). These have the advantage of greater realism without ascending too far in cost (Home & Reyner, 1996; Comte & Jamson, 2000). At the top end of the scale, more complex systems have been designed to incorporate 180° and even 360° road views, vehicle vibration and movement, and ultra-realistic, silicon graphics displays with texture mapped surfaces (e.g. the NHTSA's National Advanced Driving Simulator, USA). These offer total immersion, albeit with extremely high costs. A balance must be achieved here, and the happy medium may well be in line with the interactive, fixed base system, using a real car interface. This has the advantage of fewer problems associated with motion sickness (Törnros, 1998), and there is still room for improvements and updates to software, without altering the entire hardware setup.

Regardless of the methodology used, it is generally accepted that three main types of measurement are required by studies to investigate driver sleepiness, as demonstrated by some of the work outlined above. These are *subjective* and *objective* measurements of sleepiness, as well as some measure of driving *performance*.

Subjective Sleepiness

Self-reported measures of sleepiness, used to create data on participants' own perceptions, are particularly important in the case of driving, since drivers must decide for themselves to stop and take a rest. Several types of scale have been used for this, but numbered scales are preferred, since they can be verbally recorded during uninterrupted driving (see section 1.7).

The KSS (see figure 2.6) may be used in this way during simulated driving (e.g. Home & Reyner, 1996). Drivers are generally aware of increasing sleepiness although they may not admit it after an accident. It may be interesting to see however, how this measurement stands up in an alternate protocol such as a closed road-circuit study. If the lack of realism inherent in the driving simulator does tend to overstate sleepiness, then will subjective measurements in a more realistic study reflect this (i.e. will subjects feel more alert ?).

Objective Sleepiness

Subjective reports of sleepiness are generally found to be reliable, but more objective, physiological measures are also possible and demonstrate clear changes which may not be reflected in self-report data. Some of the studies outlined above have used parameters such as blink rate or heart rate to do this, but these have often yielded contradictory results. The most effective objective measure of sleepiness is polysomnography. Increasing sleepiness is indicated by increased EEG power in the *alpha* (8-11 Hz) and *theta* (4-7 Hz) ranges (Åkerstedt & Gillberg, 1990; Horne & Reyner, 1996 – see figure 1.6). The combined alpha and theta frequency bands are thought to reflect sleepiness in the context of driving more clearly than either alpha or theta alone (Horne & Reyner, 1996), particularly since individual differences such as alpha surges can shift power from one to the other (Kecklund & Åkerstedt, 1993; Rechtschaffen & Kales, 1968). While these methods are simple and straightforward for laboratory testing, they are less so for closed road-circuit or on road protocols, since they require an ambulatory system to record data from drivers in the car (see section 1.7). Modern ambulatory systems are able to digitally record multiple EEG signals and store these on removable disk media, but these are expensive, and at the time of this study, only older, cassette based systems were available for use.

Driving Performance

Driving performance has been measured using a variety of variables including braking, following distance, response to other vehicles and the ability to maintain speed or lateral road position. Since crashes related to sleepiness are characterised by drivers drifting off the road or into another lane of traffic (Pack et al., 1995; Horne & Reyner, 1995), it seems sensible to use *lane drifting* as the primary measure of driving performance, while accepting that braking, acceleration and other elements may also be negatively affected by sleepiness. Work on countermeasures using a driving simulator (Horne & Reyner, 1996; Reyner & Horne, 1997; 1998a; 1998b) has used lane drifting in the measurement of driving performance through visual scoring of video data (see section 2.3). This would seem a reasonable measure of driving performance, but it remains to be seen whether it holds up against a real car, as the low-stimulus characteristics of the simulated roadway may well create more driving 'incidents' due to monotony and a lack of any serious risk.

Experimental work using a realistic, fixed-base driving simulator has shown that after a relatively short period of driving on a dull and monotonous road, seemingly minor levels of night-time sleep restriction can lead to significant levels of afternoon sleepiness and deterioration in driving performance (Reyner & Horne, 1996). More recent research has evaluated potential countermeasures to the problem, and demonstrated that drivers *are* aware of a period of increasing sleepiness prior to falling asleep at the wheel (Reyner & Horne, 1998b). Is the experimental protocol used for these studies appropriate, and are additional measurements necessary or feasible?

Validity

It is often said that laboratory conditions do not reflect the real world, and that the low-stimulus, monotonous characteristics of driving simulator studies bias experimental results in favour of high levels of sleepiness and poor performance (Crawford, 1961). Additional factors, and stimuli which are not present in laboratory studies such as weather conditions, noise and vibration may serve to alert drivers and enable them to maintain driving performance. Although simulation varies greatly and at times seems far removed from 'real' driving, the same fundamental functions are used by 'drivers' (Moskowitz, 1974). Is this enough to guarantee practical relevance in the real world?

In order to be sure that the driving simulator is a practically relevant tool for examining driver sleepiness, and particularly for evaluating potential practical and technological countermeasures, can we validate it against a similar, but more realistic protocol? Will subjective sleepiness and driving performance develop similarly in each condition over time across the afternoon circadian dip?

Several studies have examined driver sleepiness using an on road protocol (Summala et al., 1999; Reed & Green, 1999). This is clearly the most favourable scenario in terms of realism, but also presents the most problems. The safety of driver, experimenter and other road users must all be considered. For this reason authorisation for such a study would be extremely difficult to obtain, and extraneous variables very difficult to predict, or control (e.g. pedestrians, traffic, roadworks). Closed road-circuit testing is the next alternative, which removes some of these problems although still complex to conduct. Most interestingly, such studies have shown that lane keeping and speed control is less accurate in simulator based work due to a lack of motion cues (Reed & Green, 1999). Closed road-circuit studies are generally accepted as having a high degree of validity since they use real cars (Huntley, 1974), while simulation gives greater control and flexibility at the cost of reduced generalisability to the real driving scenario (Gawron & Ranney, 1988). Since driving simulators vary greatly in their visual display and interfacing, it is difficult to generalise about driving simulator work as a whole, and ideally the validity of each should be examined separately.

Study Aims

Can we compare data from the driving simulator and a new, closed road-circuit scenario, to examine the practical relevance of laboratory based experimental work? How will subjective sleepiness and driving performance develop over time in the two conditions? Is closed road-circuit testing a viable alternative to simulated driving, particularly for the evaluation of potential countermeasures?

The aim of this study was to validate the findings of a simulator-based study (Reyner & Horne, 1998b), using similar data collection methods, but with sleepy subjects driving in a real car on a closed road-circuit. One might assume that the low-stimulus characteristics of simulator-based research biases findings in favour of performance deterioration which does not actually occur in the real world. How viable an alternative to simulator testing is the closed road-circuit protocol? Would this be more effective in the evaluation of countermeasures to driver sleepiness?

3.3 METHOD

Participants were eight volunteers (4 male, 4 female), with a mean age of 24.9 years (SD = 3.36), and a mean ESS of 5.75. The study used a repeated measures design, whereby participants drove without a break following restricted sleep in 2 conditions: an interactive, fixed-base driving simulator, for 2 hrs, and in a real, dual controlled car on a closed road-circuit for 1 hr 15 minutes. See chapter 2.0 for full explanation of methodologies.

Statistical Analyses

Subjective sleepiness and lane drifting data were plotted against time, and mean values calculated for each condition. Both were averaged into four 30 minute periods per subject and condition, and two-way (condition x time) repeated measures ANOVAs were applied.

3.4 RESULTS

Subjective Sleepiness

Subjective sleepiness data for both the driving simulator and closed road-circuit conditions were plotted against time. This data is presented in figure 3.8. As is clear from the graph, subjective sleepiness for the two conditions increases over time, reaching a potentially dangerous level after about 20-30 minutes of driving, and following a very similar progression.

At about 25 minutes there was a slight improvement in subjective sleepiness for the simulator-based drive, due to the appearance of a computer-generated vehicle which had to be overtaken (see section 2.3). This alerted participants in the simulator condition, but was of course not present in the closed road-circuit protocol.

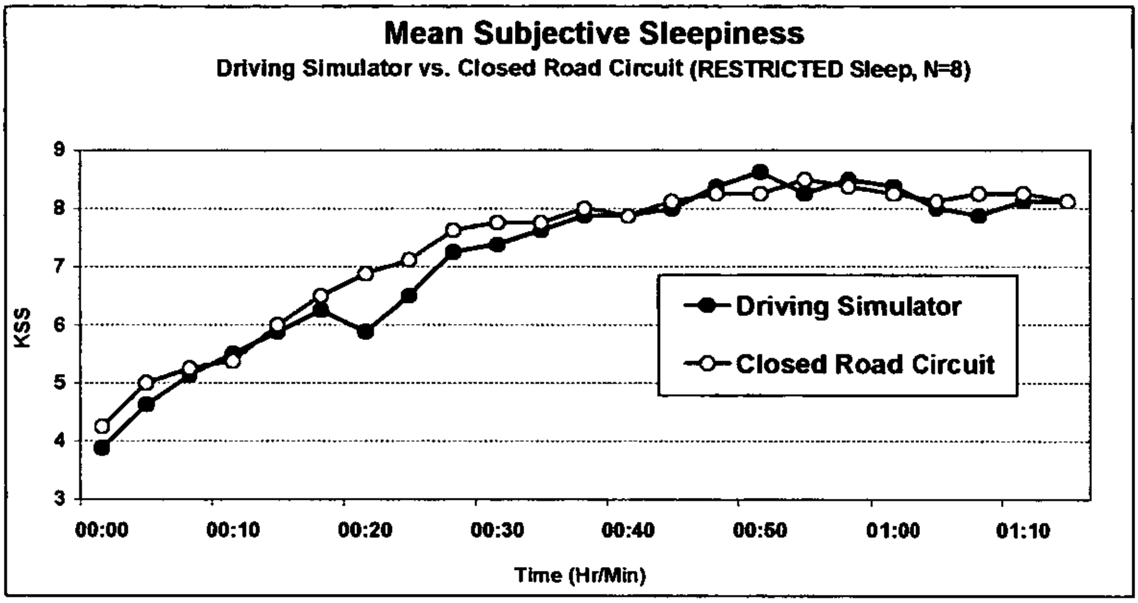

Figure 3.8

Mean subjective sleepiness over time for the 2 driving scenarios

There were no significant differences between subjective sleepiness measured on the closed road-circuit and on the simulator (F=0.19, df=1,44, p<0.66). These data actually showed a strong correlation (r=0.98, p<0.005) between the two conditions.

Driving Performance

Lane drifting incidents related to sleepiness, as taken from the video analysis for the two driving scenarios were plotted against time in 15 minute periods. This data is summarised in figure 3.9. Driving performance followed a similar pattern in both conditions, with lane drifting increasing over time. Relative changes in incidents were quite similar for the two scenarios, although proportionately more incidents occurred in the closed road-circuit condition than in the driving simulator.

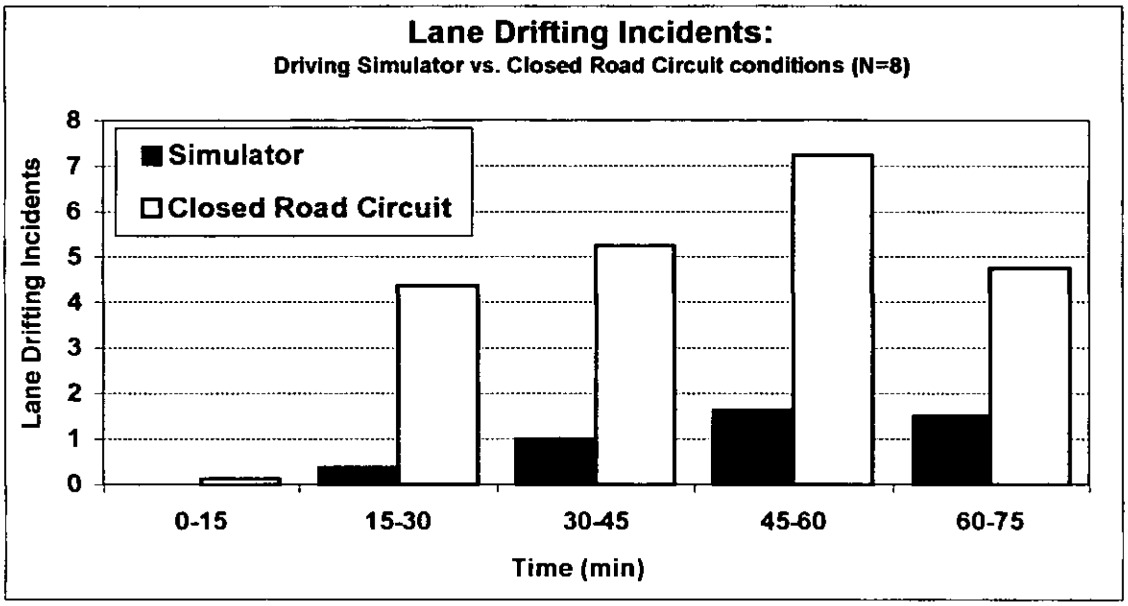

Figure 3.9

Lane Drifting incidents due to sleepiness over time

To examine more closely the relationship between subjective sleepiness and driving performance, sleepiness-related lane drifting incidents were plotted against the KSS level under which they occurred. This data is shown in figure 3.10.

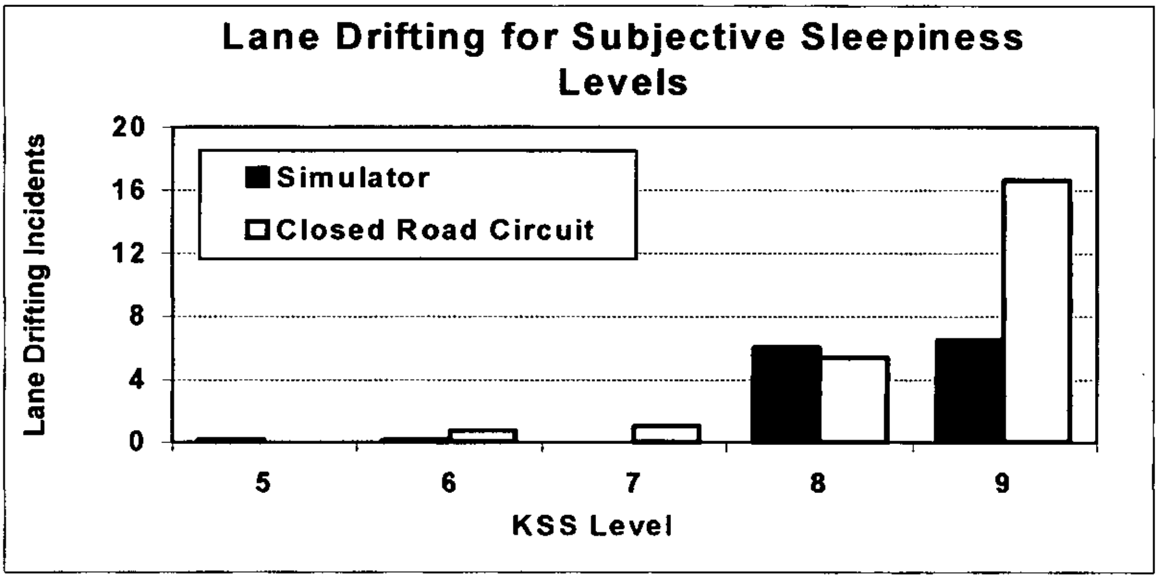

Figure 3.10

Lane Drifting incidents for each category of the KSS (all were ≥5)

As the graph shows, performance deteriorates with increasing subjective sleepiness under both driving conditions. Again, it is clear that there are more incidents coming from the closed road circuit scenario, suggesting that this is more sensitive to sleepiness.

3.5 DISCUSSION

The development of subjective sleepiness over time was very similar for both the driving simulator and closed road-circuit scenarios, increasing and then decreasing slightly to reflect the afternoon circadian dip in alertness. Statistical analysis confirms the lack of any significant difference between the two conditions ($F=0.19$; $df=1,44$; $p<0.66$), which actually show a strong correlation ($r=0.9795$; $p<0.005$). Since this progression of increasing subjective sleepiness was so similar between the two driving scenarios, we can conclude that drivers do not perceive themselves as more sleepy in the driving simulator, and therefore that it has a strong transferability for self-reported sleepiness. This was quite interesting because it was expected that drivers' would at least *perceive* themselves as less sleepy when driving a real car, even if this did not transfer to driving performance.

It has been suggested that while driving or operating machinery, subjects should be rated at 5 or less on the KSS (Reyner & Horne, 1998b). This level was reached in both driving scenarios after only 20-30 minutes of driving, and figure 3.10 shows that driving performance remains unaffected until this level is reached. Again, this demonstrates the reliability of both the driving simulator, and the KSS as a measurement of subjective sleepiness.

Changes in driving performance (as measured by lane drifting) over time were also related. This relationship is less clear than that for subjective sleepiness however, and the larger amount of incidents present in the closed road-circuit protocol does require some explanation. Since the driving simulators' computer-generated roadway was designed to simulate motorway driving, the 'road' bends in a similar way (i.e. bends are infrequent and gentle), and therefore could not be easily replicated in the real world. Driving at 30mph on the closed road circuit resulted in laps taking about 3 minutes to complete, compared to about 6 minutes in the driving simulator. The closed road-circuit also included two major bends, more difficult to negotiate than those in the driving simulator, which were encountered about every 90 seconds, resulting in the higher level of incidents on the closed road-circuit. However, the pattern of increase and decrease in incidents was the same under both driving conditions, and reflected the afternoon circadian dip in alertness. For obvious reasons, the most suitable test facility, at the most reasonable cost was used. Larger, and more similar circuits were available, but these were extremely expensive to use, and required a great deal of planning and scheduling beyond the scope of the study. Many of these also required thorough, in-house medical examinations for all drivers (both experimenters and participants) which would have been greatly time consuming. Therefore the track used for the study was much smaller than the 'virtual circuit' generated by the simulator, giving more opportunity for the incidence of lane drifting errors, due to the greater frequency of bends.

In addition to subjective sleepiness and driving performance, it would have been preferable to include EEG measures in this study to facilitate comparison of physiological data. This was not possible at the time of the study however, due to problems with recording equipment and analysis, and the complex logistics of the closed road-circuit protocol. Recently new equipment such as the EMBLA system (Flaga, Iceland) has become available (although expensive) and would be well suited for use in similar studies, facilitating up to 16 channels of EEG while driving.

The similar trends in lane drifting and subjective sleepiness between closed road-circuit and simulator conditions support the validity of research based on the driving simulator (Horne & Reyner, 1996; 1997; Reyner & Horne, 1998a, 1998b). For both driving situations even low levels of sleepiness caused marked deterioration in driving performance. These results indicate that the simulator-based findings are not due to the low-stimulus characteristics of such experiments, and rather reflect the process of falling asleep while driving in the real world. This study demonstrates that the driving simulator is a useful tool to examine driver sleepiness and evaluate potential countermeasures. The closed road-circuit protocol is also a valid methodology, with increased practical relevance to the real world, but does have several limitations which made the simulator a more sensible choice.

Although the closed road-circuit methodology was successful, field-based studies have several limitations. I have divided these into three categories, also noted by Reed & Green (1999):

Costs

The use of an outdoor, closed road-circuit track added travelling time (and fuel costs) to the project. The main impact of this was the amount of time participants were required for (increasing their payment needs), and the need to keep them from dozing off en route to the circuit. Clearly all experimenters and participants also needed to be covered under insurance. Once arrived at the circuit, some preparation was also necessary (placement of cones, paperwork, collection of high-visibility jackets and radios), which also added to the time required for each trial. These factors are irrelevant with the simulator, and costs are kept to a minimum.

Control

The most obvious difference between the two scenarios was the outside conditions. Visibility, wind speed, cloud cover and rain all affected the microclimate of the car and the complexity of the driving task. These factors are of course controlled in the laboratory setup - the temperature can be monitored effectively using thermometers, and adjusted using the heating and air conditioning systems as necessary. Secondly, hours of daylight are a problem. We are primarily interested in the natural circadian dip in alertness in the early afternoon (between 1400-1600), and depending on the time of year this may mean that sunset would commence during a trial. In planning similar, future studies, scheduling should take this into account (ideally taking place during the summer months, or even using summer/winter comparisons). Traffic systems and rates can also be replicated easily in the simulator, to facilitate overtaking procedures which were not possible in the closed road-circuit study.

Safety Issues

There are of course safety issues involved in using a real car to examine driver sleepiness. A controlled environment such as a test facility with *exclusive* usage (i.e. no other track users during testing) is necessary to ensure safety, and even then, dual controls are essential in case of emergency. In this case, two experimenters were present during testing to reduce the likelihood of an accident. Any work concerning complex interaction with other vehicles, is too dangerous and would be far better suited to simulator work.

As can be seen from the literature, simulation, closed road-circuit testing and on road studies have all been used to investigate driver sleepiness. I have outlined the problems associated with closed road-circuit work above, and it seems clear that road studies would suffer from the same problems (on a larger scale), with the addition of traffic and route planning. Obviously, the safety of other road users would also become a concern, and certainly for the purposes of studies restricting or depriving drivers of sleep, there is a strong ethical case for using the laboratory driving simulator.

Since the more primitive 'driver fatigue' studies of the 1960s and 1970s, technology has advanced and made possible more complex simulation of driving scenarios. More accurate physiological and behavioural measurements may be made, and virtual driving environments are much more realistic. The laboratory-based protocol using simulated driving tasks to examine performance has been shown to reflect driver sleepiness as tested in a real car, with regards to increasing subjective sleepiness and lane drifting. This knowledge, coupled with the many extraneous variables inherent in field based driving studies would suggest that simulator based research is an extremely useful experimental tool for the examination of driver sleepiness and potential countermeasures.

Improvements to the Driving Simulator

As I have already mentioned, driving simulation is becoming more and more powerful, with more realistic road generation software allowing greater control and manipulation of traffic systems, road types and vehicles. The current setup does have several limitations, which become apparent with extensive use. In particular, the two lane nature of the road means that motorway driving cannot be replicated. This is important as many SRVAs are thought to occur on this type of road. Secondly, the simulator does not mimic night-time driving, again important as the driving task itself changes with changes to visibility. As well as these software issues, the nature of the driving interface (the front section of a car), is not as realistic as it could be (eg. using a complete vehicle, with steering column intact to generate increased resistance and thus more realistic controls).

Further Research

The most interesting finding to come from this study was the identical progression of subjective sleepiness as measured by the KSS. This scale has been used extensively (Horne & Reyner, 1996; 2001a; Reyner & Baulk, 1998; Reyner & Horne, 1997), and closely matched to EEG changes (Åkerstedt & Gillberg, 1990). This is an important issue for several reasons. There are legal implications as drivers who fall asleep can be seen to go through a prolonged period of increasing sleepiness before falling asleep, and are therefore able to stop driving (but do not). This study has clearly shown that drivers own insight into their sleepiness is identical in both real and virtual driving conditions. This is an interesting finding because it suggests that subjective sleepiness (and in particular the KSS) may be even more sensitive than was expected, and supports the findings of Reyner & Horne (1998b) that drivers are aware of sleepiness prior to a sleepiness-related accident. As the focus of much driver sleepiness research is based on development of technologies to detect increasing sleepiness, this could provide a standard against which to test them – i.e. which is more effective, the 'device' or the driver's own perceptions ? After all, the aim of such a device is to identify and warn of the onset of sleepiness *before* the driver realises it is there. This seems an unlikely principle, but does require some further investigation.

If the brain is able to do this reliably already, but drivers ignore the warning signs and continue, then how can a device be expected to be effective ? This was noted by Lisper et al (1986) stating 'what is the use of alerting a driver already aware of the fact that s/he is close to sleep but who unwittingly still continues to drive ?' With this in mind, the next chapter aims to measure the sensitivity of the KSS against a common technological concept used in the identification of sleepiness. It was expected that further limitations of the technological approach would become apparent, and lend weight to the more practical direction. These issues are discussed in chapter 4.0.

KEY POINTS

- The KSS was a good indicator of increasing sleepiness, and was clearly related to the increasing incidence of lane drifting.

- The simulator and closed road-circuit protocol demonstrated similar results, thus validating the simulator as a methodology for investigation of driver sleepiness and potential countermeasures.

- The closed road-circuit protocol was successful but logistically complex, more expensive, and offers much less control than the laboratory environment of the driving simulator.

- The study highlighted the lack of realism in the driving simulator, which could be improved with the addition of motorway and night-time driving modes, and perhaps even a full size car.

This work was supported by the UK Department for
Transport, Local Government and the Regions (DTLR).

Presented at the 14th Congress of the European Sleep Research Society, Madrid (1998):

Baulk, S.D., Axelsson, J.S., Reyner, L.A. & Horne, J.A. (1998)
Driver Sleepiness: 'Real world' validation of simulator studies.
Journal of Sleep Research, 7; Supplement 2.

4.0 TECHNOLOGICAL COUNTERMEASURES

Secondary Task Reaction Time

4.1 SUMMARY

The *technological* approach to the formulation of countermeasures to driver sleepiness has become increasingly popular in recent years. The aim here is to design a system (or 'device'), which can reliably identify increasing sleepiness in drivers, and then warn them that it is time to stop driving. This approach has followed 3 main directions, based on the parameters used by the device to recognise drowsiness: *physiological* measures such as blink rate, have been used to distinguish the biological onset of sleepiness; *behavioural* measures, such as steering corrections, have been used to mark associated changes in performance; and finally the *secondary task* method measures the 'spare capacity' of drivers by monitoring additional responses until they fall below an 'acceptable' level. The technological approach is problematic for many reasons, and thus far seems slow to achieve any real success. Despite this, the use of reaction time (RT) as a secondary task measurement has been particularly popular, working on the principle that drivers' responses will become slowed or displaced in some way when sleepy. However, little is known about the reliability and sensitivity of RT in the context of driving (Maycock, 1998), and particularly in comparison with, for example, an established subjective measure of sleepiness, such as the Karolinska Sleepiness Scale (KSS – Åkerstedt & Gillberg, 1990). Interestingly, it may be that the very addition of the secondary task actually alters task load and alerts drivers. This could affect their driving behaviour, and depending on the level of stimulus, perhaps even cause some distraction. Clearly, these issues must be resolved if any success is to be achieved using secondary task reaction time as the basis for a sleepiness-detecting device.

The aims of this study were to investigate the extent to which RT reflects increasing afternoon sleepiness relative to other experimental measures, and also how its measurement while driving affects driving behaviour. Ten participants (6 male and 4 female) aged 20-29yrs, with a mean age of 22.90yrs (±3.28yrs) participated in a repeated measures design, whereby they drove an interactive, fixed-base driving simulator on a computer-generated monotonous roadway for two, 2.5hr afternoon drives, with and without an additional secondary RT measurement (counterbalanced), following a night of sleep restricted to 5hrs (between 0200-0700 – verified by overnight actimetry). Subjective sleepiness data was collected throughout both conditions every 200 seconds using the KSS. Driving performance data were collected using video cameras, and analysed manually for lane drifting. EEG data were recorded and spectrally analysed for increasing power in the 4-7Hz (theta) and 8-11Hz (alpha) frequency bands, which are known to reflect increasing sleepiness (Horne & Reyner, 1996). Participants also responded to simple auditory RT, with a semi-random, inter-stimulus interval averaging 2½ minutes, by pressing a steering-wheel mounted microswitch.

For both conditions subjective sleepiness, lane drifting and EEG measures showed significant changes across time to reflect increasing and then decreasing sleepiness during the afternoon circadian 'dip' in alertness. This was not reflected in RT however, which remained relatively stable throughout the drive. Differences between the two conditions showed that the additional RT task did alert subjects, significantly reducing subjective sleepiness, with trends for fewer incidents and a more alert EEG. RT measurement did not reflect changes in driver sleepiness, and rather served as a mechanism to increase task load and alert drivers although without distracting them from the primary task or having a negative effect on driving performance. Subjective ratings proved far more sensitive to increasing sleepiness than the additional RT element. Some small sex differences were noted also, with females appearing to experience more sleepiness than males. These will be investigated further in the studies that follow. The limitations of RT, as well as technological countermeasures in general are discussed in relation to the promise of the potentially more effective *practical* approach, as investigated in chapter 5.0.

4.2 INTRODUCTION

Countermeasures to driver sleepiness are widely varied, but generally fall into several clearly defined categories. *Education* is generally ongoing and seems to be making progress through changes to the UK highway code, new warning signs on motorways and trunk roads, and increased general awareness of the problem. *Practical* countermeasures such as regular rest breaks, strategic naps and psychostimulants are also being investigated for use by drivers (see chapter 5.0). Increasingly popular however, is the *technological* approach. Car manufacturers and engineers are aware of the problem, and have attempted to design and build devices which can detect increasing sleepiness and warn drivers that it is time to stop. These have been widely varied, but so far none have proved their effectiveness to any notable degree. This chapter aims to evaluate this technological approach, and outlines a study to determine the efficacy of a popular system concept, that of *secondary task reaction time.*

Great emphasis has been put upon the development of devices designed to detect and warn of increasing sleepiness, but there has been little agreement about what the output of such a device should be. Research centres on the method of *identifying* sleepiness, and few systems have successfully made it past this aspect of the design. These systems have centered on 3 main measurement types:

Physiology

Systems based on physiological measures from the driver have been designed to detect the onset of sleepiness using parameters such as heart rate or body temperature. This approach is problematic however, because the process of falling asleep while driving is different to falling asleep naturally. Drivers put great effort into staying awake in order to avoid accidents - much different to the process of falling asleep naturally when we expect to do so (Ogilvie et al., 1989; Horne & Reyner, 1999). One example has been to use blink rate to identify increasing sleepiness (e.g. Stern et al., 1994). This is problematic for two reasons: individuals have been seen to reach states of extreme sleepiness with the eyes open (Miles, 1929; Horne & Reyner, 1996) and secondly blink rate is also affected by other factors such as air temperature, humidity, and smokiness (Horne, 1988), leading to *fatigue* of the visual system, which is not synonomous with sleepiness. These methods rely on the drivers co-operation since they typically involve some intrusion through the attachment of electrodes or sensors, possibly discouraging drivers from using them. Physiological devices have had limited success, but research continues using more complex concepts such as blink *duration* (Häkkänen et al, 1999) and the *percentage* of eye closure – a system known as PERCLOS (Stutts, 2000). One study has even suggested *observer* rating as a method of identifying sleepiness in drivers (Wierville & Ellsworth, 1994), using an image of drivers' faces to study eye movements and facial expression.

Driver Behaviour

Other systems have been geared towards using some direct measurement from the car itself (e.g. steering, braking or acceleration) to monitor changes in driver behaviour, and therefore detect the point when performance decrement suggests the onset of sleepiness. This method is seen as a particularly promising one since it does not involve any of the intrusion of physiological methods or the potential distractions of the secondary task method (see below). Problems have been encountered here however, in that some aspects relate to individual differences in normal driving behaviour, and/or the characteristics of the vehicle. Therefore, at least some calibration is needed in order to familiarise the system with each driver's 'normal' level. Most research in this area has focussed on steering control – the basic hypothesis being that increasing sleepiness causes increasingly fewer fine adjustments to steering (Riemersma, 1977; Fairclough, 1997). As noted by Brown (1997), there is some promise in this, although issues need to be addressed on the output of the system, thresholds for alarm trigger, and long term evaluation. One potential shortcoming of this method is that as driving behaviour is being used to measure sleepiness, it may well already be suffering once the device detects it.

Secondary Task

A third method is to think of sleepiness as measurable by the 'spare capacity' of drivers once attention has been allocated to the primary driving task. This is done using a *secondary task*, which drivers perform whilst driving. Theoretically, reductions in performance will indicate limited capacity and therefore increasing sleepiness. The advantage here is that the device may identify sleepiness before driving performance becomes impaired. One problem with this method however, is that spare capacity is needed by drivers due to the dynamic nature of driving, so safety may be compromised if drivers become distracted by the secondary task. The secondary task may also actually alert drivers and therefore be less able to detect sleepiness masked by the system. One system recently reported using an 'artificial passenger' to raise alertness by verbally interacting with the driver, and issuing warnings/stimuli if replies were slow, lacking in tone, or non-existent (Sample, 2001). More typical examples are auditory or visual reaction time whereby subjects respond to a light or buzzer using a hand or foot switch. This principle forms the basis of the study described below.

Reaction Time

Although research has clearly shown the sensitivity of RT to sleep deprived subjects in the laboratory (Dinges, 1994; 2000) as well as in the field using portable equipment (Corfitsen, 1993; 1994; 1996), we do not know that this is the case while driving, particularly under more realistic conditions such as during the afternoon circadian dip following a night of restricted sleep. These studies have typically used RT measurements as a simple, solitary task, rather than as a secondary task alongside a primary function such as driving. Research has shown that drivers may either respond normally despite increasing sleepiness, or not respond at all – rather than showing a gradual decline which could be picked up by mathematical processing within the unit (Riemersma et al., 1977). In other words, sleepiness does not simply increase RT but actually displaces it (Dinges & Kribbs, 1991). How does RT progress over time in the driving scenario ? Is this sensitive to sleepiness ? Are drivers alerted by the increase in task load ?

Motorists' responses in an emergency are thought to be affected by sleepiness in the same way as they are by alcohol. This has been examined experimentally, with the conclusion that moderate levels of sleepiness cause performance impairment equivalent to or greater than is legally acceptable for alcohol intoxication (Dawson & Reid, 1997). This impairment of responses in drivers has led to the popularity of in-car reaction time measurement, as a secondary task to monitor sleepiness, and/or alert drivers and prevent accidents. This has come in forms such as drivers pressing a steering wheel/dashboard mounted button or a foot operated switch adjacent to the clutch pedal, in response to a flashing light or auditory beep generated by a device within the vehicle. The assumption is that sleepy drivers will respond less quickly or miss responses altogether – and the device will pick this up (most devices trip into an 'alarm' mode when response time reaches a predefined unacceptable level). This assumption is not a straightforward one however, and creates problems because we do not know if reaction time is sensitive to sleepiness in the driving scenario. Driving studies have shown that subjects may respond normally to a stimulus (even though sleepy), or that they may not respond at all (a 'lapse' - Riemersma et al, 1977). Such findings indicate that RT is *disturbed* by sleepiness, but does not follow a progressive decline – clearly this questions the validity of any in car device using reaction time as its scientific basis. More basic research has also shown that decline in reaction time responses caused by sleepiness is not uniform, and lapses are more likely to occur, leaving the remaining reactions unaffected (Dinges & Kribbs, 1991). These findings are typically based on 24 hours of total sleep deprivation, but little is known about the effectiveness of RT at reflecting increasing sleepiness, following a lesser amount of sleep loss.

Missed responses to these stimuli may well be irrelevant since a sleepy driver could easily cause a collision within the time frame of the device – i.e. he or she may be driving off the road between stimuli. This may simply not be effective however, since it has been shown that we have at least a 50% chance of responding to auditory signals while in stage 1 sleep (Ogilvie et al., 1989). One might therefore suggest that an auditory stimulus is inappropriate and a visual system might yield better results. However, driving clearly involves intensive visual attention, and any superficial visual stimulus (typically a light on the dashboard) would easily be missed due to attention directed elsewhere, and of course there is an issue of safety if drivers visual attention is to be distracted from the road ahead. Driving is a visual motor task, and an effective device *should* make use of different inputs and outputs (Desmond & Matthews, 1997), so an auditory device may be the best choice after all.

As well as attempting to use RT as a method of measuring sleepiness, what may be more useful, is the idea of RT as a secondary task used to alert the driver. When driving on monotonous roads for example, the addition of RT may have an arousing effect. Clearly, a high stimulus frequency (e.g. average of about 30 seconds) could distract drivers from their primary task (attention to the road), but a lower stimulus frequency (about 4-5 minutes) is more likely to have an alerting effect and be sensitive to sleepiness. Ideally, a frequency-response study would determine the optimal stimulus frequency to maximise alertness. To put this in perspective however, in the protocol outlined for this study, such a study would be extremely costly and time consuming – since at least 10 subjects each completing 2 sessions each of two hours in length equates to 20 days (4 working weeks) of continuous testing – for baseline and a single stimulus frequency alone. In order to achieve reliable data, at least 4 frequency conditions (perhaps more) would be necessary.

This issue of *task load* is an important one, as has been suggested by previous simulator-based work. Reyner & Horne (1998a) showed that the effects of in-car countermeasures such as listening to the car's radiocassette were only minimally effective, although having a well-defined effect on drivers' perceptions of sleepiness – that is, they felt less sleepy throughout. There is a danger here that drivers are less aware of their increasing sleepiness because of the additional stimulus, or may become distracted by it if the immediate demands of the driving task suddenly increase – as is possible at any time. This has implications for new in car technologies such as mobile phones also, since sleepy drivers may be even more at risk from accidents due to an inability to maintain driving performance while using them (McKnight & McKnight, 1993).

Study Aims

We do not really understand what is being examined by RT within the driving scenario (Maycock, 1998). This study aimed to examine the application of simple RT using auditory stimuli, given with inter-stimulus intervals averaging 2½ minutes, within the context of moderate sleepiness, in the validated driving simulator. It also aimed to find out if RT data reflected sleepiness in the same way as other measurements, and more importantly how RT otherwise affected driving behaviour.

4.3 METHOD

Participants were ten volunteers (6 male, 4 female), with a mean age of 22.9 years (SD = 3.28), and a mean ESS of 4.35. The study used a repeated measures design, whereby participants drove for 2.5 hours (with a 30 minute break after the initial 30 minute 'warm-up' drive) following restricted sleep, in 2 conditions, both in the fixed-base driving simulator: with and without reaction time. See chapter 2.0 for full explanation of methodologies.

Statistical Analyses

For the 2 hour continuous drive, lane drifting incidents, EEG and subjective sleepiness data were averaged into four 30 minute periods per subject and condition, and two-way (condition x time) repeated measures ANOVAs were applied. RT data for the 2 hour testing period were analysed in 15 minute blocks, using a one way repeated measures ANOVA.

4.4 RESULTS

Subjective Sleepiness

Subjective sleepiness data for both conditions were plotted against time, to include the 30 minute preliminary warm up period, followed by the 2 hour drive. This data is presented in figure 4.1. As is clear from the graph, the addition of RT has some reductive effect on subjective sleepiness, particularly for the middle hour of the drive (the centre of the afternoon circadian dip). When assessed in 30 minute periods using ANOVA, subjective sleepiness was significantly less with reaction time ($F=7.89$; d.f. 1,9; $p<0.02$).

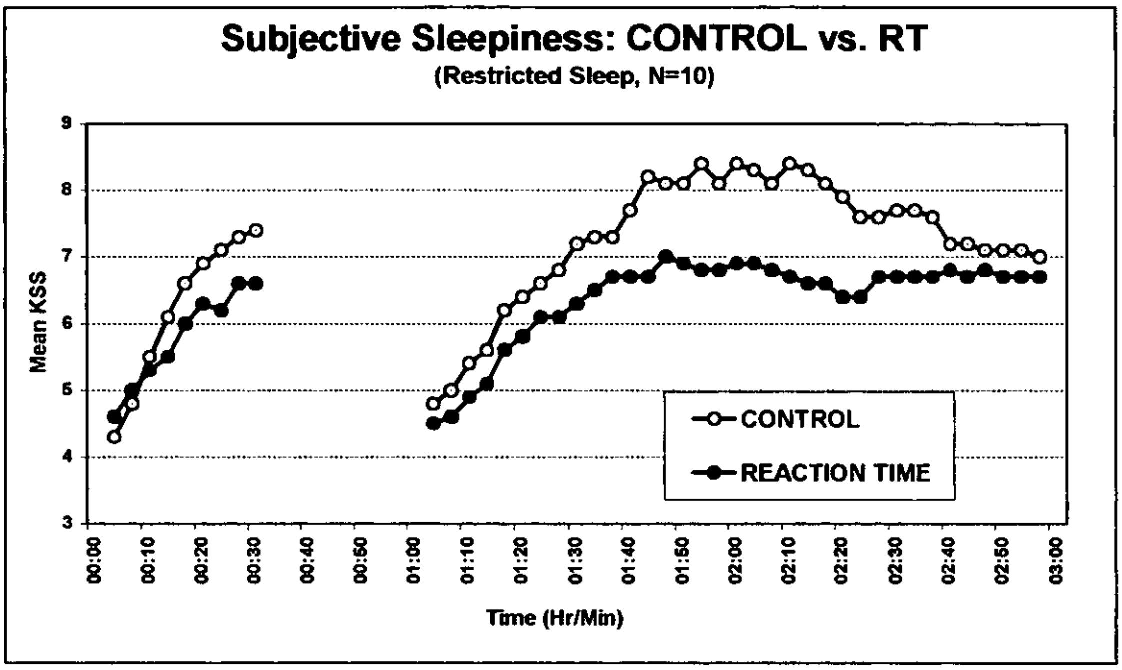

Figure 4.1

Mean Subjective Sleepiness Data over time for control and RT conditions

The effect of time was also significant (F=12.61 [d.f. 1.5,13.5] p<0.02). This time effect also showed a significantly quadratic ("inverted U") trend, with an increase in sleepiness during the mid-afternoon circadian dip, followed by an improvement in alertness. There was no significant interaction between condition and time. While it may be argued that there is an 'end of test effect' shown in the KSS data, some effort was made to make the approach of the end unknown to the driver through external cues (see section 2.1).

Data on likelihood of falling asleep (see figure 2.8) followed this pattern also, with drivers tending to feel less likely to do so in the RT condition, although this was not significant. This data is presented in figure 4.3, with points A-E on the scale converted to numerical data (1-5, see figure 2.8). The effect of time was significant however (F=9.87 [d.f. 3, 27] p<0.001).

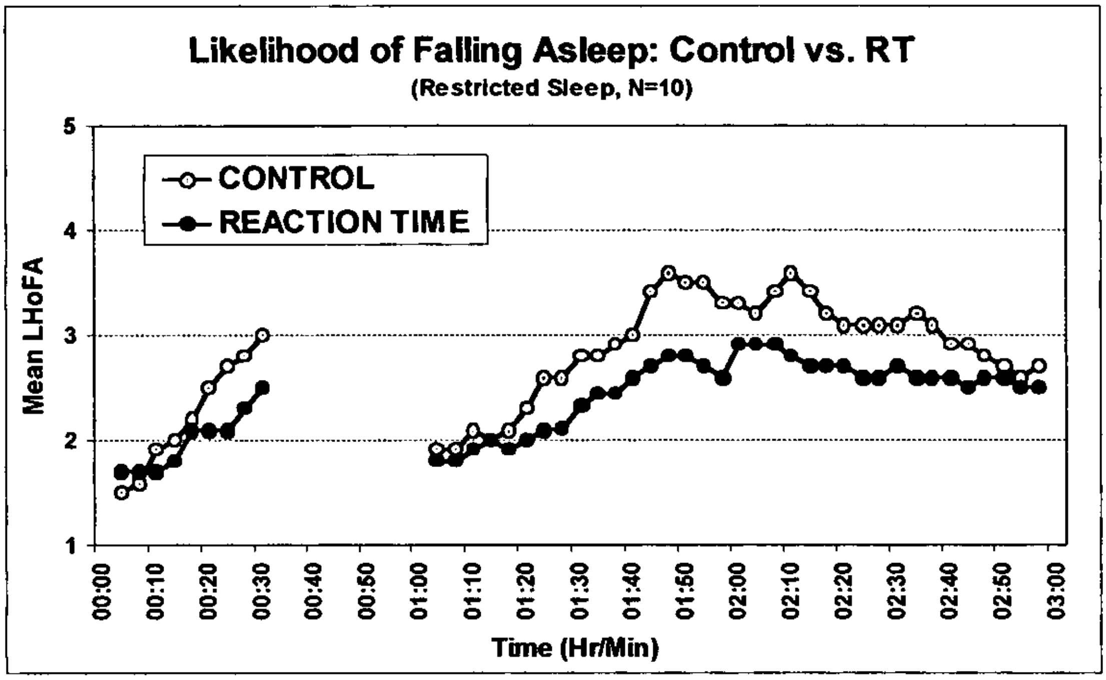

Figure 4.2

Likelihood of falling asleep Data over time for control and RT conditions

Subjective sleepiness data from both KSS and LHoFA scales is shown in table 4.1, presented as the total number of epochs spent in each level of the scales for each of the two conditions..

		A	**B**	**C**	**D**	**E**
	CONTROL	**Very Unlikely**	**Unlikely**	**Possibly**	**Likely**	**Very Likely**
1	**Extremely Alert**	0	0	0	0	0
2	**Very Alert**	2	0	0	0	0
3	**Alert**	14	0	0	0	0
4	**Rather Alert**	13	8	0	0	0
5	**Neither**	14	23	1	0	0
6	**Some signs of Sleepiness**	7	43	6	0	0
7	**Sleepy but no effort to stay awake**	0	54	54	0	0
8	**Sleepy, some effort to stay awake**	0	23	70	13	6
9	**Very Sleepy, great effort to stay awake**	0	0	2	47	40
		A	**B**	**C**	**D**	**E**
	REACTION TIME	**Very Unlikely**	**Unlikely**	**Possibly**	**Likely**	**Very Likely**
1	**Extremely Alert**	0	0	0	0	0
2	**Very Alert**	4	0	0	0	0
3	**Alert**	14	12	0	0	0
4	**Rather Alert**	48	8	0	0	0
5	**Neither**	39	7	15	0	0
6	**Some signs of Sleepiness**	15	9	59	1	0
7	**Sleepy but no effort to stay awake**	3	29	46	5	0
8	**Sleepy, some effort to stay awake**	2	14	48	13	0
9	**Very Sleepy, great effort to stay awake**	0	0	13	27	9

Table 4.1 – Progression of subjective ratings – The Subjective Sleepiness Matrix

This demonstrates drivers' typical progression through the subjective scales. Most notable is the lower left hand corner of each section, as this denotes a high level of sleepiness (KSS >5), but without the realisation that this will lead to falling asleep (LHoFA = A or B). This is most clearly demonstrated in figure 4.3. This graph shows the effect of the addition of RT on drivers perceptions of LHoFA – using the difference in the number of epochs spent in each level between the two conditions.

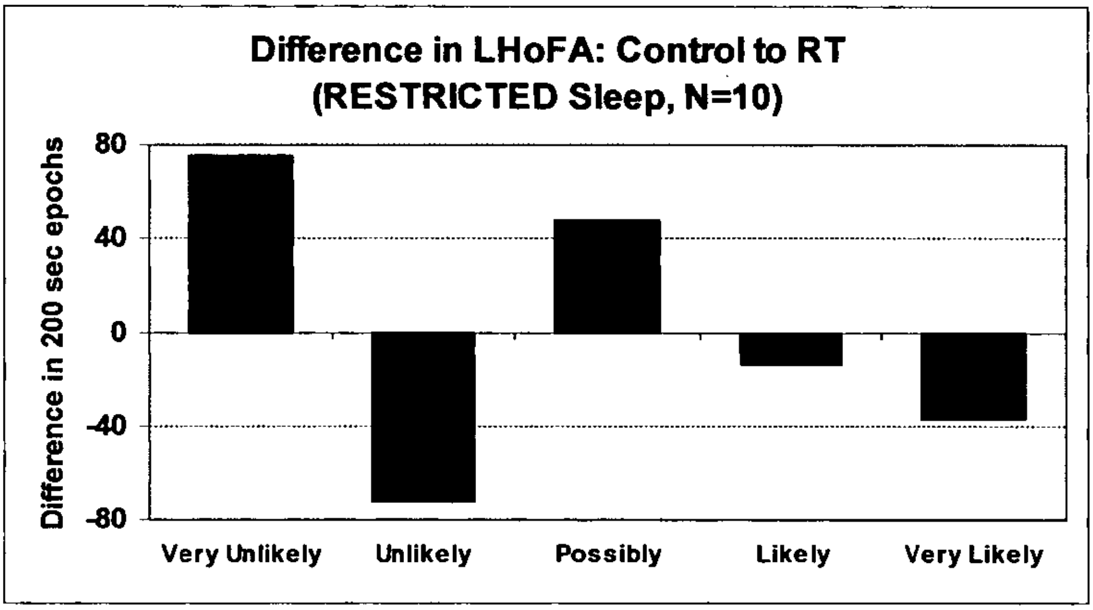

Figure 4.3
Change in LHoFA ratings due to addition of RT

Driving Performance

The data on lane drifting incidents taken from the video analysis was plotted against time for the two conditions in 30 minute periods. This data is presented in figure 4.4.

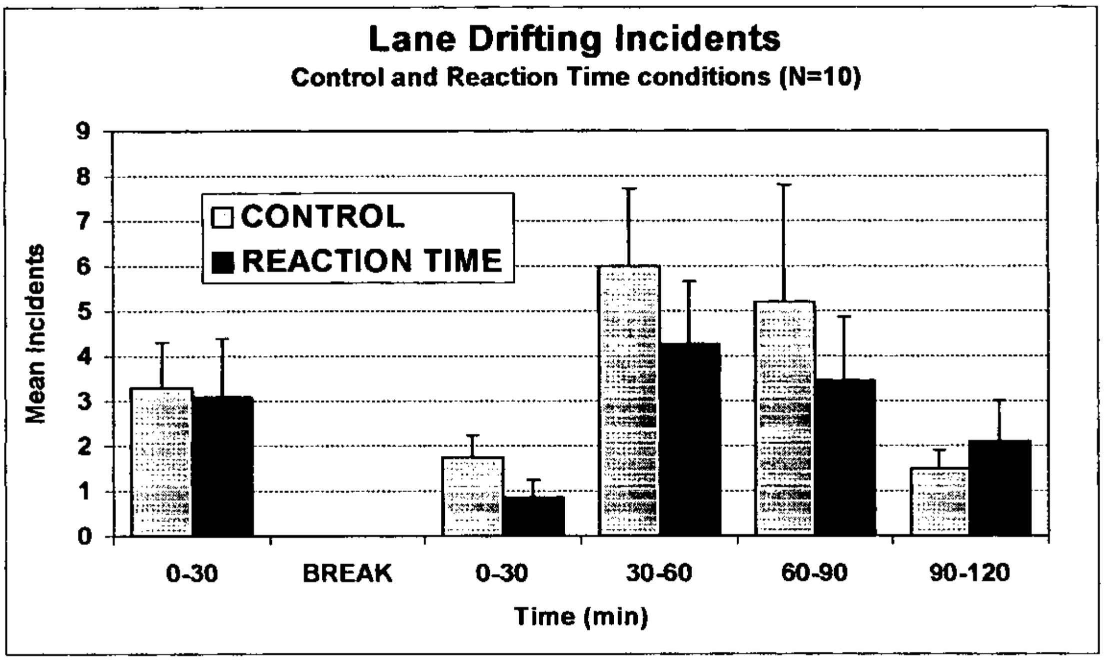

Figure 4.4

Lane Drifting Incidents related to sleepiness over time for control and RT conditions

During the 2 hour driving period there was a trend for incidents to be lower with RT, but this effect was not significant.

Again, there was a significant effect of time (F=6.31; d.f. 2.5, 22.2; $p<0.004$), that was also significantly quadratic. There was no significant interaction.

In order to examine the relationship between subjective sleepiness and lane drifting further, the driving incidents were plotted against the levels of the KSS in which they occurred. This data is presented in figure 4.5. The control condition demonstrates a clear increase in incidents with subjective sleepiness, whereas the RT condition seems to have a more even spread of incidents across the last 4 levels of the KSS.

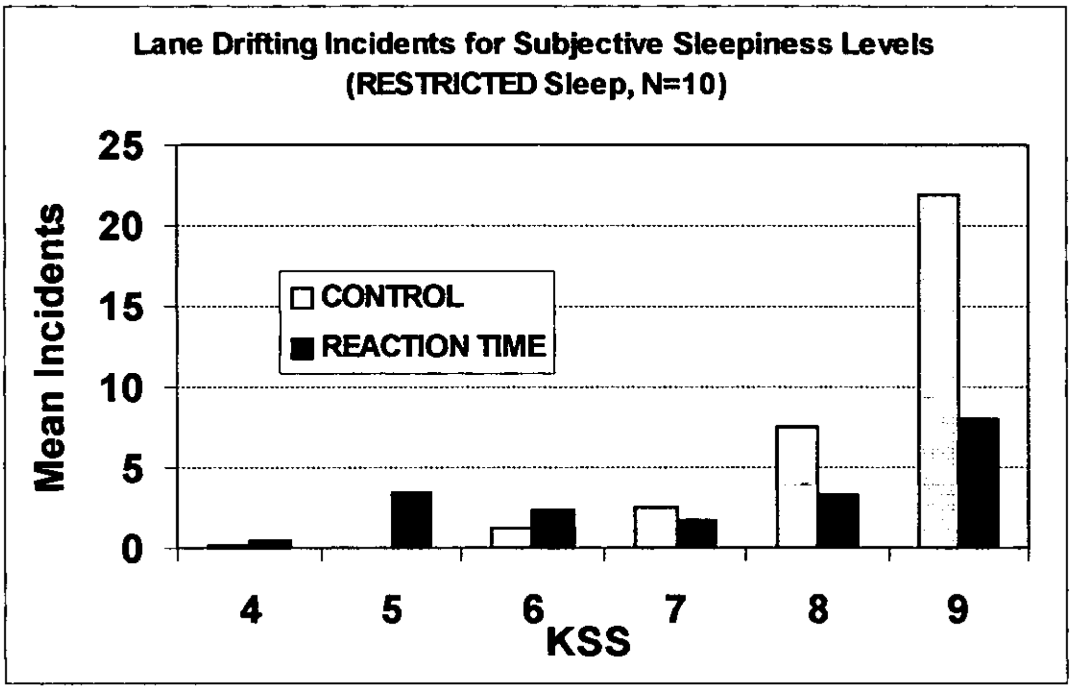

Figure 4.5

Lane Drifting Incidents for each category of the KSS (all were ≥ 4)

EEG data were standardised and averaged across participants (see chapter 2.0). This data was plotted against time and is presented in figure 4.6, including the warm up and main 2 hour drives. Increased power denotes increasing sleepiness, with the zero line marking the mean of the preliminary driving period. This is regarded as the threshold for objective sleepiness (Horne & Reyner, 1996). Both conditions follow similar trends for the first hour or so, with RT leading to a more alert EEG for the last 45 minutes of the drive. Despite this trend, there were no overall significant effects for either condition or time.

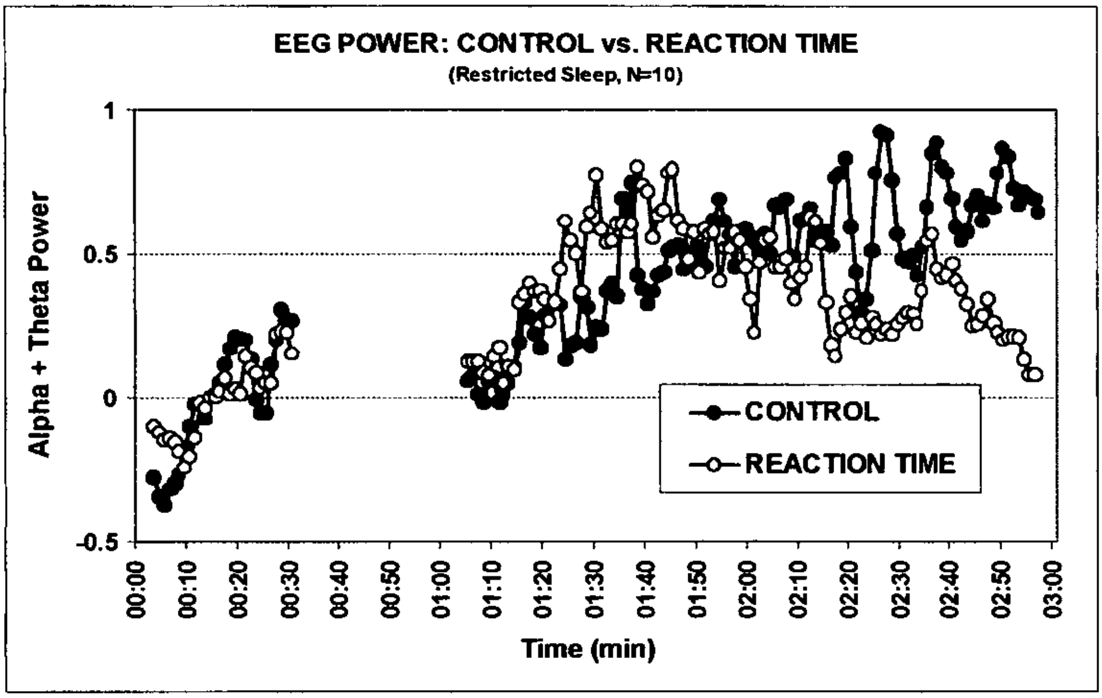

Figure 4.6

Standardised Alpha and Theta EEG Power over time for control and RT conditions

Reaction Time

Reaction time data (adjusted for lapses – see chapter 2.0) were averaged across participants, and plotted against time in 15 minute blocks. This data is presented in figure 4.7, again, showing both the warm up and main 2 hour drives, with standard error bars. As the graph shows, RT levels remained relatively constant throughout, with only small, non-significant fluctuations. There were no significant effects of time.

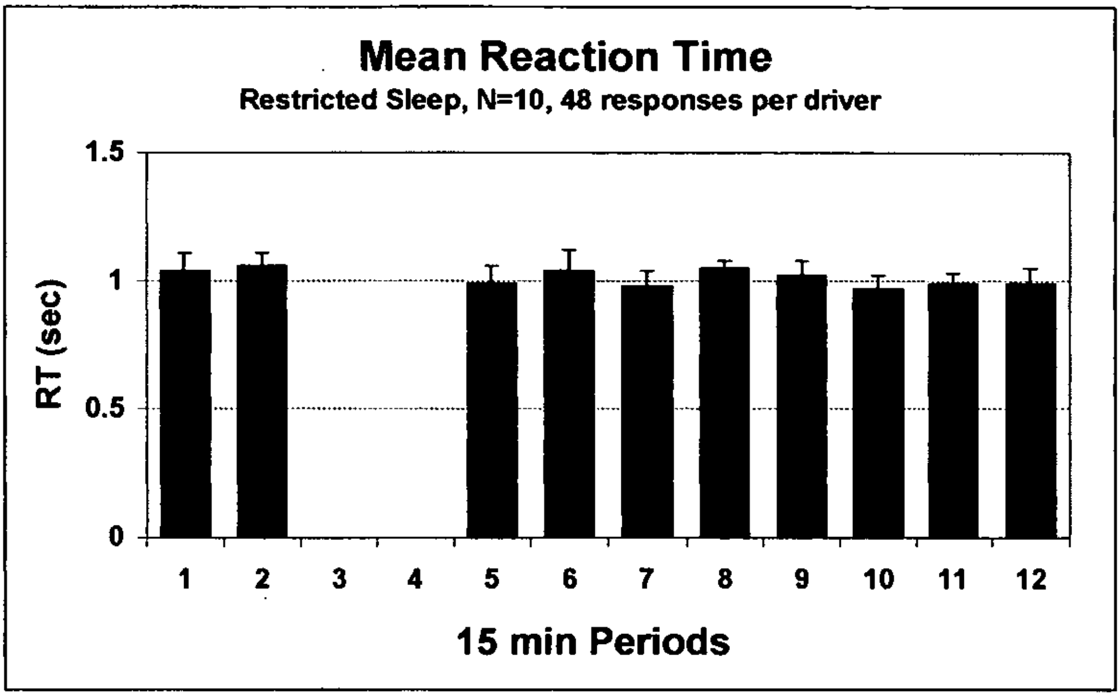

Figure 4.7

Mean Reaction Time data in 15 minute periods

In order to compare this with subjective sleepiness data, KSS and RT trends were plotted together over time in 15 minute periods. This is shown in figure 4.8.

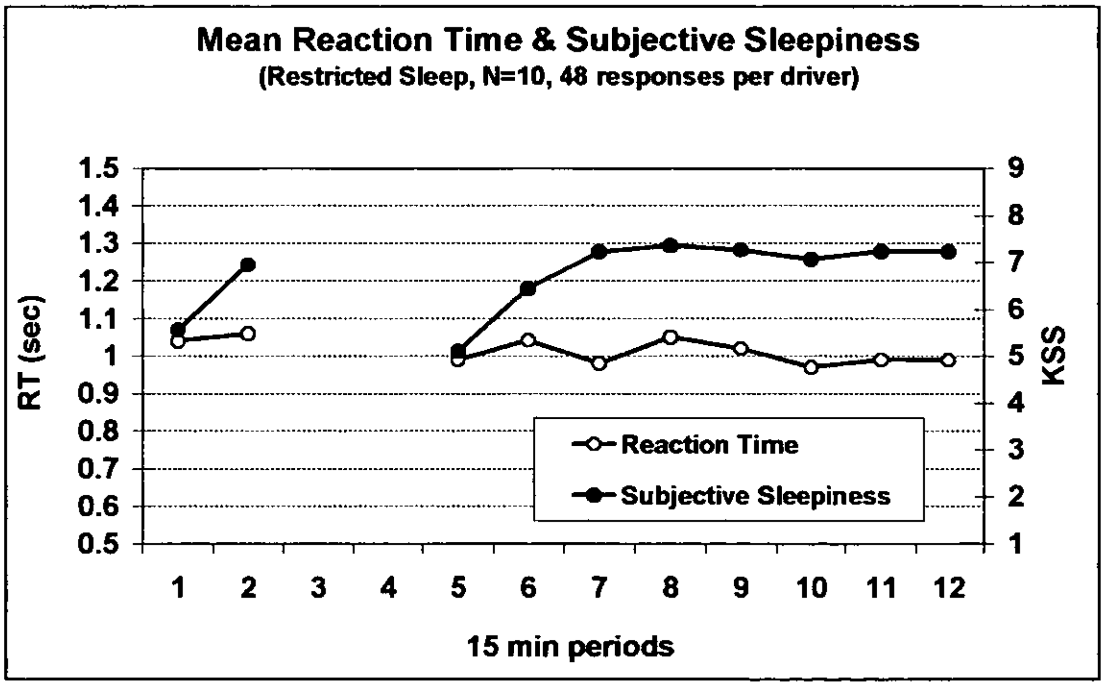

Figure 4.8

Subjective Sleepiness and RT data over time

The correlation between these values over the 2 hours was non-significant at r=0.08 (df=9). RT data were checked for 'lapses' (response times in excess of two seconds). These occurred for only three out of a total of 480 RT responses (48 for each participant). Although each was also associated with a driving incident, the reverse was not true. For the majority of driving incidents, which were indicative of lapses, there was no apparent RT lapse to be found in the nearest RT response, either preceding or following the incident.

Sex Differences

Another interesting observation was that there were some subtle differences between the sexes for subjective sleepiness under both conditions. These are summarised in figure 4.9.

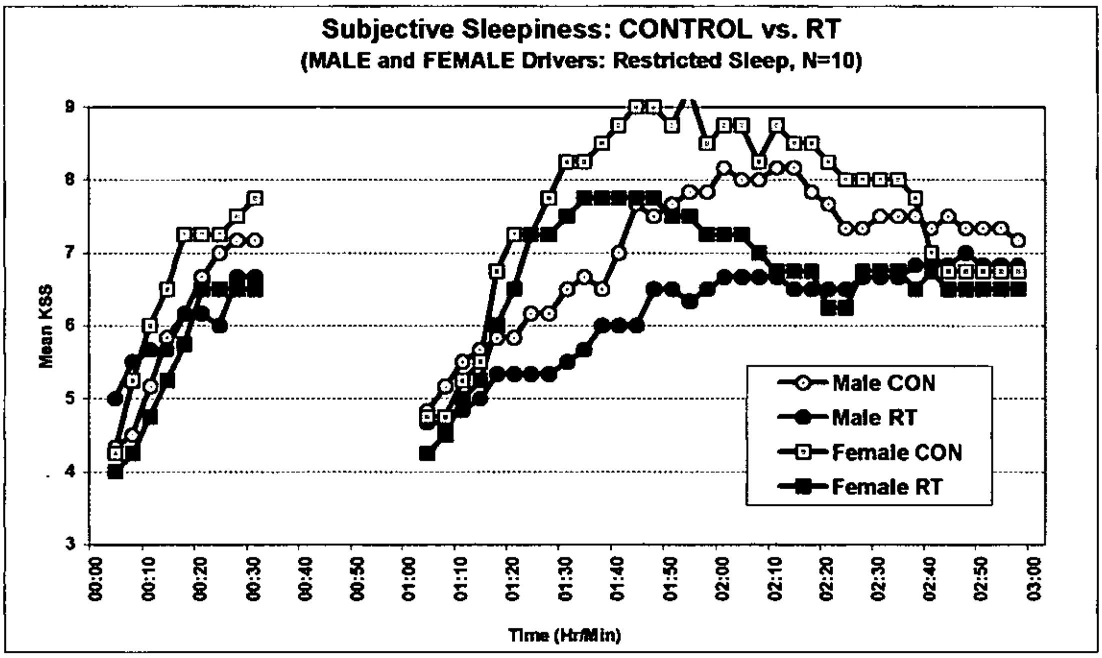

Figure 4.9

Subjective Sleepiness over time for control and RT conditions for Male and Female drivers

Although the number of drivers was not sufficient to warrant a reliable statistical comparison for gender, this is still an important finding. As the graph shows, the female drivers typically experienced greater sleepiness than the males. This was also the case for the likelihood of falling asleep scale, as shown in figure 4.10. In particular, females felt far more likely to fall asleep in the control condition.

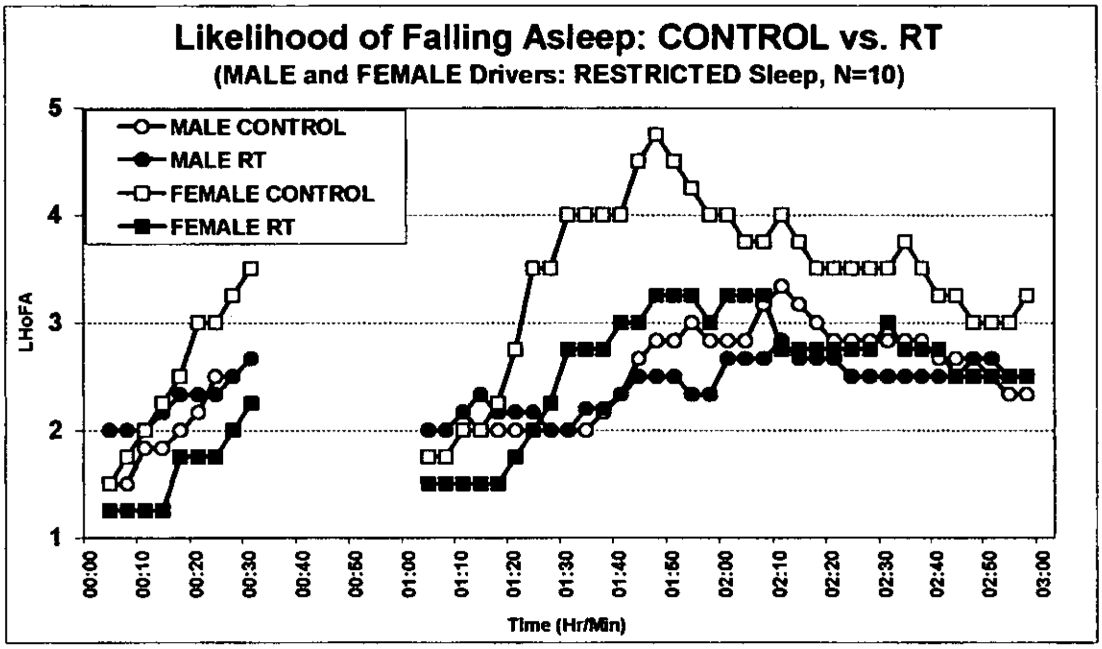

Figure 4.10

Likelihood of falling asleep over time for control and RT conditions for Male and Female drivers

4.5 DISCUSSION

Under these driving conditions and level of sleepiness, the auditory RT setup was not sufficiently sensitive to sleepiness and lapses in driving ability, even though there were manifest signs of sleepiness in the form of increased incidence of lane drifting. However, the additional RT task provided more activity and "stimulation" for the sleepy driver during the monotonous drive, thus reducing subjective sleepiness and somewhat improved driving ability as measured by the incidence of lane drifting. In particular, drivers rated themselves less likely to fall asleep in the RT condition, though not necessarily feeling less sleepy (see table 4.1). This leads to the suggestion that the RT device could make drivers complacent, assuming that it will keep them awake. Clearly this is a dangerous situation to encourage.

There are various reasons for the disparity between driving incidents and RT performance. The RT stimuli occurred on average every 2½ minutes, whereas the average interval for the incidents was approximately 7 minutes. As each event (incident or RT response) only occupied a second or so, it is unlikely that both would coincide, especially as the RT task was an externally paced event, whereas the incidents were caused by the driver. Also, both types of event could alert the driver for a while, and facilitate normal behaviour with respect to the next RT stimulus or potential for lane drifting.

It has been noted previously (Reyner & Horne, 1998b) that sleepy drivers have good insight into their own level of sleepiness. The findings of this study for KSS data support this, but it also seems that subjective sleepiness can provide a better gauge to this sleepiness than the measurement of RT.

What must seem to be problematic RT devices, are being commercially aimed at sleepy drivers. A recent study (Reyner, Barrett & Horne, 1999) examined one of these, claimed by the manufacturers to help maintain or improve driver alertness. Although based on auditory RT, it was more demanding of the driver's attention than was the case here. Alert drivers could cope adequately with both driving and the RT system, but when they became sleepy the device distracted them from the immediate driving task, leading to more incidents. This made them realise that they were having difficulty coping, which in turn heightened their perception of sleepiness. However, the RT responses showed no clear or consistent changes, indicating that the sleepy drivers put more compensatory effort into their responses (perhaps in order to avoid triggering the loud and rather annoying alarm), at the expense of driving ability.

Clearly, the application of RT as some kind of detection for sleepiness is not a simple one. Many aspects of the concept need further investigation – and I think more importantly, even if this could be made effective and reliable, longitudinal studies would be necessary in order to investigate adaptation effects which may well eradicate any reliability after a few months of using the device. Added to this, we cannot be sure that reliability would apply to the entire population of drivers, as dual task performance has been found to decline with age (Crook et al., 1993). It seems that although well meaning, much research on the use of devices, is really geared to making the device work without sufficiently thinking ahead to ensure that the effects are sustained. As has been suggested (Horne and Reyner, 1999), we should not put too much faith in devices, thus complicating a simple matter of common sense. Ultimately also, even the most reliable device still cannot stop the driver from driving. If this is the case are we not simply complicating the issue by adding additional elements and making excuses for driving when sleepy?

Added to this, is it ethical to encourage drivers to rely on technology to detect sleepiness when they must still be legally and morally responsible themselves? Indeed, can we really expect to design a system which can detect sleepiness before we can? Even if this is possible, how can we ensure that the driver won't ignore it? If a device tells me I am sleepy before I realise, what prevents me from concluding that the device is wrong, or over-sensitive?

Technological Feedback

While some researchers have suggested a subtle approach to driver warning, others have even hinted at the possibility of the device actually taking control of the vehicle, despite the obvious risks to other road users (Richardson, 1995). Assuming that some reliably successful system can be designed to detect increasing sleepiness, what should its output be ? This question has received very little attention, as research tends to concentrate on the inputs and processing required to detect sleepiness (Haworth et al., 1989). Effectively a successful device must be *more* capable of detecting sleepiness than the driver, and deliver this message in a way that does not distract or irritate.

One of the problems with technological countermeasures is that the time taken to design, evaluate and test them is long, and many different ideas are tried out by different people. Ultimately, the *concept* may be flawed, as devices *complicate* the driving scenario, taking away the emphasis from the driver. This is a dangerous direction to take since the driver is in control of the vehicle and may not rely on a device which tells him he is not fit to do so. Technological devices have attempted to measure sleepiness from several different physiological variables, but essentially the brain already monitors all of these together in a way that could not be replicated in a device. Thus the driver's own perceptions of sleepiness are the best method of measuring this in terms of countermeasures. This is an important area for future work also, as accidents increasingly occur wherein drivers claim to have 'suddenly' fallen asleep. Although this has been investigated previously (Reyner & Horne, 1998b), in a group of 28 drivers, subjective sleepiness was the main focus of the study, and EEG data were not included in the analysis. Future work could examine this relationship between EEG, subjective sleepiness and sleepiness-related lane drifting, and demonstrate the power of driver's own perceptions against objective physiology.

As a result of this study, together with the findings of others concerning secondary task RT (Reyner & et al, 1999), and in car countermeasures to driver sleepiness (Reyner & Horne, 1998a), the issue of *distraction* arose. A key issue here seems to be *task load.* That is, up to a point, additional stimuli may alert the driver, until a level is reached where he actually becomes distracted by it. In the context of driving this is very interesting, because the scenario is by nature continuously dynamic and at any time the 'spare capacity' may be called upon by the changing environment. How is this relationship affected by sleepiness? Although not sensitive to increasing sleepiness here, the addition of RT did alter driver's subjective sleepiness, as well as their driving performance due to the changes in *task load.* This has important implications for issues such as mobile phone use, and indeed, technological devices based on the secondary task concept. Certainly, it would seem that RT may be more useful as a tool for reducing sleepiness than measuring it. The driver's own insight into their sleepiness had much more validity as a tool for assessing sleepiness. This is important, because it is only drivers themselves who can decide to stop driving when sleepy. Therefore, countermeasures should focus on the *driver*, rather than *vehicle* or *device*.

Research centering on the use of blink duration as a warning system (e.g. Hakkanen et al., 1999), combined with that using visual assessment of sleepiness (Wierville & Ellsworth, 1994), seem to point towards the potential of camera-based systems. Although this may seem problematic in terms of social acceptance and intrusion, the transition to a 24 hour society already brings with it heightened security, and cameras in many more areas. Society has become much more voyeuristic and is more at home with the idea of watching people, and of being watched, noted over 50 years ago by the author of '1984' (Orwell, 1949). This can be seen in the popularity of 'reality television shows' based on hidden cameras, and fly-on-the-wall documentaries. The addition of cameras and black-box type recorders for some professional drivers is much more acceptable today than it was 10 years ago. Indeed, the West Yorkshire Fire Service in the UK has already started installing cameras in its fire engines, as a result of incidents of violence in urban areas (Wood, 2001). It is possible that this could form some future intervention to driver sleepiness – at least for professional drivers.

This sensitivity of drivers to their own sleepiness is interesting, because they do continue to drive, even when sleepy. It seems that the best method of counteracting this sleepiness is to concentrate on education and raising awareness of the problem so that drivers can recognise their sleepiness and also that it is highly dangerous. This programme of education has been slow in materialising, as road safety campaigns in the UK have tended to concentrate on problems such as speeding and alcohol. As well as awareness of the problem itself and how to recognise it, a successful campaign must address the issue of practical countermeasures, because we cannot assume that sleepy drivers will simply stop driving upon realising how tired they are. The trip momentum, work and leisure motivations will cause drivers to complete their journeys, so we must be realistic and aim to compromise with these motivations. If we encourage drivers to take rest breaks regularly, and suggest effective measures they can take within these, then the resulting awareness will undoubtedly reduce the number of deaths due to driver sleepiness.

The technological approach is theoretically flawed, complex and driven by a desire to invent the ultimate device which can monitor more effectively and further ahead than the brain, *and* warn the driver in a way that does not annoy, distract, or too greatly alarm him. In short, devices show very limited promise and much greater difference can be made in 1 or 2 years with education and practical countermeasures than is anticipated in 5 or 10 with technological ones (Brown, 1997).

Interestingly, the data from this study also show some difference between male and female drivers. Although there were too few subjects of each sex to enable statistical comparison, this is an important finding. It is well known that male drivers are greatly over represented in accident statistics (SRVAs), but it would seem that females at least *feel* more sleepy. This is an unexpected finding, which has been investigated further in the chapters that follow.

KEY POINTS

- Reaction time did not reflect increasing sleepiness during driving, showing only small and non-significant fluctuations over time.

- Self-ratings were far more effective at assessing driver sleepiness than reaction time.

- Reaction time is a complex measurement, and a key issue is task load: the nature of driving is dynamic, and spare capacity is needed suddenly. The secondary task concept therefore seems flawed.

- Reaction time may be more useful as a method of increasing driver alertness, though this too is problematic, as drivers feel less likely to fall asleep – effectively relying on the device to prevent this.

- The technological approach to countermeasures is complex, problematic and has been slow to achieve success generally. More practical methods may be more effective at reducing sleepiness, and therefore more beneficial for drivers.

- Some small sex differences in subjective sleepiness were found, which may be examined further in other studies, since the design employed here does not support statistical comparison. These differences showed that females may experience more sleepiness than males.

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5.0 PRACTICAL COUNTERMEASURES

Functional Energy Drinks

5.1 SUMMARY

As outlined in chapter 4.0, technological countermeasures to driver sleepiness have been slow to achieve success, and in principle, take the emphasis away from the driver. This is a questionable approach, and one which can over-complicate the problem. More rapidly effective, *practical* countermeasures have also been evaluated – the results informing education to raise awareness and change drivers' attitudes, making them realise that they are morally and legally responsible. The most effective countermeasure to sleepiness undoubtedly is sleep, but this advice is often ignored by sleepy drivers for a number of reasons. Practical countermeasures to sleepiness are necessary to prevent accidents, and since drivers are often highly motivated to keep driving, advice must achieve a balance between reducing sleepiness, and allowing them to continue safely. Psychostimulants such as caffeine can improve alertness, and are the most effective alternative to sleep (Horne & Reyner, 1999). Previous research has also demonstrated their effectiveness in counteracting driver sleepiness (Reyner & Horne, 1997; 1998a; 1998b). This is now recognised nationally, and resulted in the inclusion of new advice for motorists in the UK Highway Code (November 1999). Variation in the caffeine content of coffee however, combined with the increasing popularity of 'functional energy drinks' (FEDs) has prompted some interest in their use for helping people to stay awake while working at night or driving long journeys. These drinks contain a fixed amount of caffeine (about 80mg per 250ml can), and are widely available. How effective are they using typical, realistic doses, at reducing subjectively and objectively measured sleepiness ? Do they also have an effect on driving performance ? What are the implications for advice given to sleepy drivers ?

Two studies aimed to evaluate the efficacy of different dosage levels (250/500ml: one or two cans) of a commercially available FED, taken during a 30 minute break from driving in the mid afternoon, at reducing subjective and EEG measures of sleepiness, as well as lane drifting. Each study involved twelve drivers, who participated in a repeated measures design, whereby they drove an interactive, fixed-base driving simulator on a computer-generated, monotonous roadway for two, 2.5hr afternoon drives, consisting of a 30 minute warm up drive, a 30 minute break including consumption of the 250 or 500ml drink, followed by a 2hr drive. Drinks were either the active FED (80mg caffeine per 250ml), or similar 'control' drink (containing no active ingredients). These were administered double blind, conditions counterbalanced, and participants were randomly assigned to the two dosage groups. For the 250ml study, participants were 12 adults (8 male, 4 female), with a mean age of 21.92 yrs (±1.93 yrs). For the 500ml study, participants were 12 adults (9 male, 3 female), with a mean age of 22.5 yrs (±2.75 yrs). Sleep was restricted to 5hrs (between 0200-0700 - verified by overnight actimetry) the night before all testing conditions in order to augment the natural tendency for afternoon sleepiness. Subjective sleepiness, EEG and lane drifting data were collected as described in chapter 2.0.

For all conditions subjective sleepiness, lane drifting and EEG measures changed across time to reflect the characteristic development of sleepiness during the afternoon circadian dip. Differences between the control and treatment conditions showed that the 250ml FED dose significantly reduced subjective sleepiness, likelihood of falling asleep and the incidence of lane drifting for the first 60-90 minutes of the drive. There was also a trend for the EEG to reflect less sleepiness during this period. It was concluded that a 250ml (one can equivalent) dose of FED has a beneficial effect in reducing sleepiness and sleep-related driving incidents, under conditions of afternoon monotonous driving following sleep restriction. In comparison, the 500ml dose practically *removed* the incidence of lane drifting, and significantly reduced subjective sleepiness and likelihood of falling asleep for the remainder of the drive. EEG showed little or no sleepiness for 90 minutes, and only began to increase slightly during the last 30 minutes. Thus the higher dose had a stronger and longer lasting effect. The implications for practical advice to sleepy drivers on current practical countermeasures are discussed, particularly in relation to energy drinks in general, and for individuals who may be particularly at risk from accidents related to sleepiness, considered further in chapters 6.0 and 7.0. Functional energy drinks are an effective countermeasure to driver sleepiness, although they also have high potential for abuse. They promise more reliability in caffeine content than coffee, although direct comparisons are not supported by these studies. There is scope for further research on their use, particularly in terms of a) comparison with coffee, b) the other active ingredients, and c) the longer term effects on alertness and sleep onset. Again, minor sex differences were noted, although the study design did not support a reliable statistical comparison. This may be addressed using an additional study to directly examine driver sleepiness in male and females drivers (see chapter 7.0).

5.2 INTRODUCTION

As discussed in chapter 4.0, the technological approach for countermeasures to driver sleepiness is problematic, and has been slow to achieve realistic success. It seems clear that even if suitable systems are developed and brought into use within the next 10 years (Brown, 1997), the use of alternative, *practical* countermeasures could see positive results within 2 or 3. Education and awareness are highly important, and must be informed by scientific research into *practical* advice for sleepy drivers. Road safety campaigns on issues such as seatbelts, alcohol and speeding have all been seen to have a positive effect on motorists' attitudes in recent years. 'Drink driving' in particular, has now become socially unacceptable, and the same must be achieved for driving when drowsy, while also suggesting ways for motorists to stay alert.

Typically, the focus of driver education on sleepiness has been the 'take a break' concept, as shown by the now common road signs on UK motorways (initially 'Tiredness can Kill, Take a Break,' and later 'Tiredness Kills, Take a Break'). This advice was really based on common sense, following on from survey studies to investigate the extent of the problem (Horne & Reyner, 1995) in an attempt to make drivers think about getting off the road when tired. More in-depth experimental examination of such practical advice showed this to have little beneficial effect (Horne & Reyner, 1996), and new, more active practical countermeasures were investigated. This led to the advice now given in the UK highway code (updated November 1999). Drivers themselves often suggest popular ideas for staying alert during driving, such as winding down the window, or turning up the car's radiocassette system (Maycock, 1996). These too have been found to have only transient beneficial effects (Reyner & Horne, 1998a). While the idea of taking breaks is a good one, many drivers will continue driving after only a short time, and soon return to a similar level of sleepiness. Ideally these breaks should be combined with some practically relevant, active element to reduce sleepiness effectively for a significant length of time. It should be remembered that these should not be used to continue driving for extended periods – the ideas are intended only to aid sleepy drivers to travel far enough to a place where sleep is possible.

Without question, the best countermeasure to sleepiness is sleep. Ideally, drivers would plan their journeys to allow time for rest breaks every 60-90 minutes of driving, ensure that they are fully rested before setting out, and avoid driving at the more dangerous times of day such as in the early morning (0200-0600) and the mid-afternoon (1400-1600). However, particularly for professional drivers, commuters, and those who drive as part of their work, this is often impossible to put into practice. Trip momentum, work commitments, time constraints, lack of suitable places to stop and even personal safety issues all make continuing to the end of the journey more agreeable. Those who do stop, again constrained by time, will often push on after only a short break. What further advice can we offer to increase alertness during these breaks ?

Napping

One idea is to suggest a short nap during this break, aiming to refresh the driver. This idea has become popular in recent years, with the concept of *power napping* advocated by some Japanese businesses. Napping has been shown to be effective in increasing alertness in operational settings (Naitoh, 1992; Rosekind et al., 1995), a 4 minute nap providing the minimum for some improvement in alertness (Naitoh, 1992). Napping for longer than about 20 minutes is counterproductive however, due to descent into the deeper stages of sleep - resulting in sleep inertia upon awakening. It seems that 15 minutes is the optimum length (Naitoh, 1992; Gillberg et al, 1996b). This has also been extended into the driving area (Horne & Reyner, 1996) to show that naps of <15 minutes duration have a positive effect. However, this does present several problems for drivers. Although sleepy, many will be unable to nap given the opportunity. Dozing has been shown to be effective (Reyner & Horne, 1997), but is not ideal. Noise and distraction are also an issue, but more important to drivers are the problems of personal safety (particularly during night-time journeys and when stopping in remote areas), as well as how to wake up promptly (Horne & Reyner, 1996; 1999). Many drivers would be reluctant to nap for fear of sleeping too long and therefore interrupting their journey, particularly if it is related to work, and therefore time-dependant. Since napping may not be feasible for many drivers, other active solutions have been noted. Many drivers suggest that walking around for 10-15 minutes will have a beneficial effect. This has also been shown to be ineffective, and only improves alertness for a very short time. Food and drink, again providing an instant stimulus, do not alert a sleepy driver for long (Horne & Reyner, 1996).

Much more effective at increasing alertness are *psychostimulants*. Psychoactive drugs such as modafinil and caffeine are known to do this, and have been well examined in the field of applied sleep research (Bonnet & Arand, 1994a; 1994b; Pigeau et al., 1995). The most common and widely available of these is caffeine, which also has fewest negative side effects (Fox, 1993). Experimental work has also shown that 150-200mg caffeine significantly improves alertness in sleepy people (e.g. Griffiths et al., 1990; Lorist et al., 1994; Bonnet & Arand, 1994; Muehlbach & Walsh, 1995; Åkerstedt & Ficca, 1997).

Caffeine

Tea and coffee have been consumed around the world for centuries, the discovery of tea dated as early as 2737 BC (Conlay et al., 1997). Both contain drugs from the *xanthine* group which are a common part of the human diet. Caffeine is one of these, and is known as the world's most commonly consumed drug (Griffiths & Woodson, 1988; Fox, 1993; Penetar et al., 1993; Conlay et al., 1997). It is found in about 60 species of plant including tea leaves, coffee beans, cocoa and the cola nut (Fox, 1993), and used in many modem foods such as tea, coffee, soft drinks and chocolate, as well as painkillers and some prescription drugs. Caffeine is absorbed in humans in about 20-30 minutes, and metabolised in the liver with a plasma half life of about 3-6hrs (Griffiths & Woodson, 1988). There are several effects, on the kidneys, cardiac and smooth muscles and levels of gastric secretions, and most notably, the stimulation of the central nervous system, leading to increased alertness, sustained attention and some effects on mood (Penetar et al., 1993). Although much research has posed questions on adverse side effects, these have on the whole been answered, and there is no conclusive evidence that moderate caffeine use is harmful to health (Fox, 1993). Caffeine is thought to work by antagonising receptors of the neuromodulator adenosine, an effective sleep promoter (Radulovacki, 1995; Porkka-Heiskanen et al., 1997), although there are other routes by which caffeine acts on alertness, for example, by affecting the synthesis of catecholamines (Battig & Welzl, 1993).

The effects of caffeine on driving have been experimentally investigated by Regina et al. (1974), although the study used only alert subjects, driving on a completely straight road. No measurement of lateral position (i.e. lane-drifting) was made, instead concentrating on responses to light signals and changes in the speed of a lead car. More recent work has attempted to examine more closely the effects on sleepy drivers. Subjects were given realistic amounts of caffeine (equivalent to about two cups of coffee) added to decaffeinated coffee, and tested with their sleep restricted to 5 hours the night prior to testing. Driving the subsequent moming or afternoon for two hours continuously in a driving simulator under monotonous road conditions, drivers experienced levels of sleepiness that were significantly reduced by the 150 or 200mg caffeine dose given under double blind conditions (Home & Reyner, 1996; Reyner & Home, 1997). Significant improvements were found in driving performance (lane-drifting), subjective sleepiness and EEG measures. Combination of caffeine with a <15 minute nap has also been shown to be very effective (Reyner & Home, 1997), if the caffeine is taken *before* the nap during a 30 minute break. Since the caffeine takes approximately 30 minutes to be absorbed, this synchronises the beneficial effects of both the nap and the caffeine dose when driving resumes. This finding now forms the basis of the advice given to sleepy drivers in the UK highway code (see figure 1.7).

The effectiveness of caffeine in coffee is clear, and in combination with a nap (where possible) forms a very effective countermeasure (Reyner & Home, 1997). However, the caffeine content of coffee is highly variable (Nehlig, 1999), and since drivers would have to purchase it at different locations this is problematic. This can undermine the advice given to motorists in the highway code, because the 'two cups of strong coffee' recommendation is really based on the assumption that those cups contain a total of about 150mg caffeine.

Drivers will be unaware of the actual content, which may be well below this level as caffeine is undetectable by colour, taste or smell. It is also unclear what the synergistic effects of coffee (with the addition of milk and sugar) are as compared to pure caffeine. The practical reliability of this advice is therefore not as strong as was first thought.

Functional Energy Drinks

A modern alternative source is new caffeinated 'functional energy drinks' (FEDs). These have come onto the market in the last 5 years and have become more and more popular. They are readily available, as are traditional soft drinks, and their key feature is a standard high caffeine dose, which is comparable with a strong cup of coffee. FEDs contain various other biologically active ingredients such as sucrose, glucuronolactone, the amino acid taurine, and vitamin B complex. One can (typically 250ml) of FED contains about 80mg of caffeine (approximately that of a cup of filter coffee), as well as about 28g of sucrose, 1g of taurine and 0.6g of glucuronolactone. The energy value of a can is about 480 kj (112 kcal). Glucose (from the sucrose) can also have a fast alerting effect, although this only lasts about 10 minutes. The absorption rates for both taurine and glucuronolactone are unclear, but taurine has a variety of effects on the CNS (Mandel et al., 1985). Taurine is an essential amino-acid occurring naturally in the body, and these effects are largely of an inhibitory nature (Lapin et al., 1982; Lidsky et al., 1995; Birdsall, 1998). At times of physical exertion, the body no longer produces required amounts of taurine, resulting in a relative deficiency. Taurine acts as a metabolic transmitter and additionally has a detoxifying effect and strengthens cardiac contractility. Taurine has also been found to modulate mood (e.g. Mandel et al., 1985; Lidsky et al., 1995). Glucuronolactone is a substance found in the body which accelerates the elimination of both endogenic and exogenic toxins.

A recent pilot study examined whether two cans (500ml) of a functional energy drink had a beneficial effect in alleviating impaired driving performance due to sleepiness (Horne & Reyner, 2000). The FED was given under double blind conditions with 500ml of a control drink with similar colourings, flavourings and taste, but which did not contain caffeine, or any of the other active ingredients. Lane drifting, reaction time and subjective sleepiness were significantly improved, particularly for the first 60-90 minutes of driving. It may be interesting to examine more closely the effects of these drinks on sleepiness and performance, particularly in realistic doses available to drivers, in a break from driving during the afternoon circadian dip.

Study Aims

This investigation aimed to assess the effects of one (250ml) and two cans (500ml) of FED, under double blind placebo control conditions, in two separate studies. Reaction time measures were not used, given the findings of the previous chapter (Baulk et al., 2001) regarding its sensitivity to sleepiness in comparison with lane drifting or self-ratings. Traditionally, studies on the effects of drug treatments have used doses based on participants' body weight, administering Xg of caffeine per kg for example. However, in evaluating the effects of *practical* countermeasures, the aim is to study a *realistic* scenario. In general, when consuming caffeine, alcohol (or other drugs), people do not consider body weight, and rather use logical, practical doses, without deviating from the recommended amount. After all, drug labels do not instruct patients to adjust dosage for body weight and only advise on dosage alterations for adults or children. Therefore, for these studies the most simple and practical doses were used, that is 250ml (one can), and 500ml (two cans) of FED. As this is the amount readily available to purchase it seems likely that drivers will consume one can as a minimum amount, or two in extreme cases. If drivers are within the normal limits of weight for height, results should not be greatly affected by variations in body size.

If the 250ml FED is sufficient, we might expect significant reductions in subjective sleepiness as compared to the control. This may well extend to driving behaviour, as measured by lane drifting. EEG measures can be more problematic when working with caffeine, as it has been found to increase beta EEG activity (waves >15Hz), which would obviously reduce the proportions of alpha and theta, suggesting a more alert brain, and thus apparently magnifying the effects of the caffeine. However, this has been found generally in doses between 90-200mg (Bruce et al., 1986; Hasenfratz & Battig, 1994), and would not therefore cause great interference in the 250ml (80mg) study design although more relevant to the 500ml (160mg) condition. The effects of the 500ml dose may well be more marked and longer lasting that the single can, and of particular interest is the effect on driving performance.

5.3 METHOD

Participants for the 250ml study were twelve volunteers (8 male, 4 female), with a mean age of 21.92 years (SD = 1.93 years), and a mean ESS of 5.29. Those for the 500ml study were twelve volunteers (9 male, 3 female), with a mean age of 22.50 years (SD = 2.74 years), and a mean ESS of 6.29. Summaries of participants' details are shown in Tables 5.1 and 5.2. The 'normal' range for Body Mass Index (BMI), as shown, is 20-25 (Heyward & Stolarczyk, 1996). All were moderate drinkers of caffeinated coffee (2-4 cups daily). There is no evidence (c.f. Griffiths & Woodson, 1988; James, 1991; Battig & Welzl, 1993) that this level of daily intake would have led to any caffeine withdrawal effects in the control sessions during the study. Participants were informed that they would be consuming several unspecified 'energy drinks,' which were explained in full after all trials were complete.

N	Sex	Age (yrs)	ESS	Height (m)	Weight (kg)	BMI
1	M	22	6	1.70	69.85	24.17
2	M	26	5	1.88	85.73	24.26
3	M	21	4	1.72	69.85	23.61
4	F	22	3	1.65	60.33	22.16
5	M	22	2	1.91	82.56	22.63
6	M	21	6	1.91	85.00	23.30
7	M	20	5.5	1.83	76.20	22.76
8	F	20	8	1.65	68.00	24.98
9	M	25	9	1.72	69.85	23.61
10	F	21	4	1.70	58.20	20.14
11	F	23	3	1.70	58.00	20.07
12	M	20	8	1.80	69.85	21.56
MALE		MEAN		1.81	76.11	23.24
		StDev		0.09	7.27	0.90
FEMALE		MEAN		1.68	61.13	21.84
		StDev		0.03	4.70	2.31

Table 5.1

250ml Study: Summary of Participant Details

N	Sex	Age (yrs)	ESS	Height (m)	Weight (kg)	BMI
1	M	22	6	1.70	69.85	24.17
2	M	26	5	1.88	85.73	24.26
3	M	21	6	1.80	69.85	21.56
4	M	21	4	1.72	69.85	23.61
5	F	29	3	1.67	70.00	25.10
6	M	22	4	1.83	71.00	21.20
7	M	20	5.5	1.83	76.20	22.76
8	M	25	9	1.72	69.85	23.61
9	F	21	10	1.75	62.00	20.24
10	F	21	6	1.67	57.15	20.49
11	M	20	8	1.91	82.56	22.63
12	M	22	9	2.01	88.91	22.01
MALE		MEAN		1.82	75.98	22.87
		StDev		0.10	7.75	1.12
FEMALE		MEAN		1.70	63.05	21.95
		StDev		0.05	6.49	2.73

Table 5.2

500ml Study: Summary of Participant Details

The study used a repeated measures design, whereby participants drove for 2.5 hours (with a 30 minute break after the initial 30 minute 'warm-up' drive) following restricted sleep in the fixed base driving simulator in two conditions: a 'control' condition (non-caffeinated drink), and the 'FED' condition (caffeinated drink – either 250 or 500ml) both taken in a 30 minute break after the initial 30 minute 'warm up' drive. Participants were randomly assigned to either the 250 or 500ml study group. Hardware problems associated with the 'millennium bug' prevented use of the Labview logging system for this study. EEG data was therefore recorded using an alternative setup (Embla system).

Statistical Analysis

For all measurements, the pre-treatment data should be the same under each condition. To check this statistically, the 30 min of pre-treatment data were averaged within groups and compared between conditions using a paired t test. If this was satisfactory, then post-treatment data were averaged in four, 30 minute blocks and analysed by a two way (condition x time) repeated measures ANOVA. Post hoc "t tests" were undertaken when appropriate, with findings of $p<0.05$ reported.

5.4 RESULTS

250ml Study

Subjective Sleepiness

Subjective sleepiness data, measured at 200 second intervals was averaged across participants and plotted against time for both the pre- and post-treatment drives. This is presented in figure 5.1. Although slightly higher for the control drink pre-treatment, this difference was not significant. Clearly there is a marked post-treatment difference, with subjective sleepiness being noticeably lower following the FED treatment for much of the two hour drive. The ANOVA showed this effect to be significant ($F=19.39$; d.f. 1,11; $p<0.001$). Post hoc t tests were significant ($p<0.05$) between the two conditions for the first two, 30 minute periods. There was an overall significant effect of time ($F=12.07$; d.f. 1.9,21; $p<0.001$), and a significant interaction between condition and time ($F=3.05$; d.f. 2.7,30; $p<0.05$); that is, the effect of time was greater during the control condition.

KSS data was also plotted to show the number of 200 second epochs spent in each level of the scale for the two conditions (post-treatment only). This data is presented in figure 5.2, showing a clear frequency shift caused by the intervention, with a 2 point peak difference (i.e. two KSS points between the most common level in each condition).

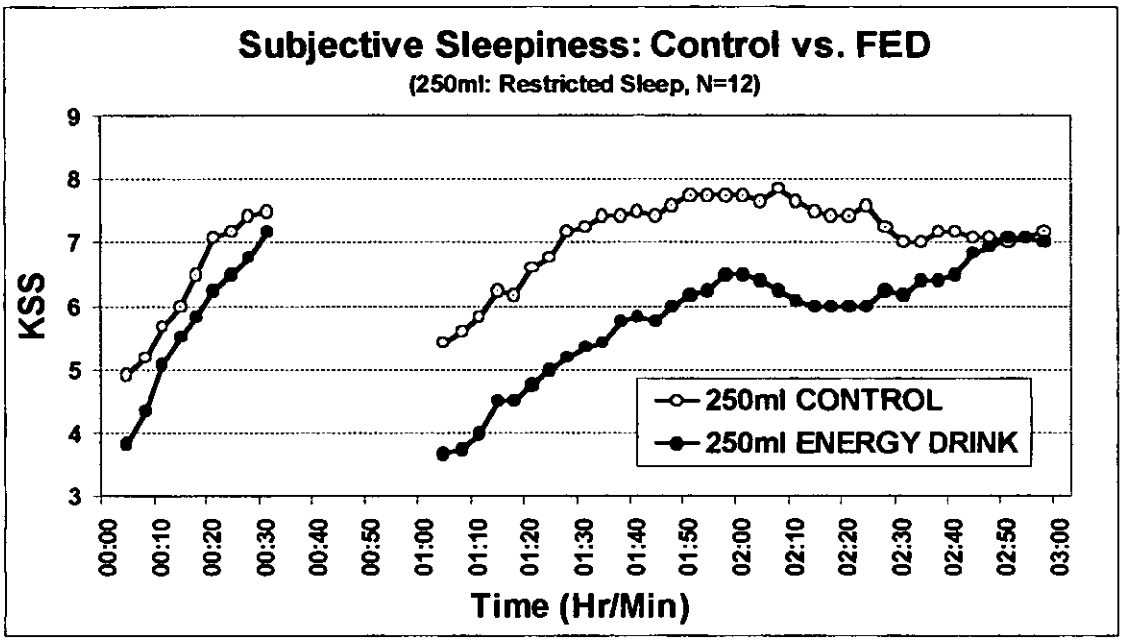

Figure 5.1

Mean subjective sleepiness (KSS) over time before and after treatment for 250ml CONTROL and FED conditions.

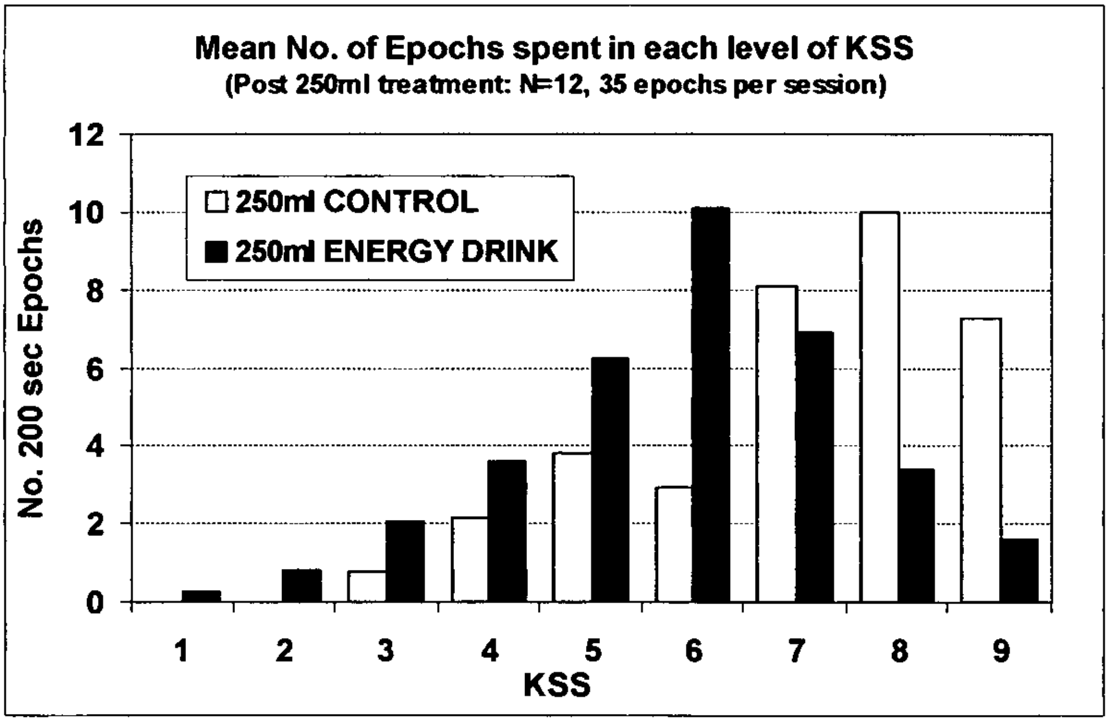

Figure 5.2

Time spent in each level of subjective sleepiness (KSS) for 250ml CONTROL and FED conditions post-treatment

As expected, drivers also rated themselves less likely to *actually fall asleep* in the FED condition, for almost all of the 2 hour drive. This data is presented in figure 5.3, showing a clear alerting effect of the FED. This was found to be significant using ANOVA (F=12.90, d.f. 1, 11; p<0.004), and there was also a significant effect of time (F=6.24, d.f. 3, 33; p<0.002), a post-hoc tukey test confirmed that drivers were most alert during the first 30 minute driving period, as compared to the middle hour of the drive (p<0.05). There was no significant interaction.

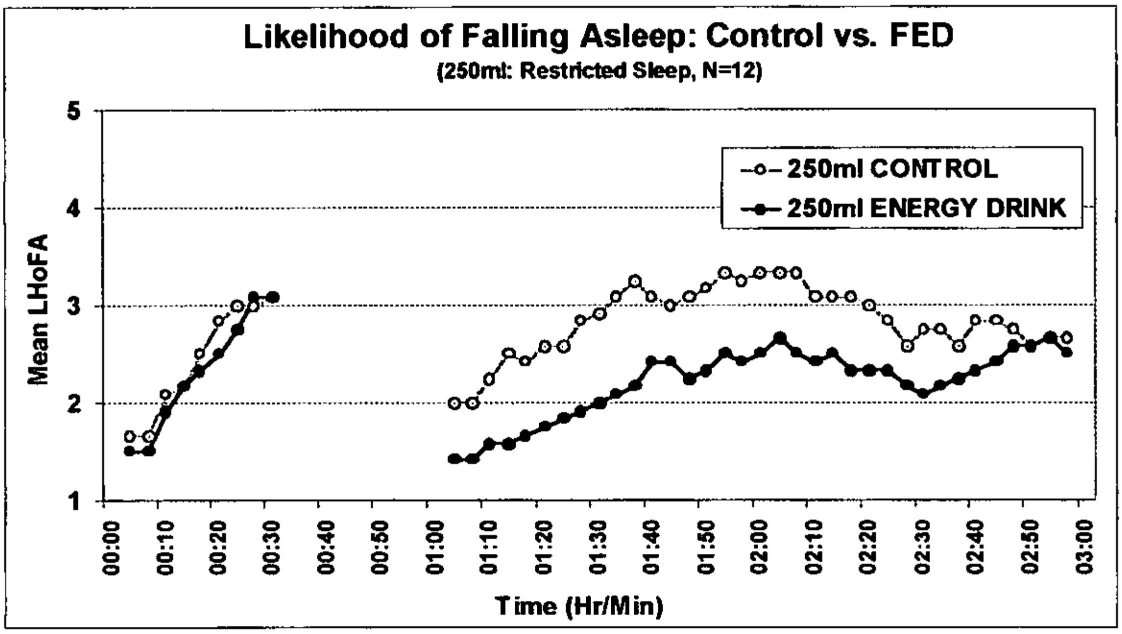

Figure 5.3

Mean subjective sleepiness (LHoFA) over time before and after treatment for 250ml CONTROL and FED conditions.

The effect of the FED on LHoFA can be seen more clearly in figure 5.4 also. This graph shows the *change* in epochs spent in each level of the scale, caused by the addition of the FED. There is a progressive shift here to a reduced likelihood of falling asleep.

The progression of drivers through the 2 subjective sleepiness scales in combination can also be seen in table 5.3.

		A	B	C	D	E
	250ml CONTROL	Very Unlikely	Unlikely	Possibly	Likely	Very Likely
1	Extremely Alert	0	0	0	0	0
2	Very Alert	0	0	0	0	0
3	Alert	8	1	0	0	0
4	Rather Alert	10	16	0	0	0
5	Neither	30	13	3	0	0
6	Some signs of Sleepiness	8	20	7	0	0
7	Sleepy but no effort to stay awake	2	17	77	1	0
8	Sleepy, some effort to stay awake	0	43	44	32	1
9	Very Sleepy, great effort to stay awake	0	1	7	33	46
		A	B	C	D	E
	250ml FED	Very Unlikely	Unlikely	Possibly	Likely	Very Likely
1	Extremely Alert	3	0	0	0	0
2	Very Alert	10	0	0	0	0
3	Alert	24	1	0	0	0
4	Rather Alert	21	22	0	0	0
5	Neither	41	29	5	0	0
6	Some signs of Sleepiness	14	57	50	0	0
7	Sleepy but no effort to stay awake	4	26	51	2	0
8	Sleepy, some effort to stay awake	0	13	14	12	2
9	Very Sleepy, great effort to stay awake	0	0	0	5	14

Table 5.3 – Progression of Subjective ratings –
The Subjective Sleepiness Matrix (250ml FED Study)

This shows the total number of epochs spent in each level of the combined scales under both conditions. There is a clear skewing of epochs to the top left of the table as the FED reduces sleepiness.

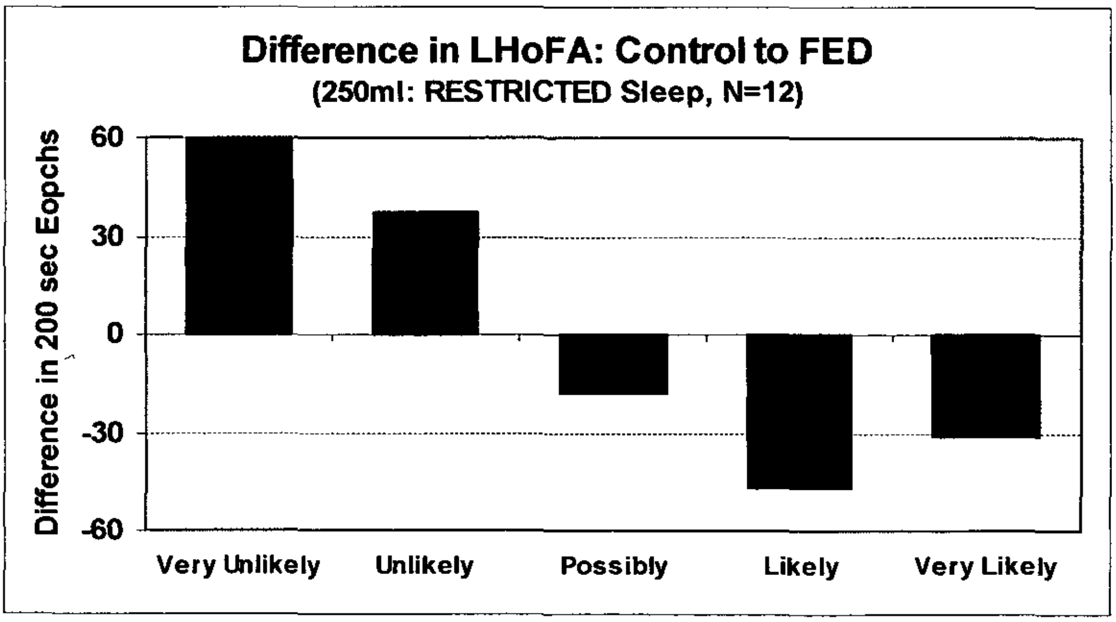

Figure 5.4
Change in LHoFA ratings, after 250ml FED treatment

Driving Performance

Group means for lane drifting incidents related to sleepiness (as taken from video analysis), were plotted in 30 minute periods against time for both CONTROL and FED conditions. This data is shown in figure 5.5, with the rate of incidents being similar for both conditions during the pre-treatment drive. Post-treatment, there was a marked decrease in lane drifting in the FED condition, and the ANOVA showed this to be significant (F=24.45; d.f. 1,11; p<0.001). Post-hoc t tests were significant (p<0.05) for the 0-30 min, 30-60 min and 60-90 periods. There was no significant effect of time.

EEG

EEG data was spectrally analysed and standardised in one minute epochs before averaging across participants. This data was plotted against time for both conditions and is presented in figure 5.6, including the pre- and post-treatment driving periods. Increased power denotes increasing sleepiness. The zero line marks the mean of the preliminary driving period – and is regarded as the threshold for objective sleepiness (Horne & Reyner, 1996). There were no significant findings, although it can be seen from the graph that there was a trend for EEG power to be reduced (less sleepy) in the FED condition during the middle hour of the drive.

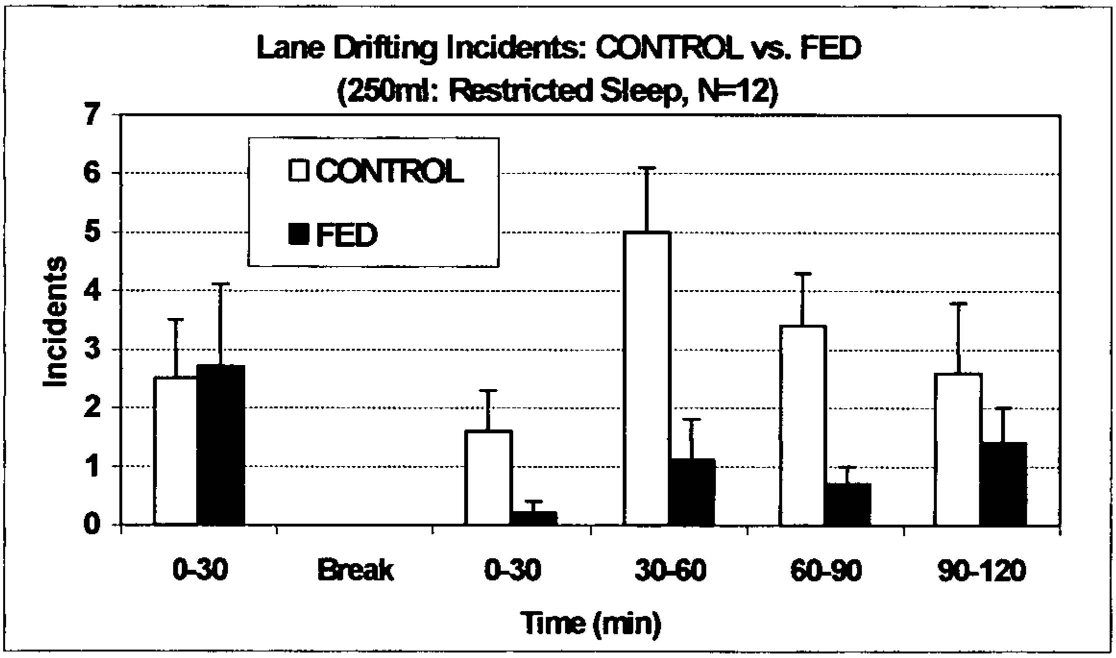

Figure 5.5

Lane drifting incidents related to sleepiness –

before and after treatment for 250ml CONTROL and FED conditions.

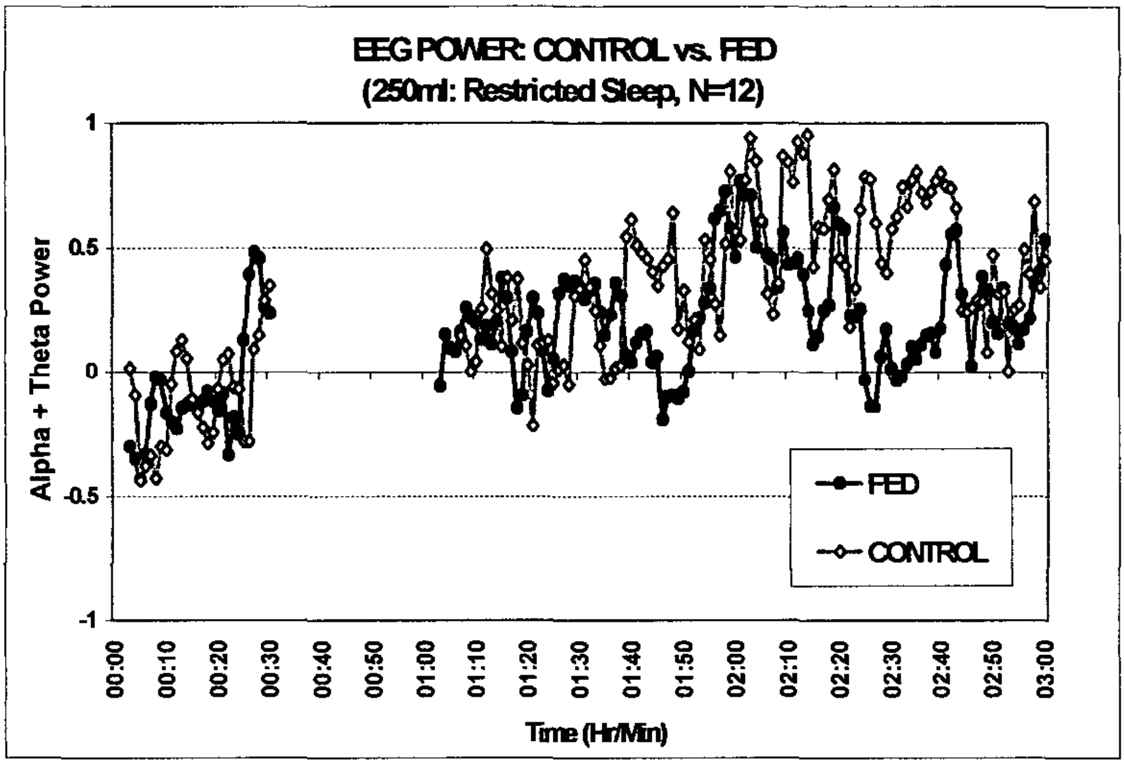

Figure 5.6

Standardised Alpha and Theta EEG power over time for the 250ml CONTROL and FED conditions.

500ml Study

Subjective Sleepiness

KSS data for the 500ml study is shown in figure 5.7. Changes in subjective sleepiness were the same pre-treatment. After treatment, the sustained alerting effect of the FED was very clear, and highly significant for the 2 hour drive, as demonstrated by the ANOVA (F=34.55; d.f. 1,11; p<0.001). All post hoc tests were significant (p<0.05). There was a significant effect of time (F=12.25; d.f. 1.7,18.4; p<0.001); that is, sleepiness generally changed over the four time periods. However, this change was less in the FED condition, as was reflected in the significant interaction effect (F=6.36; d.f. 2.4,26.3; p<0.004).

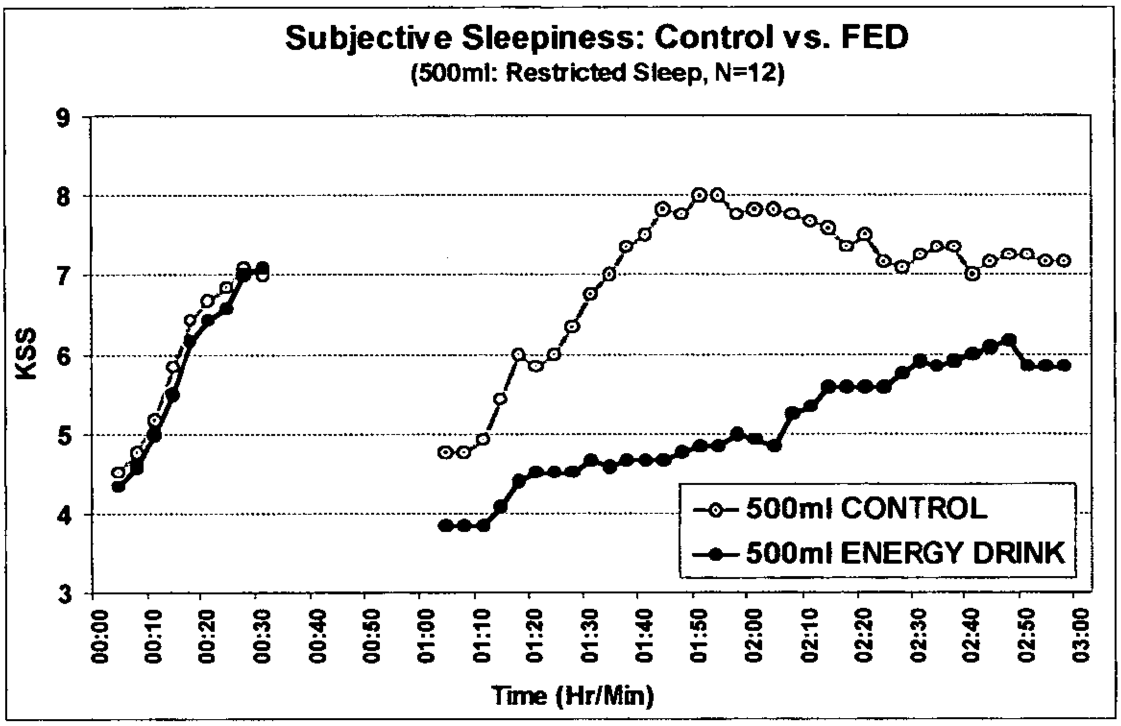

Figure 5.7

Mean subjective sleepiness (KSS) over time before and after treatment for 500ml CONTROL and FED conditions.

Again, KSS data was plotted to show the number of 200 second epochs spent in each level of the scale for the two conditions (post-treatment only). This data is presented in figure 5.8, and shows a clear shift caused by the addition of the FED, this time a stronger effect, marked by a 3 point peak difference (see figure 5.2).

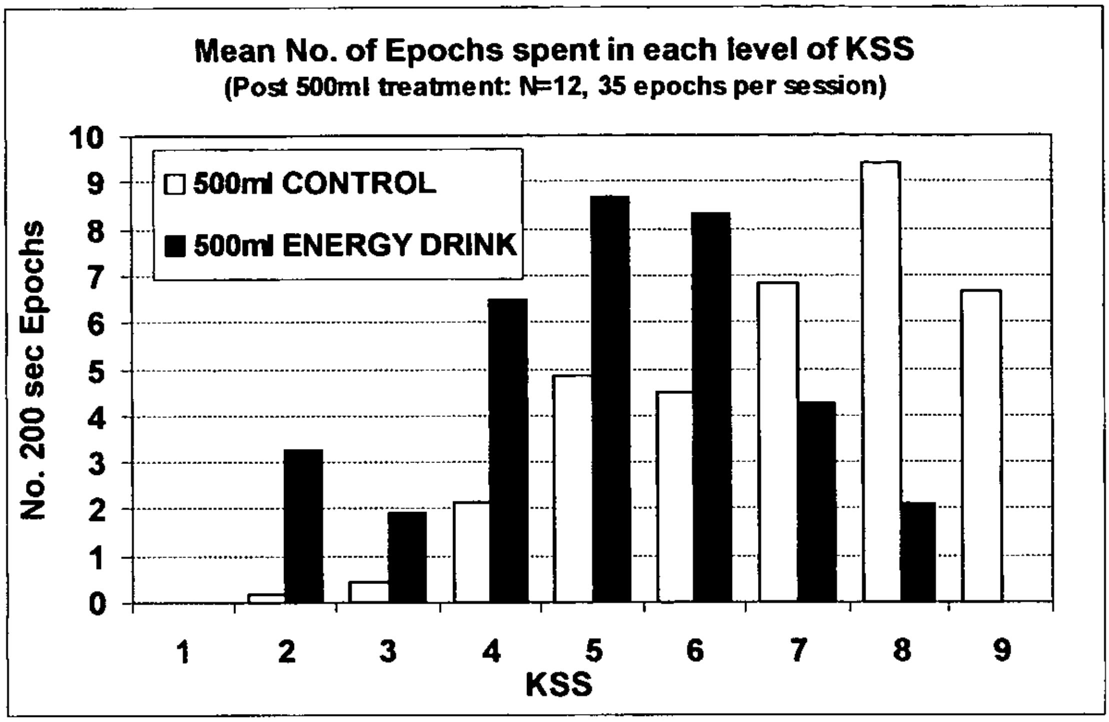

Figure 5.8

Time spent in each level of subjective sleepiness (KSS) for 500ml CONTROL and FED conditions post-treatment

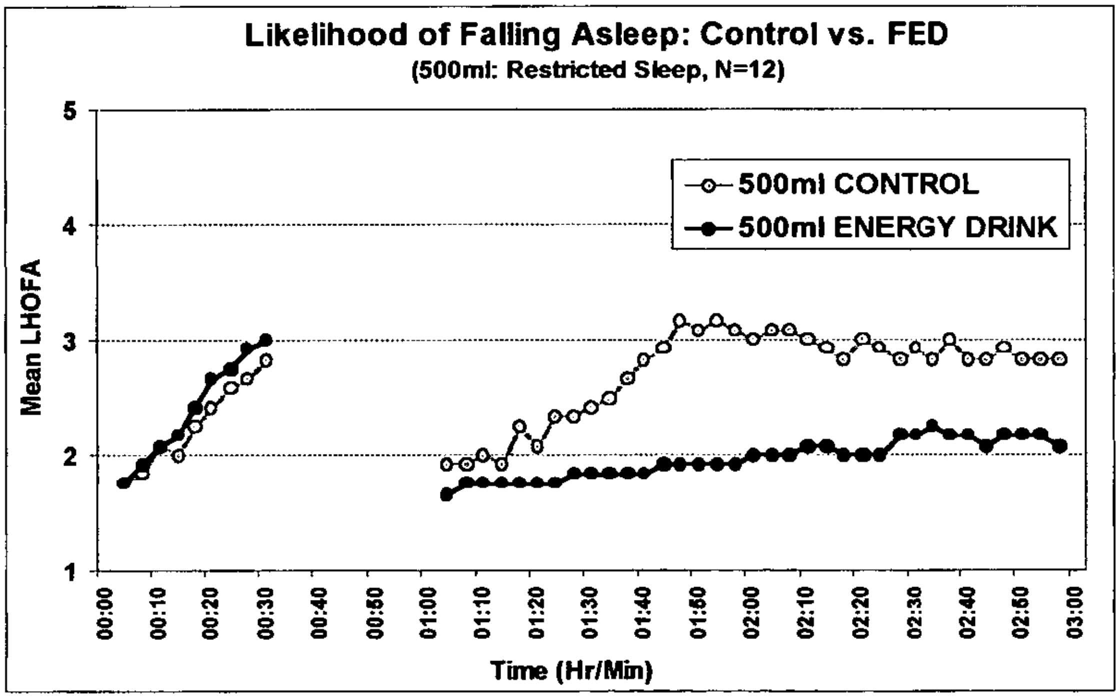

Figure 5.9

Mean subjective sleepiness (LHoFA) over time before and after treatment for 500ml CONTROL and FED conditions.

As expected, drivers also rated themselves as less likely to actually fall asleep in the FED condition, for almost all of the 2 hour drive. This data is presented in figure 5.9. In particular, the FED demonstrates a general flattening of this progression across time (i.e. drivers do not generally feel any more likely to fall asleep as they continue to drive).

The effect of the FED was significant (F=11.25, d.f. 1, 11; p<0.006), and there was also a significant effect of time (F=6.30, d.f. 3, 33; p<0.005), relating to the first (post-treatment) 30 minute driving period (p<0.05). There was no significant interaction.

The effect of the FED on LHoFA can be seen more clearly in figure 5.10 also. This graph shows the change in epochs spent in each level of the scale, caused by the addition of the FED. Again, there is a clear and consistent shift towards the reduced likelihood of falling asleep.

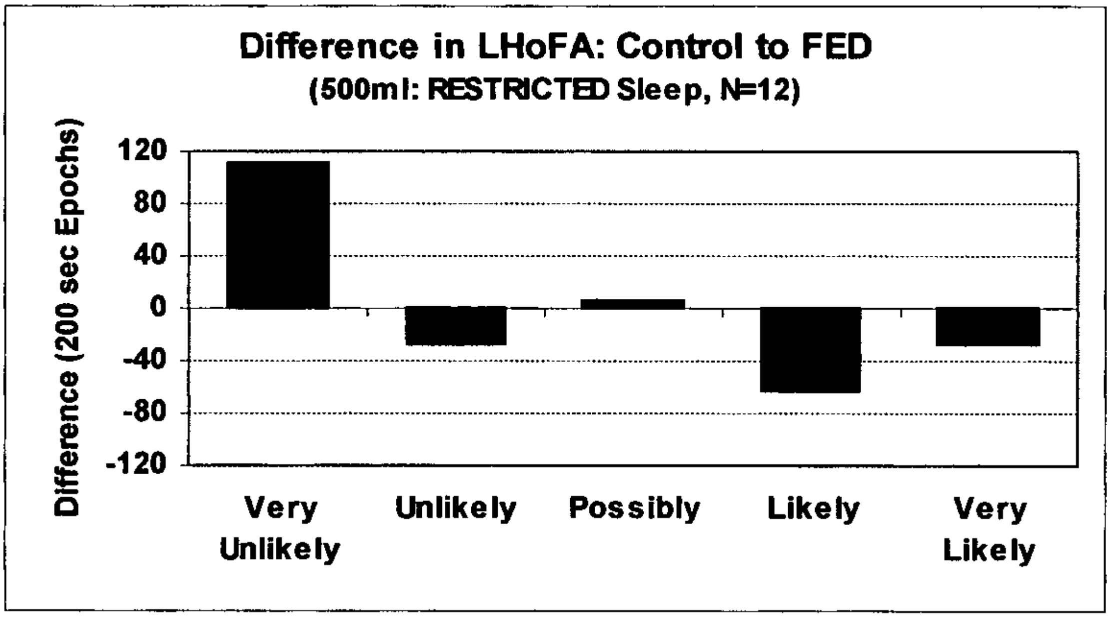

Figure 5.10

Change in LHoFA ratings, after 500ml FED

The progression of drivers through the 2 subjective sleepiness scales in combination can be seen in table 5.4, which shows the total number of epochs spent in each level of the combined scales for the 2 conditions. There is a clear movement to the top left of the table as the FED reduces sleepiness. Note in particular also the truncation of the bottom right section (i.e. most sleepy) under the 500ml FED condition.

		A	B	C	D	E
	500ml CONTROL	Very Unlikely	Unlikely	Possibly	Likely	Very Likely
1	Extremely Alert	0	0	0	0	0
2	Very Alert	2	0	0	0	0
3	Alert	2	3	0	0	0
4	Rather Alert	14	12	0	0	0
5	Neither	22	31	5	0	0
6	Some signs of Sleepiness	6	34	13	1	0
7	Sleepy but no effort to stay awake	1	26	54	1	0
8	Sleepy, some effort to stay awake	0	39	53	21	0
9	Very Sleepy, great effort to stay awake	0	0	12	41	27
		A	B	C	D	E
	500ml FED	Very Unlikely	Unlikely	Possibly	Likely	Very Likely
1	Extremely Alert	0	0	0	0	0
2	Very Alert	39	0	0	0	0
3	Alert	16	7	0	0	0
4	Rather Alert	37	35	6	0	0
5	Neither	54	19	31	0	0
6	Some signs of Sleepiness	13	32	55	0	0
7	Sleepy but no effort to stay awake	0	24	27	0	0
8	Sleepy, some effort to stay awake	0	1	24	0	0
9	Very Sleepy, great effort to stay awake	0	0	0	0	0

Table 5.4 – Progression of Subjective ratings –
The Subjective Sleepiness Matrix (500ml FED Study)

Driving Performance

For the pre-treatment drive incidents were similar under both conditions. Post-treatment, 500ml (two cans) of the FED almost totally suppressed driving incidents, as can be seen in Figure 5.11. The ANOVA was highly significant (F=28.31; d.f. 1,11; $p<0.001$), with post hoc t tests significant ($p<0.05$) for all four periods. There was no significant effect of time, or any significant interaction effect. Clearly the low number of incidents under the FED condition would have masked any effect of time.

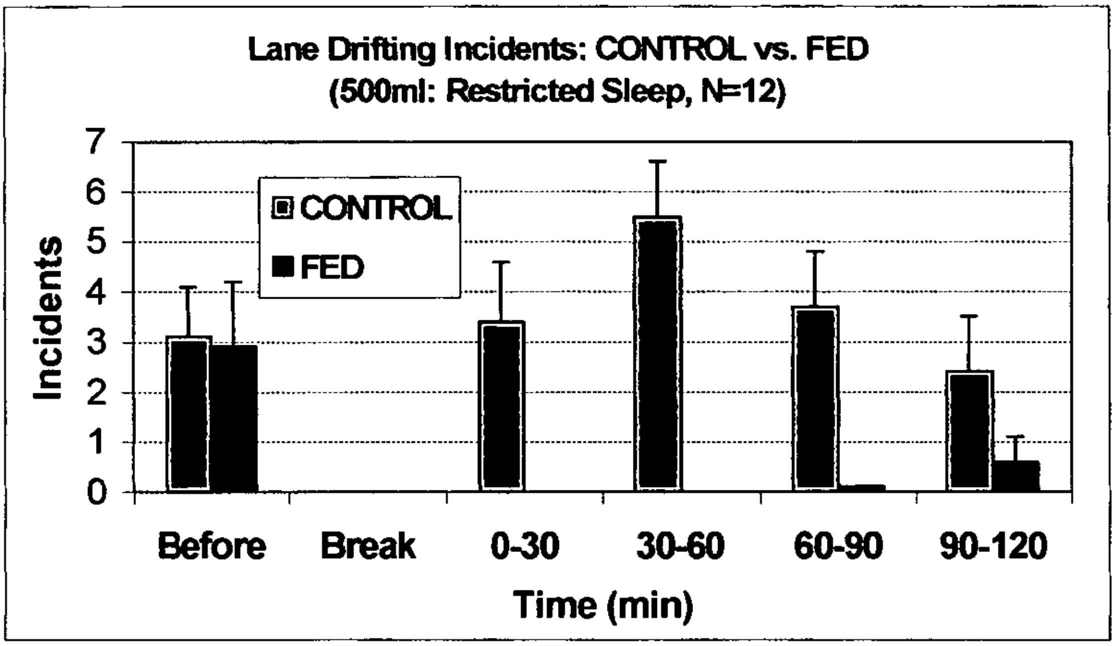

Figure 5.11

Lane drifting incidents related to sleepiness –

before and after treatment for 500ml CONTROL and FED conditions.

EEG

The standardised EEG data for the 500ml study is shown in figure 5.12. There were similar changes pre-treatment for the two conditions. Post-treatment however, there was a sustained effect of the FED in reducing alpha + theta power throughout the two hour period, and particularly for the first 90 minutes. This was found to be significant using ANOVA (F=8.34; d.f. 1,11; $p<0.02$). Post-hoc tests for the first three, 30 minute periods were also significant ($p<0.05$). There were significant overall effects of time (F=6.79; d.f. 2.7,24.6; $p<0.002$), and the interaction between condition and time was also significant (F=6.22; d.f. 2.9,26.1; $p<0.003$). That is, as with subjective sleepiness, EEG sleepiness changed with time, but less so under the FED condition.

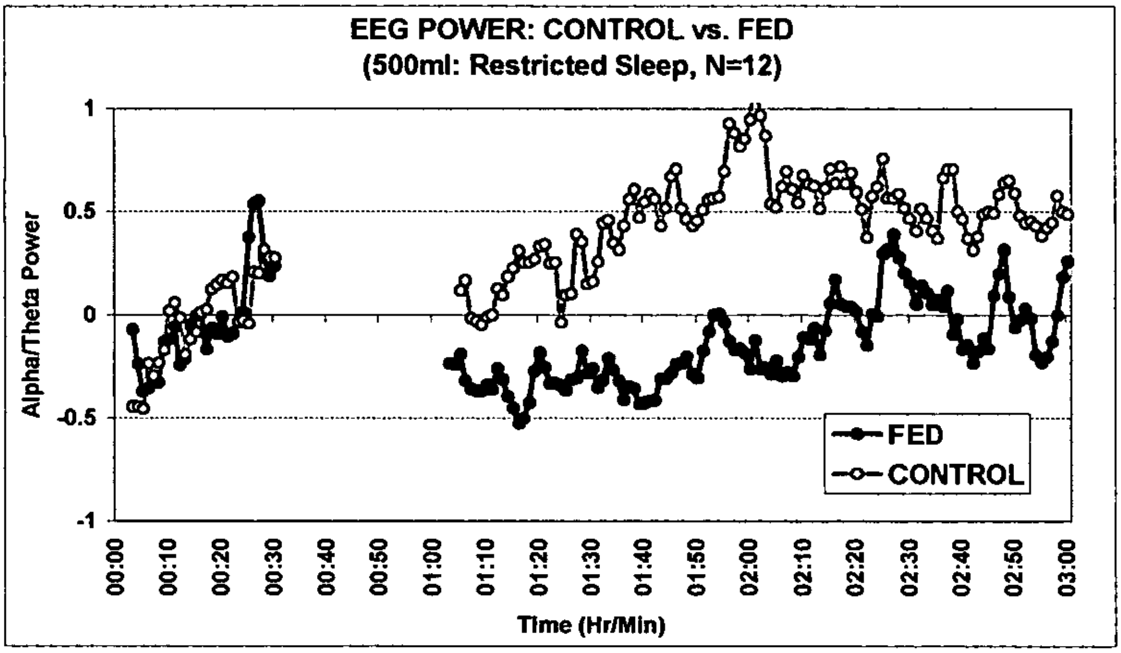

Figure 5.12

Standardised Alpha and Theta EEG power over time for the 500ml CONTROL and FED conditions.

Comparison of 250ml & 500ml Studies

Figure 5.13 compares all conditions with respect to subjective sleepiness. All pre-treatment sessions were similar, as were post-treatment control drives. Post-treatment FED conditions appeared more alert depending on the dosage level. These were compared (in 30 minute periods) using ANOVA to show a significant difference (F=6.47; d.f. 1,11; p<0.027). Post-hoc tests showed that the 500ml dose resulted in a significantly lower level of sleepiness than the 250ml dose, for the second (30-60 min) and final (90-120 min) periods.

Figure 5.14 presents the same comparison for lane drifting incidents, which again were similar for pre-treatment and post-treatment control drives. Statistical comparison between the 250ml and 500ml FED treatments was not possible due to the large number of nil incidents for the 500ml data. But clearly, compared with the 250ml condition, there were fewer incidents throughout the two hour drive following the 500ml dose.

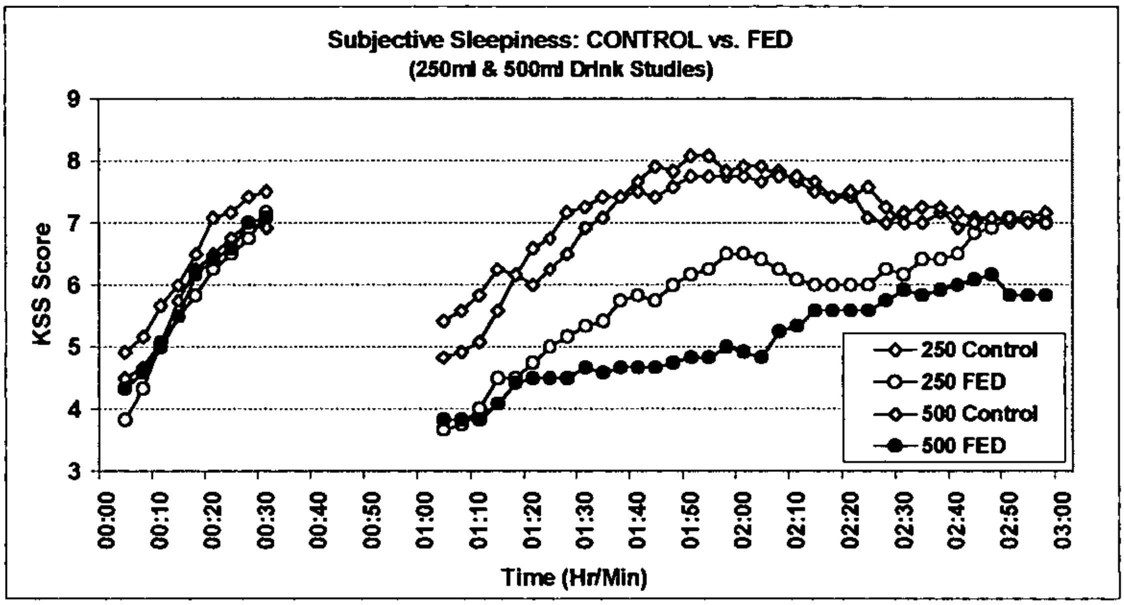

Figure 5.13

Subjective Sleepiness (KSS) over time for all conditions

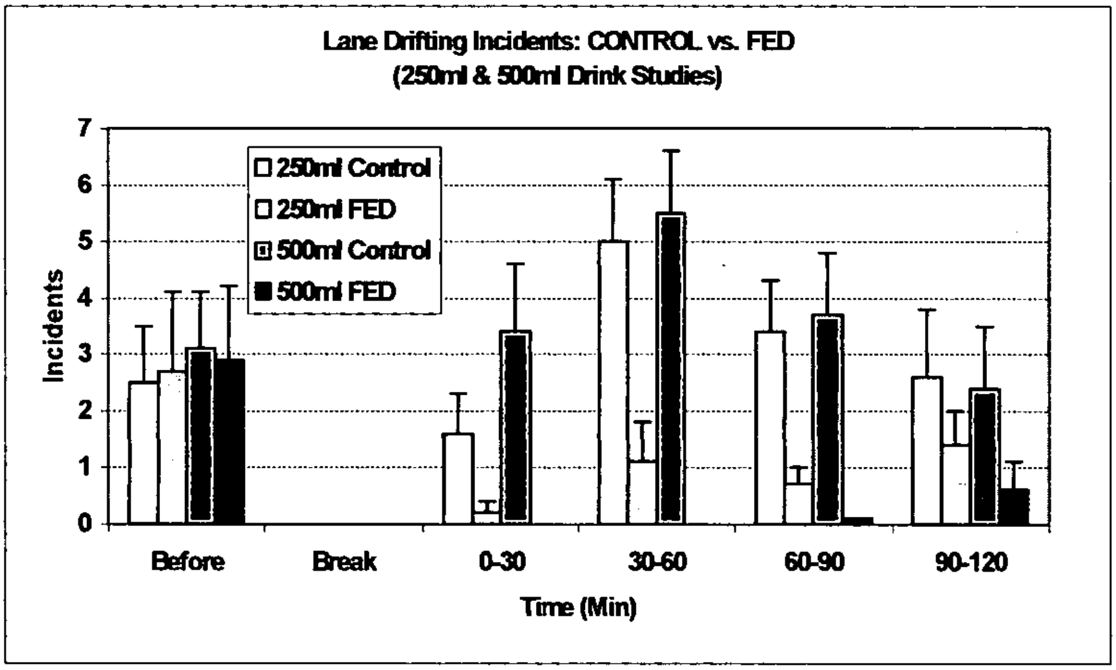

Figure 5.14

Lane drifting Incidents over time for all conditions

Looking also at figures 5.6 and 5.12, it is clearly demonstrated that the 500ml FED condition has a more defined effect on the brain, leading to increased alertness for much of the 2 hour driving period.

Sex Differences

Again, it is difficult to make reliable comparisons between the sexes, as a 12 participant study provides only a 6 x 6 pairing. In any case, the study suffered from having fewer female volunteers, effectively making this impossible. This is still an interesting issue, and one which could yield results given the opportunity to complete a more sex balanced study.

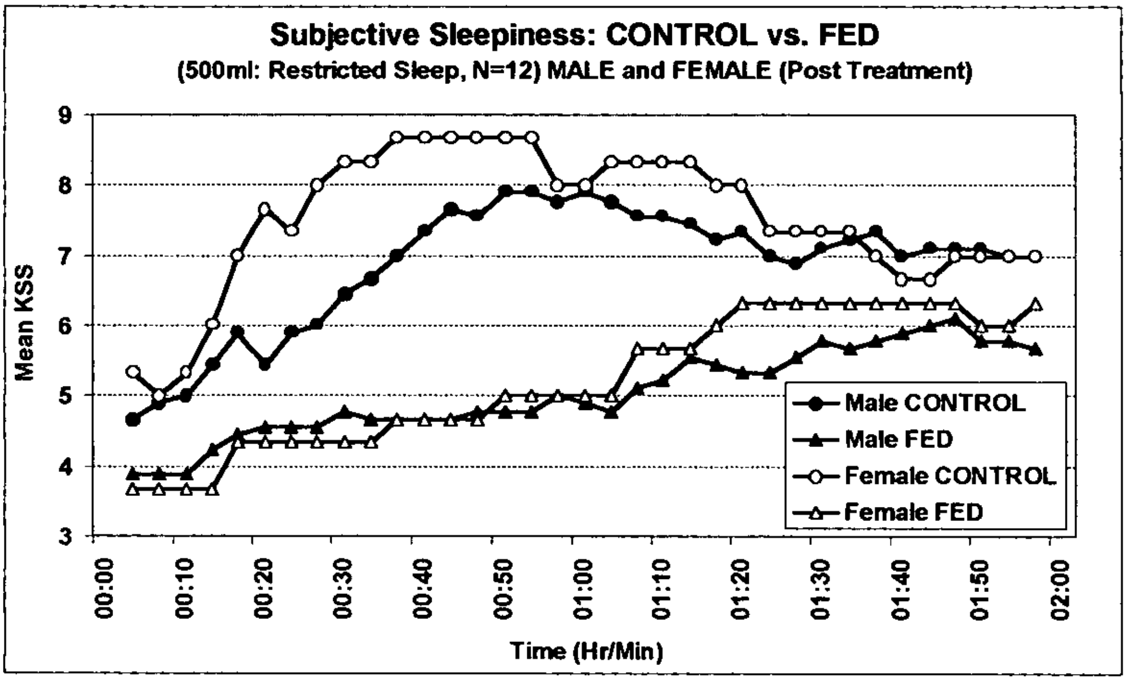

Figure 5.15
Subjective sleepiness over time for the 500ml study – to show MALE (8) vs. FEMALE (4) comparison

Incident data generally suffers from large individual differences, making comparisons here of little use. Figure 5.15 illustrates post-treatment subjective sleepiness for the 500ml study, showing the difference in male and female perceptions. It should be remembered that this is an uneven comparison (N=12: 8m, 4f), but while the FED conditions are largely similar, there is some difference between self-ratings in the *control* condition, as previously demonstrated in chapter 4.

5.5 DISCUSSION

The one-can study showed that 250ml FED was effective at reducing sleepiness during the first hour of the drive, as shown by reductions in sleepiness-related lane-drifting incidents and subjective sleepiness. This also extended to the likelihood of actually falling asleep, and a clear shift in subjective sleepiness overall could be seen as a result of the FED intervention. Trends in the EEG also reflected this, although not significantly. Sleepiness was not eliminated during this first hour, but was clearly reduced compared to the control condition. With more severe prior sleep loss and higher levels of afternoon sleepiness however, the efficacy of the 250ml treatment would be reduced.

The two-can study demonstrated, as expected, that 500ml FED markedly reduced afternoon sleepiness. This was clearly evident during the two hour monotonous drive, with hardly any sleepiness-related lane drifting incidents, and greatly reduced subjective levels. Again, this extended to the likelihood of falling asleep ratings, flattening the curve to the effect that this changed minimally over time. The progression of subjective sleepiness was altered by the addition of the FED, as the 500ml effectively removed it (see table 5.2). The EEG showed little sign of sleepiness for the first 90 minutes, and this only began to increase slightly in the remaining 30 minutes of driving. These overall effects were highly statistically significant when compared with the control drink, and support the findings of the earlier pilot study with a 500ml dose (Horne & Reyner, 2000).

Comparing the two FED studies, the reliability of the methodology is underlined by the close similarity of data for all pre-treatment, and post-treatment control drives, on all measurements taken (conditions were counterbalanced). Also, the two dosage levels for the FED demonstrated a clear difference, the 500ml dose much more effective at reducing sleepiness and for a more sustained period.

FEDs are readily available in many outlets, including motorway services and petrol stations all over the UK and internationally. Since the completion of this study, they are being more directly aimed at sleepy drivers. Their efficacy at alleviating driver sleepiness has been clearly demonstrated with a 250ml dose, as well as having greater effects with a 500ml dose. As a countermeasure to driver sleepiness, assuming that drivers also take a break of at least 30 minutes, FEDs seem to be very effective. The standard amount of caffeine provides greater reliability than coffee, while their increasing popularity means that they are just as convenient to use. There are however, several limitations at this stage, and questions to be answered by further research.

Again, some small sex differences were found in the data, although the study design prevented meaningful statistical comparison. This issue is becoming more interesting, and suggests the importance of a study to *directly* examine sex differences experimentally (see chapter 7.0), although it would seem that differences may only exist under *control* conditions, the FED resulting in similar levels of post-treatment sleepiness.

The study design was based on the use of realistic countermeasures to driver sleepiness, in this case, *cans* of the FED, rather than a dose based on body weight. Obviously, this introduces a potential gender effect, as the female drivers are lighter than the males. As shown in figure 5.15 however, females perceived themselves as *more* sleepy than males. This is contrary to what would be expected – that is, if the smaller size of the female group led to increased effects of the FED.

In particular, the effects of each of the treatment conditions were clearly visible when examined using the progression of subjective sleepiness as shown in the subjective sleepiness matrix (see tables 5.1 and 5.2). While the 250ml condition demonstrated a general skewing towards the top left of the matrix, the 500ml dose could be seen clearly in a similar skewness together with the truncation of the bottom right section. This relates well to the data from chapter 4.0 (shown in table 4.1) which demonstrated the effects of the addition of secondary RT on the pattern of increasing sleepiness (see section 4.5). This matrix has proved a useful tool to examine subjective sleepiness, and in particular demonstrate experimental effect between conditions.

Limitations

Since this study did not include any investigation of the effects of caffeine in coffee, it is not possible to make any strong conclusions about comparison with it. A similar study using 150mg of caffeine, dissolved in decaffeinated coffee (Horne & Reyner, 1996), only involved a single hour of driving. A follow-up study to this (Reyner & Horne, 1997) utilised a slightly higher dose (200mg) however, and incorporated a two hour drive. Looking at these two studies, it appears that at least during the hour after absorption, 250ml of FED (containing 80mg caffeine) may be comparable in effectiveness with somewhat higher levels of caffeine in coffee. This may be due to the additional sugar, or the active ingredients (taurine and glucuronolactone) and their synergistic effects. Further investigation is required to explore this more closely, using a measured caffeine dose (80 or 160mg) in decaffeinated coffee for direct comparison with the FED, and perhaps also some additional variants of the original FED (identical but without taurine or glucuronolactone). This issue has been investigated recently with reference to 'readiness potential' in various states of physical activation (Barthel et al., 2001) using different control versions of a FED. There is a need for research on these drinks outside of the sports science field however, focussing on their effects on the brain.

While readily available and effective at reducing sleepiness, some of the other characteristics of the FED may mean that it is less useful as a countermeasure for drivers. Although drivers were not asked for information on taste or palatability, this may have some effect. The drink is marketed as a 'functional energy drink,' and is aimed at a young adult consumer group. It therefore has a different taste to that of traditional soft drinks, and may be less favoured by drivers.

Further Research

The caffeine content of coffee varies largely according to volume, type of coffee used, and method of preparation (Nehlig, 1999), and is not easily distinguishable by taste, colour or smell. Future work to address this issue should aim to assess the content of a variety of brands of coffee, by comparison between- and within-location. This is important information as many drivers may believe that a standard cup of coffee will improve alertness while driving, as suggested by the UK Highway code (November 1999).

Caffeine is also available in other forms, such as slow-release and even chewing gum. These are not currently available in the UK, but would perhaps warrant some experimental investigation. The effects of slow-release caffeine in particular, have been examined in a recent study on sleep deprivation (Beaumont et al., 2001), using a daily dose of 600mg to effectively reduce sleepiness and impairment at cognitive and vigilance tests, and to demonstrate some success in counteracting sleepiness while driving (De Valck & Cluydts, 2001).

There are also other drugs which have an alerting effect. Modafinil is perhaps the most well known of these, used in the USA for patients suffering from EDS and related conditions. Drugs such as this may become more popular in the future, and would require some investigation before being recommended for use by sleepy drivers. Conversely, many drugs which are available already without prescription (over-the-counter) may have the effect of causing *unwanted* drowsiness. A recent review of these in relation to driver sleepiness highlighted this problem, noting that the recommended dose of some antihistamines is thought to impair performance more than the UK limit for blood alcohol while driving, and also that the 'non-sedating' drugs are not free from sedative effects (Horne & Barrett, 2001). Many of these medicines do not warn of drowsiness on the labels, which can sometimes be misleading.

From a practical viewpoint, there is potential for abuse of advice given on FED use, so future research should also address the issue of safe limits regarding dosage, and in particular repeated doses of equal volume over time. Clearly this would also provide feedback to the FED industry regarding the implications for product labelling. Another very interesting question to come from this research, is what happens to sleepiness and performance later, at the point where the effects of the drink wear off? Do these deteriorate quickly and to what level? Will drivers experience greater sleepiness after the FED has been metabolised than before it was taken? Is the afternoon dip accentuated by earlier consumption of FED, if taken during the morning? In addition to this, do some drivers experience reduced sleepiness after driving has ceased? Does the FED inadvertently affect later sleep onset or sleep quality? These issues are all vital to understanding the effects of *regular* use – which is probably likely given the results presented here, combined with the increasing pressure for work in the 24 hour society. A follow up study to investigate this could be based around actimetry, subjective ratings and possibly home EEG recordings, taken during the night *after* the driving session.

There is also some cause for investigating the combined effects of FEDs and alcohol. Socially, the combination is extremely popular already, and some work has begun to investigate the effects of the two drugs. Since caffeine is a stimulant, and alcohol is a depressant, there may be some interesting effects. While there is a need for research here which is unrelated to driving, there is also the implication that while alcohol impairs drivers, the caffeine may actually alter their perception of this with the result that they 'incorrectly assess their fitness to drive,' and do so anyway (Riesselmann et al., 1996). This can be related to similar findings for the combined effects of alcohol and cannabis on driving (Sexton et al., 2000), and together with the implications of unwanted sleepiness caused by over-the-counter medicines as already discussed, is an indication of the importance of drug effects in future research on driving and driver sleepiness. Clearly also, simulator-based work offers the safest and most effective experimental scenario in which to attempt this (see chapter 3.0).

The use of FEDs in combination with breaks in driving form an effective countermeasure to driver sleepiness. However, this advice must be given with caution. Motorists must not be encouraged to rely on or over use caffeine for this purpose, and it must be stressed that this is effectively a last resort, only put forward to get drivers to a place where they can stop driving and sleep. The danger here is that drivers do not pay enough attention to the details of this advice, and use FEDs regularly and even exceed recommended consumption levels. This may also be a problem for drivers who are at work, since added motivation, and time constraints make it difficult to take breaks. Employers attitudes may even change to *suggest* the use of FEDs, effectively encouraging drivers to use them and therefore *continue* driving just a little further. This must be separately addressed, since the most careful and cautious commercial drivers can still be pushed or encouraged by their employers.

While this research is effective in identifying further, effective countermeasures to driver sleepiness, it also creates further questions, since many drivers may abuse the advice we generate. Those people who drive regular long journeys, or who drive for many hours every day at work, may already suffer from sleepiness while driving. Given practical advice such as this, combined with recent media coverage of SRVAs and resulting litigation, there is great potential for over reliance on caffeine. There is a need therefore to address *social* caffeine use, for reasons of habituation and increasing resistance.

KEY POINTS

- The 250ml (80mg caffeine) dose successfully reduced subjective sleepiness and lane drifting for about 60-90 minutes, with a trend for a more alert EEG.

- The 500ml (160mg caffeine) dose had a stronger and more sustained effect, and effectively removed subjective sleepiness and lane drifting incidents. This also extended to the EEG, which was significantly improved for at least 90 minutes of driving.

- FEDs are an extremely beneficial countermeasure to driver sleepiness given that they are readily available and convenient, and the variation in caffeine content of coffee. This may be even better in combination with a nap.

- There is however some potential for abuse, so caution must be exercised in giving advice. Drivers who regularly drive long journeys and at difficult times of the day may use FEDs excessively.

- Further research should examine direct comparison of FEDs with coffee, the synergistic effects of the other active ingredients (taurine and glucuronolactone), and the longer term effects on sleep onset and quality, particularly given this potential for abuse.

- Other caffeine sources or other psychostimulants may be introduced in the UK and these may be effectively evaluated in the same way.

- Experimental effects of potential countermeasures may be described using the subjective sleepiness matrix as shown in appendix 9.

- Some small sex differences in subjective sleepiness were observed. Again the study design was not sufficient for statistical comparison, but data did support the previous finding that females experience more sleepiness.

This work was supported by Red Bull.

6.0 INDIVIDUAL DIFFERENCES I

Trait Sleepiness

6.1 SUMMARY

The success of practical countermeasures to driver sleepiness relies largely on education and awareness, which are necessary to convey information effectively to the public. However, commercial drivers may be at greater risk from accidents related to sleepiness due to their high mileage and long working hours (Maycock, 1997), which often coincide with the more dangerous periods due to circadian biology (Folkard, 1997). This means that some drivers will be continually looking for ways to increase their alertness and push themselves further. We cannot assume that they aren't *already* experimenting with FEDs and even other stimulants to help improve or sustain alertness due to economic pressures. We must be cautious in giving practical advice as there is great potential for over-reliance on caffeine, and even some abuse of it. While investigation of practical countermeasures is essential, we must also tackle driver sleepiness from other angles. Companies also, must ensure that they are aware of the potential problems as they too have legal responsibility. Medical screening of drivers is one possibility for identifying clinical causes of driver sleepiness, and may have some potential to predict problems based on more general, 'trait' sleepiness. Survey and epidemiological work has examined the links between clinical causes such as obstructive sleep apnoea and narcolepsy, and even undiagnosed sleep problems such as heavy snoring – to accident risk in driving. High levels of trait sleepiness may be able to identify sleepier types of people more prone to these types of accidents. Changes in sleep problems with age such as those caused by sleep disorders may also be picked up by re-screening at a later date. The Epworth Sleepiness Scale (Johns 1991) is a simple and easy to use method of identifying trait sleepiness and could possibly be used to identify sleep related problems in commercial drivers. Its reliability at a test-retest level also suggests that it could be useful in highlighting sleep problems in later life. Can it be used to predict driving performance under sleep restricted conditions ? That is, do high scorers perform worse, and experience more sleepiness than low scorers ?

The aim of this study was to evaluate the power of the ESS to predict driver sleepiness as measured in the previous chapters – that is, to examine the relationship between trait/situational sleepiness and performance at a monotonous task (driving). From a total of 61 young adult drivers tested in programmes investigating driver sleepiness (Horne & Reyner, 1996; Reyner & Horne, 1997; 1998a; 1998b – see also chapters 3-5), data were compiled from the ten lowest (ALERT) and ten highest (SLEEPIER) participants within the normal range (0-10) for the ESS. All drove the interactive driving simulator under monotonous conditions, for 2 hours in the afternoon following a night of normal and a night of restricted sleep (5 hours, between 0200-0700 – verified by overnight actimetry). Subjective sleepiness (as measured by the KSS and LHoFA scales), EEG, and lane drifting were measured throughout as described previously, and data were compared between the two groups for both normal and restricted sleep conditions.

The alert and sleepier groups showed no overall significant between-group differences for driving incidents and subjective sleepiness, although there were trends with respect to the sleepier group having more incidents following sleep restriction. Nevertheless, this group tended to perceive themselves to be less sleepy following the sleep restriction. That is, the extent of perceived changes in subjective sleepiness appear to depend on one's general (trait) frame of reference. Interestingly, the sleepier group rated themselves significantly more likely to fall asleep than the alert group, under normal sleep, while there were no significant differences under restricted sleep. There were no significant differences in the EEG under restricted sleep, but there was a trend for alert drivers to experience more sleepiness during the first 30 minutes of the drive. While only demonstrating subtle differences, these may well be more apparent in drivers with ESS scores beyond the norm (i.e. >10). It is not safe to assume that professional drivers are within the normal range for ESS (0-10) as were the volunteers in this study. There is some support for the suggestion that medical screening for professional drivers should include some examination of sleep related issues in the interests of safety, and the implications of this are discussed. Future research should attempt to address and investigate driver sleepiness at work as well as focussing on practical countermeasures to it.

6.2 INTRODUCTION

Research into *practical* countermeasures (as discussed in chapter 5.0), may be the best way to tackle driver sleepiness. However, advice for sleepy drivers must be given with care, to avoid encouraging them to prolong driving for any length of time. An added danger here is that drivers who are particularly at risk from SRVAs (such as professional drivers, company car drivers, commuters and people whose work involves a lot of driving), may rely too much on this and other practical advice. If this is the case, they may already use FEDs or other types of stimulants extensively. New advice would then seem to endorse such behaviour. We must therefore exercise caution when giving advice, and also tackle the problem on a different level.

As has already been discussed, SRVAs are usually serious, and often fatal due to the high speed of impact and lack of avoidance manoeuvres (Horne & Reyner, 1995). These accidents are even more serious if heavy goods vehicles (HGVs) are involved, and can often spill onto the opposite carriageway if vehicles break through or cross the central reservation (Horne & Reyner, 1999). Similarly, tankers or other vehicles carrying hazardous or toxic materials have the potential to cause massive damage in an accident. Although many HGVs are speed-limited (typically to 56mph), they are still able to cause a great deal of destruction in the hands of a sleepy driver. The characteristics of the HGV drivers' job are also cause for concern: long work hours, high mileage and complex working time regulations mean that drivers can legally spend many hours each day behind the wheel. Added to this, the nature of the road haulage industry is such that deliveries are time-dependent – meaning little flexibility for essential rest breaks. Although the highway code clearly advises motorists to take breaks from driving every 2 hours, for at least 15 minutes (see figure 1.7), the working hours regulations for truck drivers in the UK allow them to drive for 4 hours without a break (Horne & Reyner, 1999). While this might seem surprising, it should be noted that there are no restrictions *at all* on van drivers, taxi drivers or company car drivers – all of whom may spend similarly long periods of time behind the wheel on a daily basis. Another interesting point to note is that many companies specialising in 'next-day deliveries' typically operate several different types of vehicle. Therefore there is legally nothing to stop a driver who is up to the regulation hours in a HGV, getting out of his cab and straight into a smaller van for further work.

SRVAs involving heavy goods vehicles (HGVs) have the potential to cause greatest damage, particularly if carrying hazardous substances, or if they collide with other vehicles. Truck drivers are thought to be at greater risk for sleep problems due to obesity, particularly a fat neck (Horne, 1992; Maycock, 1997), now commonly associated with sleep disorders, and disordered breathing during sleep. Therefore the question of medical screening arises for professional drivers. If it is possible to identify sleep disorders, or potential sleepiness problems which may result in an increased accident risk, then support and guidance can be made available for those concerned. As disorders such as obstructive sleep apnoea (OSA) may well develop during middle age, could this also be used as a re-screening method to identify potential problems before accidents can happen, thus encouraging employers to take more responsibility for the welfare of their drivers?

Pathological Sleepiness

Sleep disorders causing EDS are typically those such as OSA and narcolepsy. OSA is a respiratory sleep disorder causing patients to wake up many times during sleep, when obstructions to the airway make it impossible to breathe. Awakenings are short, and the patient begins breathing again and usually goes back to sleep without even realising he/she has woken up. However, this can happen several times each hour in extreme cases, with the result that deeper sleep is never sustained, so overall sleep quality is poor and daytime sleepiness increases, apparently without reason. OSA has been found to be associated with factors such as middle age, male gender, snoring, obesity, existing respiratory problems, and nasal surgery. Treatments typically involve continuous positive airway pressure (CPAP) whereby patients wear a mask during the night, and air is pushed through to keep the airway open. The main complication for the OSA problem is that sufferers may have no idea about it. If this is combined with long hours of driving, particularly at difficult times of day or night, the results could be disastrous. Narcolepsy is a more complex disorder whereby the circadian rhythm of REM sleep somehow intrudes into normal life, causing patients to suddenly lose muscle tone and fall into sleep. This is less relevant to driver sleepiness however, as narcoleptics would typically be prohibited from driving after diagnosis.

This link between EDS and SRVAs emphasises the evidence for accidents related to sleepiness, and also demonstrates that there are clinical causes. Ultimately however, this gives us further direction for the formulation of countermeasures. George et al. (1987) showed that OSA patients had twice the incidence of RTAs compared to controls. Survey work has also made this connection for undiagnosed sleep problems including snoring (Hanning & Welsh, 1996; Young et al., 1997). Zomer & Lavie's (1990) survey of 3000 sleep laboratory patients in Israel used about 900 with sleep problems resulting in EDS. All were given scores on 'accident proneness' and 'excessive sleepiness,' and the two measures significantly correlated ($r=0.36$, $p<0.0001$). Hanning & Welsh (1996) used insurance company information to examine EDS, snoring, car accidents and 'near misses.' Although snorers were found more likely to experience daytime sleepiness, and also to change their driving habits because of this, there were no significant results for accident rate. There were some problems with the subject sample however, as subjects were selected from policy holders with an insurance company only covering drivers aged >25 years with the maximum 'no claims.' Clearly, this would exclude 50% of the drivers thought to be most at risk based on age alone (Horne & Reyner, 1995b), and the no-claims condition would exclude sleepy drivers already having had accidents (Hanning & Welsh, 1996). Aldrich (1989) reviewed accident data in control subjects and sleep disordered patients, to find that apnoea and narcolepsy patients are more at risk of accidents, but also noted that their *awareness* of sleepiness may play a major role in accident risk, since some are fully aware and will stop driving appropriately. Thus 'a patient with a less severe condition who denies or does not perceive his sleepiness may be a more dangerous driver than one with a severe condition who takes appropriate precautions' (Aldrich, 1989).

Measuring Sleepiness

Traditionally, the identification of sleep disorders has centered on polysomnography, and specifically the multiple sleep latency test (MSLT). EEG is logistically complex to record, but offers a high level of insight into what is happening in the brain of the 'patient.' The MSLT itself attempts to measure sleepiness and identify abnormalities by measuring the time taken to fall asleep naturally in the absence of alerting stimuli at any time. Subjects are monitored (with EEG) in a quiet, darkened room and told 'Close your eyes and try to go to sleep'. The mean sleep latency in minutes is used to draw conclusions about the patients condition, < 5 minutes representing pathological sleepiness, and 10-20 minutes for 'normal'. However, MSLT scores of 5-10 minutes are inconclusive and uncertain, described as a 'diagnostic grey area' (Carskadon et al, 1986). Although widely accepted in US clinical research as a reliable objective measure, the MSLT has been criticised for its lack of relevance in applied research, where resistance to sleepiness is more important than ability to sleep. This led to the need for a test of maintained wakefulness, which would tell us more about sleepiness and its implications for performance. Alternatives to the MSLT have attempted to achieve the same high level of acceptance worldwide, but with a more simple and realistic protocol which is applicable to the world of work. The maintained wakefulness test (MWT – Mitler, 1982a) for example, works on the opposing principle to the MSLT, asking subjects to try to stay awake when placed in a dimly lit room, sitting in a comfortable chair facing a blank wall. The eyes are open and some movement is allowed, but vigorous or repetitive movements are not permitted. Subjects remain in this situation for 20 minutes, or until they fall asleep. Their instructions are to 'stay awake as long as possible.' This test is more relevant to applied research, since it measures subjects ability to stay awake in a monotonous situation – something which is much more likely to happen than the scenario suggested by the MSLT. Clearly the processes involved are different, and this test therefore has more practical relevance to sleepiness at work, and in particularly to driver sleepiness. If we were to consider the screening of professional or high risk drivers however, such a test would prove logistically very difficult. A much simpler alternative here is to use a basic questionnaire or self-rating scale, to measure general 'trait' sleepiness. The idea is that individuals vary in their susceptibility to sleepiness, depending on their normal routines, personality traits, and the situation in which you ask them. The morningness-eveningness questionnaire (Horne & Östberg, 1976) is one example of this, and has been used to demonstrate significant differences in performance between the two types of individual at different times of day (Horne, Brass & Pettitt, 1980).

Trait Sleepiness

The Epworth Sleepiness Scale (see fig. 2.1) has been offered as an alternative (Johns, 1991), and several studies have shown this to be effective (Johns, 1992; 1994; 1997), even more so than the MSLT (Johns, 1999). If this could be used in some way to predict whether certain types of people are more at risk from accidents based on general 'trait,' or situation-dependent sleepiness (Johns, 2000) there are important implications for professional drivers and those who drive for long periods on a regular basis.

The Epworth Sleepiness Scale (Johns, 1991) is a commonly used self assessment tool for measuring trait levels of sleepiness. The scale is self-administered and asks subjects to rate on a scale of 0-3 their typical chances of 'dozing' in 8 different situations which are common to everyday life (see figure 2.1). These scores are added together to give the total ESS score, ranging from the minimum of 0 to the maximum of 24. The 8 situations were chosen to reflect different levels of sleepiness, or 'situational-sleep-propensities' (Johns, 1991). Generally individuals have been shown to rate themselves at these items in the same way, with 'lying down to rest in the afternoon when circumstances permit' scoring highest, and 'sitting and talking to someone' scoring lowest (Johns, 1994). The ESS is said to represent trait sleepiness or 'average sleep propensity' (Johns, 1998), and the higher the score, the more likely a person is to doze in situations which are not soporific for others (Johns, 1998). It has reliable test-retest conditions and a high level of internal consistency (Johns 1992, 2000). Scores of 10 or under are regarded to be within the normal range (Johns, 2000) and largely exclude people with pathological excessive daytime sleepiness such as those suffering from a sleep disorder such as OSA, who have also been found to score higher on the ESS (Johns, 1998). In a large survey of UK car drivers, Maycock (1996) included the ESS. Respondents fell within the ESS range 0-13 (just beyond the normal cut off) and he reported that those who did not snore but had ESS scores higher in this range (more sleepy) had a greater accident liability than those with low ESS scores. Although Maycock could not establish whether this increased liability was associated with sleep related accidents rather than with accidents in general, it does suggest a link. Johns himself has also addressed the driving issue directly, concluding that drivers average level of daytime sleepiness is related to dozing at the wheel (Johns & Martyn, 1999; Johns, 2000b), and calling for further efforts to increase awareness in Australia (Johns, 2000b).

Given the simple nature of the ESS, and its sensitivity and specificity (Johns, 2000), together with the apparent limitations of the MSLT, could we use a measurement such as the ESS in medical screening of commercial drivers in order to identify possible sleep related problems and therefore individuals who are more at risk ? That is, will higher scorers become more sleepy and perform worse in the driving simulator ?

Study Aims

It may be that some people as we have seen at a clinical level through work on sleep disorders and driving, are more likely to be at risk from SRVAs. Reasons for investigating this are really to raise awareness of employer and employee and also to offer support and guidance to those who are at risk.

This can be further examined using the laboratory database of participants from a series of studies into driver sleepiness (Horne & Reyner 1996; 2000; Reyner & Horne 1997; 1998a; 1998b – see also chapters 3-5) using the interactive driving simulator and standard experimental protocol. The ESS was routinely administered to all volunteers as part of the selection process for these studies, to include only drivers within the normal range for trait sleepiness. Of a total of 61 participants studied using the simulator, all were within the ESS range of 0-10. Within this range, high and low scoring groups could be identified (see figure 6.1). It may be that for subjective sleepiness, lane drifting and EEG measures, there is some difference between the two groups reflecting the sensitivity of the ESS at measuring drivers trait level of sleepiness, which relates to their everyday experiences of sleep propensity (Johns, 1991). Also, since data is available from the driving simulator for baseline (normal sleep) and non- treatment (restricted sleep) conditions, there may also be some difference in the effects of increased afternoon sleepiness upon driving for the two different groups. Since we are using ESS scores of 0-10 (i.e. the normal range), we should remember that ideally and in the future, this group could include drivers outside this normal range (e.g. 10-15) as this would draw on sleep disordered drivers, whereby the ESS may become more reliable and powerful.

6.3 METHOD

The study compared the subjective, EEG and lane drifting measurements of sleepiness, in two separate groups of participants, based on their individual levels of trait sleepiness as measured by the Epworth Sleepiness Scale (Johns, 1991), for both normal and restricted sleep conditions.

Participants were 20 volunteers (10 male, 10 female), with a mean age of 23.30 years (±2.58 years), chosen from previous studies using the interactive simulator. For the purposes of the study, 10 "ALERT" drivers (ESS scores 0-4 inclusive [4 males, 6 females], mean age = 23.30 yrs [±2.75 yrs], mean ESS = 2.0), and 10 "SLEEPIER" drivers (ESS scores 8-10 inclusive [6 males, 4 females], mean age = 23.30 yrs [±2.54 yrs], mean ESS = 9.0), were compared.

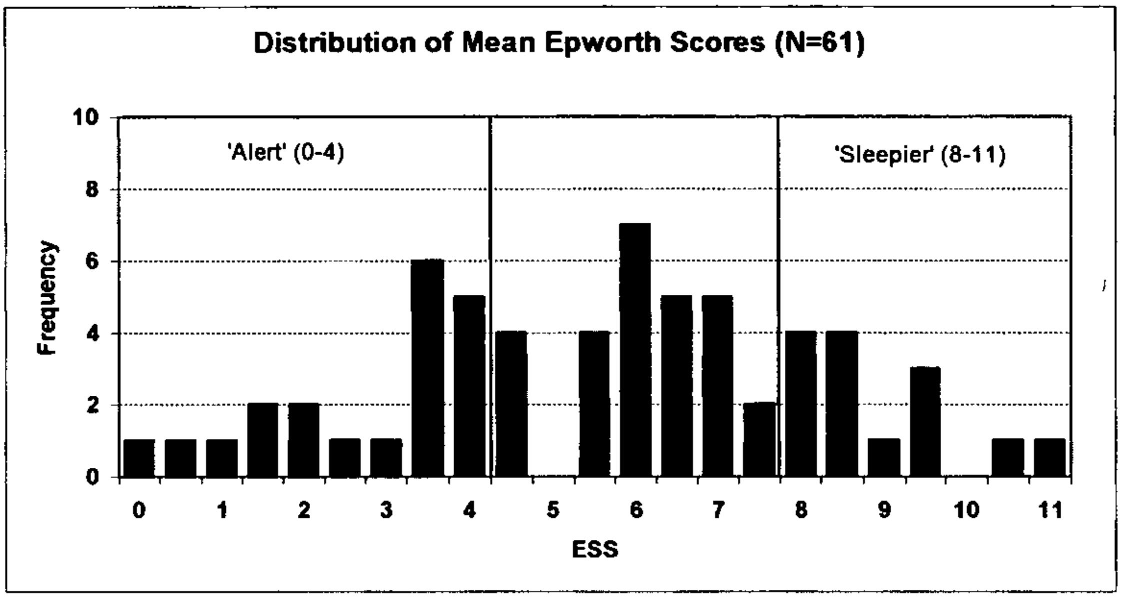

Figure 6.1
Distribution of volunteer drivers' ESS scores - showing
Lower (ALERT) and higher (SLEEPIER) scoring groups

Statistical Analyses

ANOVAs were based on each participant's mean values in 30 minute periods for the 2 hour drive.

6.4 RESULTS

Subjective Sleepiness

The mean KSS scores for the two groups for the normal and sleep restricted conditions were plotted against time. This data is summarised in figures 6.2 and 6.3. Comparison of the mean values revealed no overall significant difference between the two groups, but as expected, there was a significant difference between the sleep conditions (F=11.00 d.f. 1,18; p<0.001). There was no significant interaction.

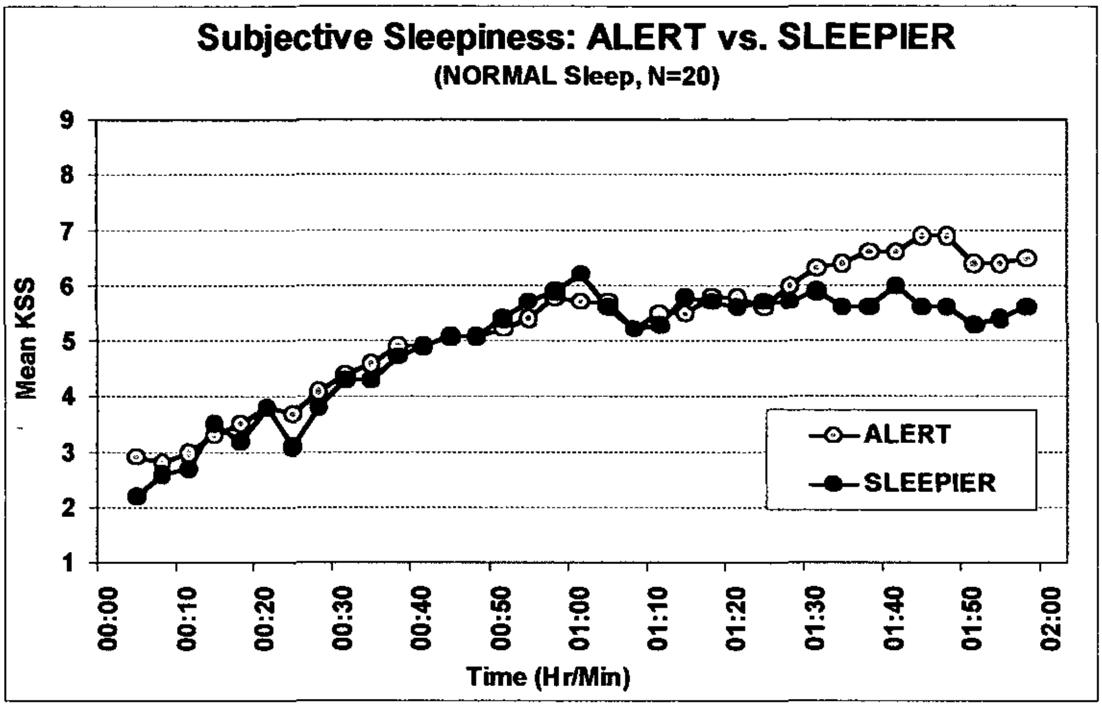

Figure 6.2

Subjective sleepiness (KSS) over time for ALERT and SLEEPIER groups following NORMAL sleep.

There is a clear trend for the alert drivers to feel more sleepy than the other group following restricted sleep.

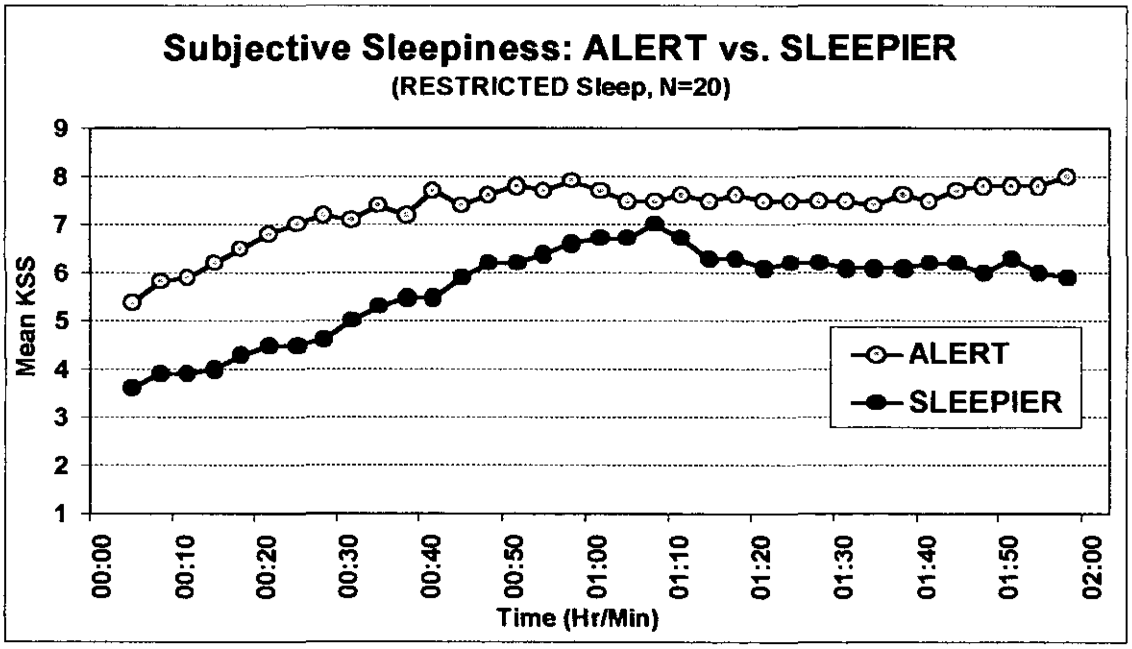

Figure 6.3

Subjective sleepiness (KSS) over time for ALERT and SLEEPIER groups following RESTRICTED sleep.

This data was also plotted in terms of the time spent in each level of the scale. This is presented in figure 6.4 for restricted sleep only. Again, the slight tendency for alert drivers to experience more sleepiness can be seen.

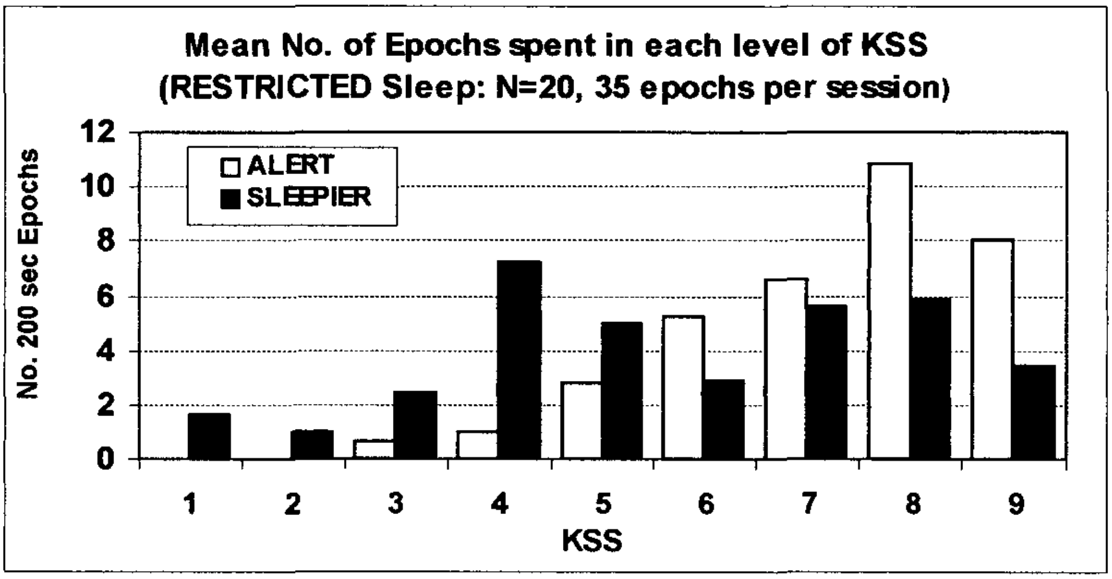

Figure 6.4

Time spent in each level of subjective sleepiness (KSS) for ALERT and SLEEPIER drivers following RESTRICTED sleep.

Drivers also rated their likelihood of falling asleep on the LHoFA scale. This data is shown in figures 6.5 and 6.6. Interestingly, although data were very similar after restricted sleep, there were some differences following normal sleep. The higher scoring group perceived themselves as more likely to fall asleep than the alert group. This difference was significant (F=5.76, d.f. 1, 72; p<0.019), and there was also a significant effect of time (F=2.20, d.f. 3, 72; p<0.016), that is, drivers became more likely to fall asleep as driving continued. A post-hoc tukey test demonstrated that this difference existed between the first and last 30 minute periods of the driving session (p<0.011). There was no significant interaction, and there were no significant outcomes for the restricted sleep condition.

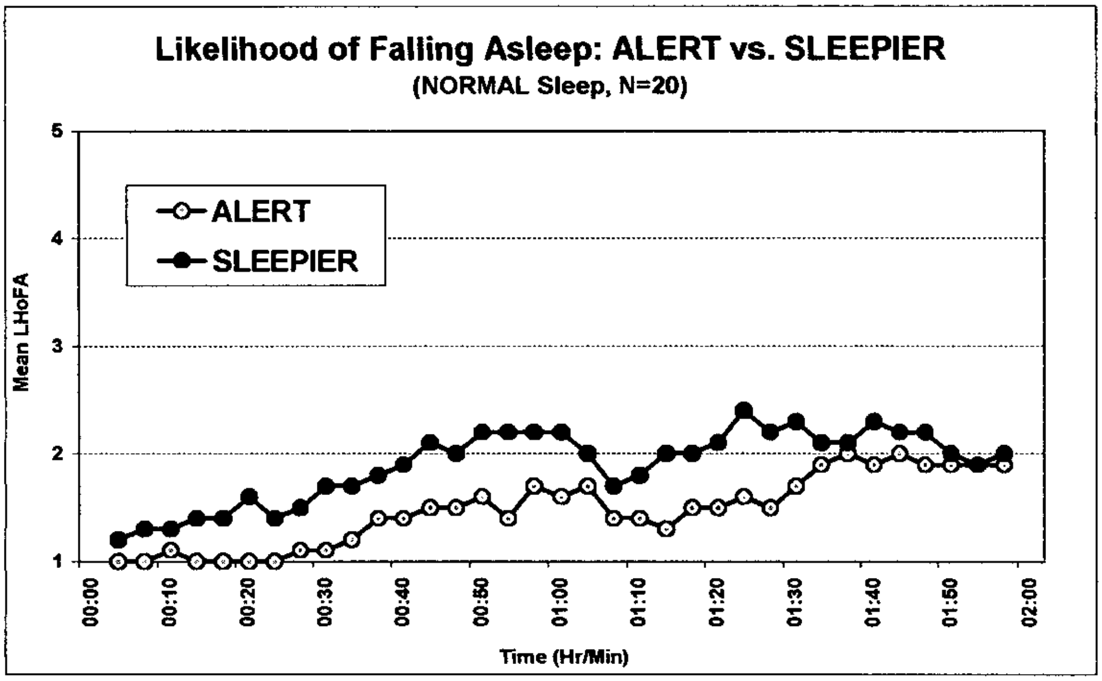

Figure 6.5

Likelihood of falling asleep over time for ALERT and SLEEPIER groups following NORMAL sleep.

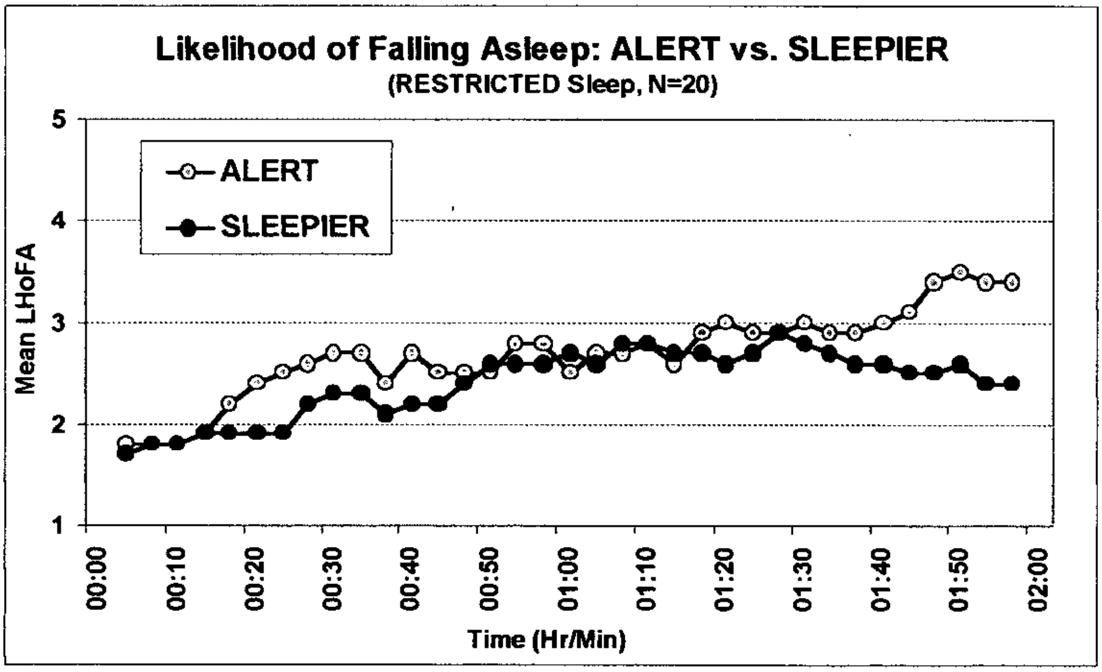

Figure 6.6

Likelihood of falling asleep over time for ALERT and SLEEPIER groups following RESTRICTED sleep.

Tables 6.1 and 6.2 show the progression of drivers through the subjective sleepiness scales. Table 6.1 (normal sleep) in particular shows the truncation of the pattern as the alert drivers do not reach the higher levels of sleepiness (although the sleepier drivers do).

	NORMAL SLEEP	A	B	C	D	E
	ALERT DRIVERS	Very Unlikely	Unlikely	Possibly	Likely	Very Likely
1	Extremely Alert	6	0	0	0	0
2	Very Alert	20	0	0	0	0
3	Alert	40	3	0	0	0
4	Rather Alert	38	25	0	0	0
5	Neither	48	8	3	0	0
6	Some signs of Sleepiness	24	22	4	0	0
7	Sleepy but no effort to stay awake	46	16	9	0	0
8	Sleepy, some effort to stay awake	1	14	23	0	0
9	Very Sleepy, great effort to stay awake	0	0	0	0	0
	NORMAL SLEEP	A	B	C	D	E
	SLEEPIER DRIVERS	Very Unlikely	Unlikely	Possibly	Likely	Very Likely
1	Extremely Alert	16	0	0	0	0
2	Very Alert	37	1	0	0	0
3	Alert	57	21	1	0	0
4	Rather Alert	20	15	0	0	0
5	Neither	10	12	2	0	0
6	Some signs of Sleepiness	16	8	22	0	0
7	Sleepy but no effort to stay awake	7	19	35	0	0
8	Sleepy, some effort to stay awake	2	3	26	1	2
9	Very Sleepy, great effort to stay awake	0	0	2	12	3

Table 6.1 – Progression of Subjective ratings –
The Subjective Sleepiness Matrix (Normal Sleep)

	RESTRICTED SLEEP	A	B	C	D	E
	ALERT DRIVERS	Very Unlikely	Unlikely	Possibly	Likely	Very Likely
1	Extremely Alert	0	0	0	0	0
2	Very Alert	0	0	0	0	0
3	Alert	6	0	0	0	0
4	Rather Alert	8	2	0	0	0
5	Neither	21	7	0	0	0
6	Some signs of Sleepiness	29	17	6	0	0
7	Sleepy but no effort to stay awake	10	32	24	0	0
8	Sleepy, some effort to stay awake	1	31	55	14	7
9	Very Sleepy, great effort to stay awake	0	0	18	26	36
	RESTRICTED SLEEP	A	B	C	D	E
	SLEEPIER DRIVERS	Very Unlikely	Unlikely	Possibly	Likely	Very Likely
1	Extremely Alert	16	0	0	0	0
2	Very Alert	10	0	0	0	0
3	Alert	14	10	0	0	0
4	Rather Alert	5	65	2	0	0
5	Neither	0	49	1	0	0
6	Some signs of Sleepiness	0	19	10	0	0
7	Sleepy but no effort to stay awake	0	26	30	0	0
8	Sleepy, some effort to stay awake	0	4	39	16	0
9	Very Sleepy, great effort to stay awake	0	0	5	21	8

Table 6.2 – Progression of Subjective ratings –
The Subjective Sleepiness Matrix (Restricted Sleep)

Table 6.2 (restricted sleep) shows the bottom left section denoting sleepiness but less likely to fall asleep (alert drivers). This change can be seen in figures 6.7 and 6.8, which show the difference between the 2 groups for LHoFA under normal (6.7) and restricted sleep (6.8). While sleepier drivers are more likely to fall asleep under normal conditions, this seems to be reversed following restricted sleep.

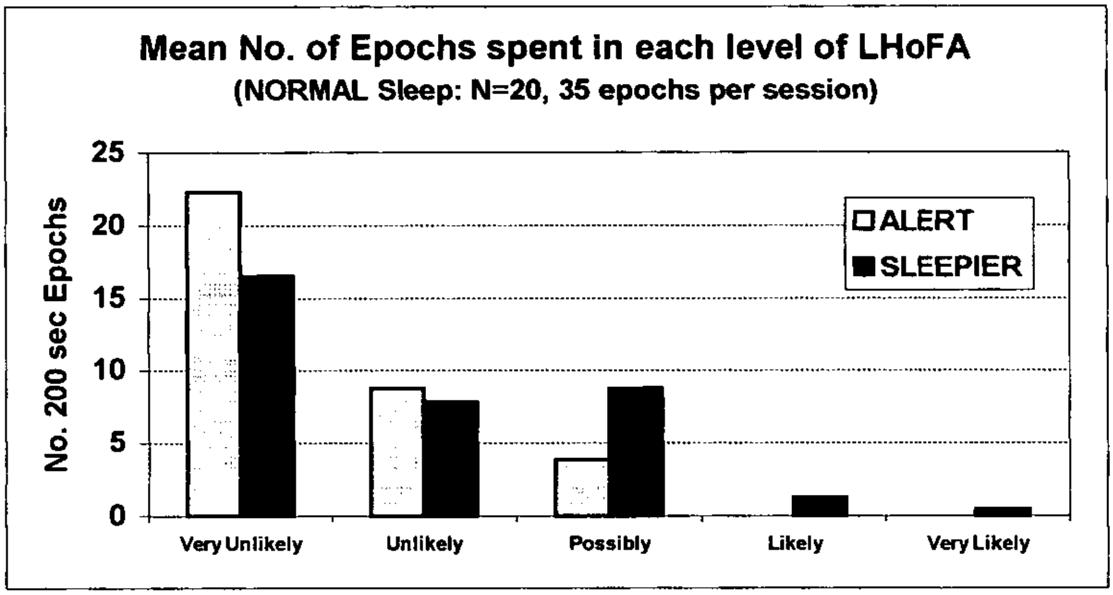

Figure 6.7
Time spent in each level of LHoFA scale for ALERT and SLEEPIER drivers after NORMAL sleep.

Driving Performance

Lane drifting incidents related to sleepiness (as identified by video analysis) were averaged across participants and plotted in 30 minute periods, as shown in figure 6.9. These data are also presented in figure 6.10, averaged over the whole 2 hour afternoon drive. Although there are trends for the driving incidents, especially with the effects of sleep restriction on the sleepier group, there were no significant outcomes.

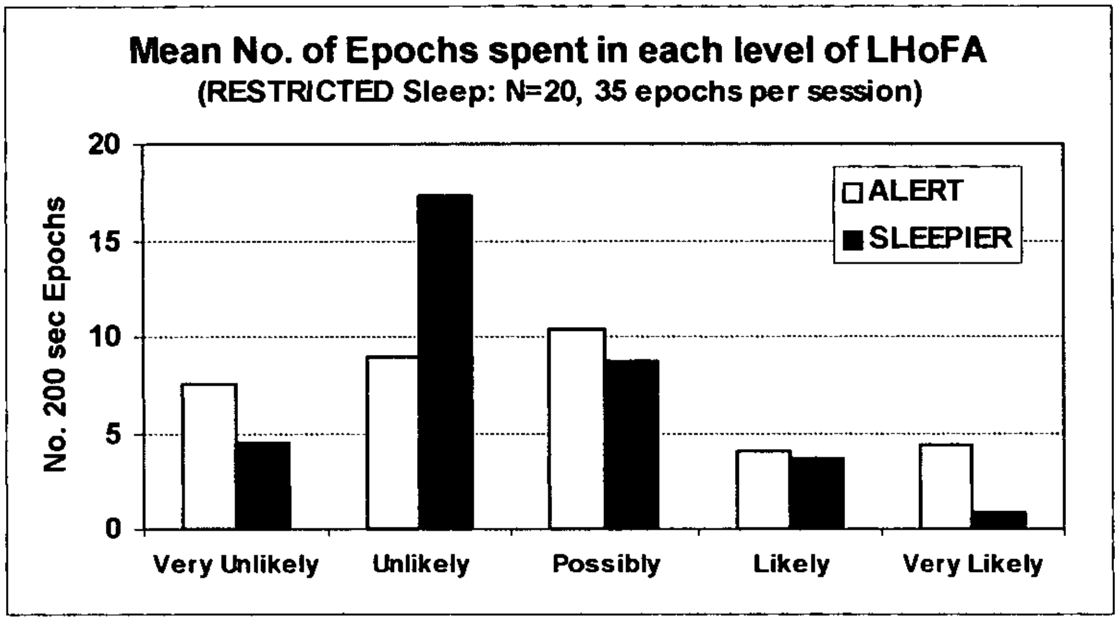

Figure 6.8

Time spent in each level of LHoFA scale for ALERT and SLEEPIER drivers after RESTRICTED sleep.

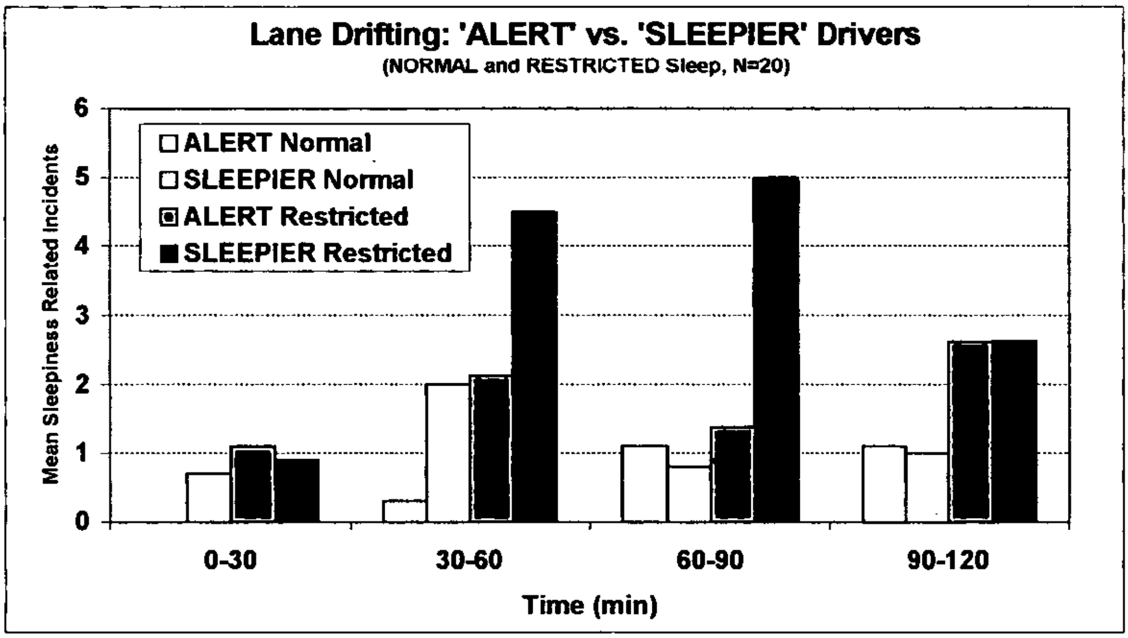

Figure 6.9

Mean lane drifting incidents in 30 minute periods for ALERT and SLEEPIER drivers after NORMAL and RESTRICTED sleep

It should be noted that there were large between subject differences, especially among the sleepier group, and also that the afternoon dip became particularly apparent in the sleepier group during the middle of the drive (see fig 6.9) and lifted somewhat by the end of the session.

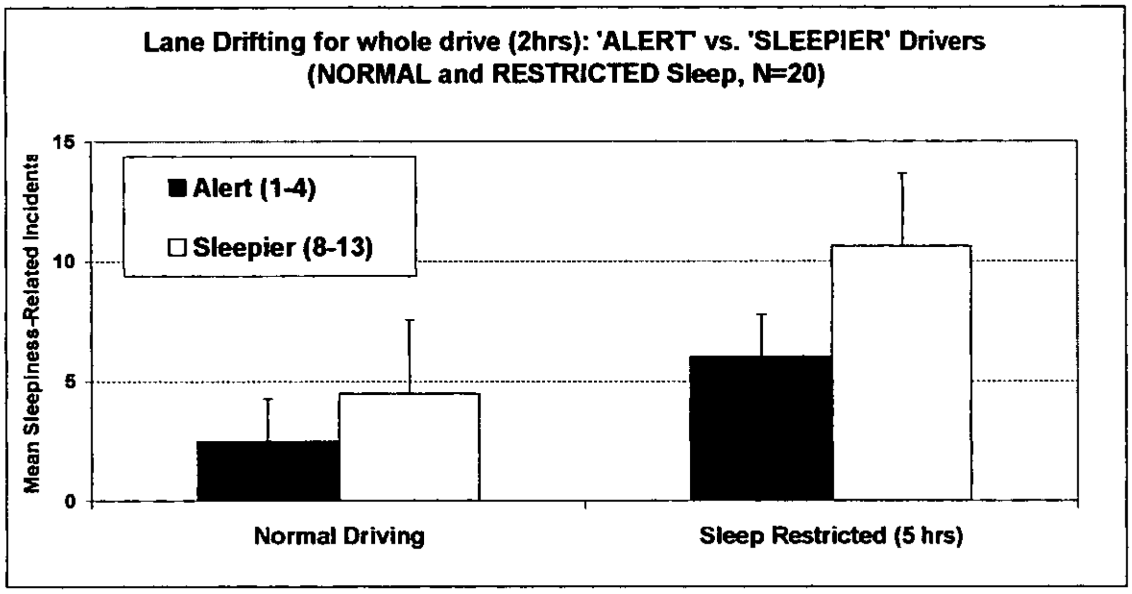

Figure 6.10

Mean lane drifting incidents for the whole 2hr drive for ALERT and SLEEPIER groups after NORMAL and RESTRICTED sleep

EEG

EEG data was spectrally analysed and standardised in one minute epochs before being averaged across participants. Since this data came from different studies, the raw data files were used, spectral analysis redone (using Rhythm), and all data standardised together in order to ensure identical treatment and minimise errors. The averaged data was plotted against time for alert and sleepier groups, as shown in figure 6.11. Only sleep restricted data (not baseline) is represented here. Baseline EEG data from the earlier studies was not analysed as a matter of routine, and some was lost in transfer from older data storage systems, leaving too few participants for comparison.

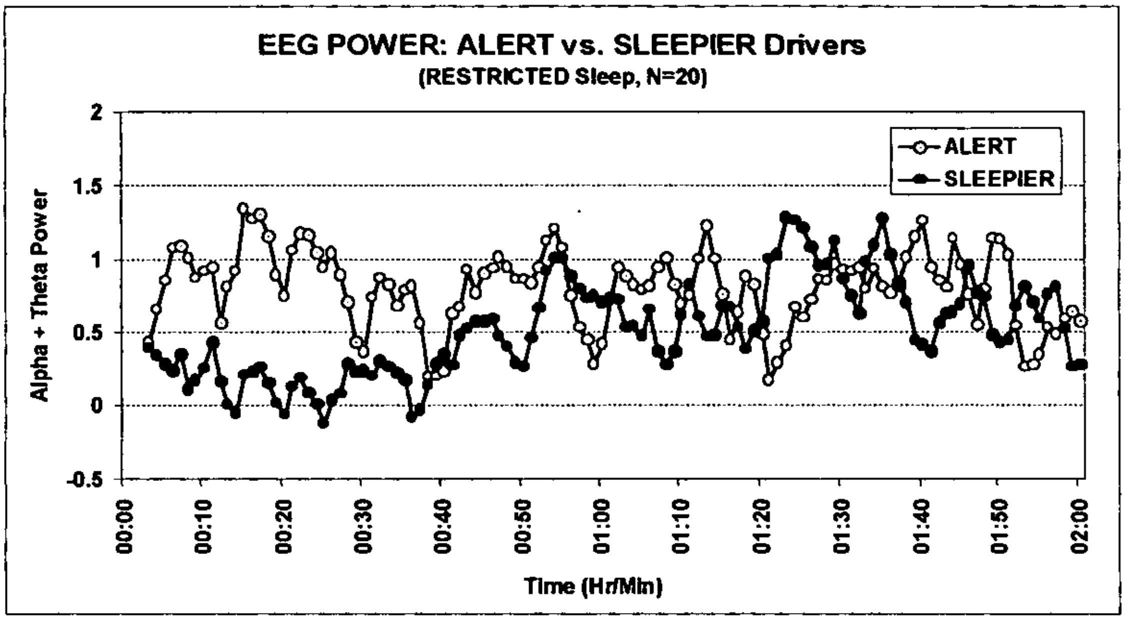

Figure 6.11

Standardised Alpha and Theta EEG power over time for ALERT and SLEEPIER groups following RESTRICTED sleep.

There were no significant differences in EEG data between the two groups, although the alert drivers clearly tended to be more sleepy in the first 30 minutes of the drive as compared to the sleepier group.

6.5 DISCUSSION

The alert and sleepier groups showed no overall significant differences for driving incidents and subjective sleepiness, although there were trends with respect to the sleepier group having more incidents following sleep restriction. Statistically it would seem therefore, that people within the normal (0-10) ESS range behaved similarly. This might seem contrary to Maycock's (1996) findings but it should be noted that he interpreted the normal ESS range to be 0-13 whereas the data described here is based on a lower cut off, as others would view scores above 10 to be indicative of sleep-related problems (Johns, 2000). Projects using the driving simulator used here have been oriented towards normal, healthy young adult drivers, as this is the group most represented in the accident data (Pack et al., 1995; Åkerstedt & Kecklund, 2001), and drivers outside this range or those suffering from sleep disorders or chronic sleep deprivation were not recruited. Nevertheless, these findings do support those of Maycock (1996), that drivers in the high-normal range for ESS may be liable to have more accidents.

Future research should perhaps address this issue more directly, recruiting drivers outside the normal range for ESS. Although individuals with higher scores, for example 10-15, could be argued to be suffering from clinical sleep disorders resulting in EDS (Johns, 1994), it is also likely that they are unaware of it, and would not therefore be undergoing treatment, or more importantly have any cause to perceive themselves as being at greater risk from SRVAs than 'normals'. Most importantly however, this may mean, as shown here, that they are less able to recognise sleepiness and therefore less likely to modify their driving behaviour because of it.

Under baseline non-sleepy conditions, both groups had similar KSS scores. Interestingly, when afternoon sleepiness was enhanced by a fixed amount of prior sleep restriction, there was a tendency for the sleepier group to perceive this to a lesser extent than the alert group (see figure 6.2). Despite this, the trend for incidents went in the opposite direction, that is, worsened for the sleepier group. This points to the latter group having more incidents for a given KSS score when sleepiness is further enhanced by sleep restriction.

While the alert drivers did not reach high levels of sleepiness under normal conditions (as expected), it should be noted that there was some instability as shown by the subjective sleepiness matrix (see table 6.1), as drivers rated themselves highly on the KSS but not on the LHoFA scale. Surprisingly, it was the alert drivers who experienced greater levels of subjective sleepiness following sleep restriction, again demonstrated by the matrix (see table 6.2) which shows high levels of sleepiness (bottom right), as well as some instability (bottom left). This would suggest that while some individuals experience greater levels of sleepiness than others, this depends on the general 'trait' point of reference.

It seems that perceived changes in subjective sleepiness may well depend on a trait or initial frame of reference, whereby the perceived magnitude of increase in acute sleepiness (caused by sleep restriction) is seen to be less with a higher level of trait sleepiness. Conversely, the lower the trait sleepiness, the greater the perceived effect of the sleep restriction. This is supported further in the EEG, which although largely similar for the two groups, shows a trend for the alert drivers to be more sleepy during the first 30 minutes of the drive.

This study also raises the question of medical screening for commercial drivers. It is unlikely that employers pay much attention to potential sleep disorders or daytime sleepiness problems in their recruitment, and certainly they would not monitor drivers over time for new sleepiness related problems which may arise due to changes in lifestyle, domestic duties (e.g. childcare), or health issues (weight gain, respiratory problems, ageing). Through education of management, the education and welfare of workforces could be vastly improved, and awareness increased at all levels. The ESS is just one potential tool to be used for doing this. Other sleep research methodologies (EEG, MSLT) are far less accessible or likely to be utilised in this way.

It has been the general practice to regard drivers outside the normal range of the ESS (0-10) as unsuitable to participate in the driving studies using the simulator. This study has yielded some important findings however, and some examination of these drivers (e.g. ESS 10-15) would add a most interesting comparison to the existing data. Another interesting direction might be the amount of sleep loss – if drivers are very similar under normal sleep, but differences become more noticeable following sleep restriction, what will be the effects of a whole night without sleep on driving in the afternoon, or indeed the early morning ?

Regarding screening, the driving protocol currently does not ask volunteers about several important elements as part of the recruitment procedure. In line with survey studies (e.g. Maycock, 1996, 1997), this could be modified to ask for more information on previous experience with driver sleepiness, and knowledge of available countermeasures. Some of this information could be used to replicate survey studies, giving the additional advantage that a picture can be built up of the young driving population (those most at risk from SRVAs statistically). This would also generate useful data from unsuitable volunteers. These can simply be added to the background information questionnaire used to recruit driving participants (see appendix 1) as suggested below.

Additional Questions

- Have you felt close to falling asleep at the wheel during the last 12 months ?
- On a long journey, for how many hours would you drive without a break ?
- When taking breaks from driving, for how long do you typically stop ?
- What do you do during this time ?
- If you feel sleepy when driving, what methods do you use to keep yourself awake ?

- What percentage of all road accidents do you think are caused by sleepiness ?
- How serious do you think these accidents might be, as compared to others ?

(Adapted from Maycock, 1996)

Although the results of this study showed less clear results than were hoped for, it should be noted that there was some trend within the data which suggests that further investigation could be useful. Medical screening for professional drivers is another element to the increasing education and awareness of the driver sleepiness problem, and does require some further investigation.

KEY POINTS

- No difference in sleepiness levels was seen under normal sleep, but there was a trend for alert drivers to experience more sleepiness after sleep restriction.

- Sleepier drivers tended to be more impaired by sleep restriction (i.e. make more driving errors) than the alert drivers.

- Alert subjects showed a less alert EEG during the first 30 minutes of the drive following sleep restriction.

- There is an interesting relationship between trait sleepiness, and sleepiness experienced during driving. This seems to depend on the individuals general frame of reference.

- Although results were not greatly significant overall, there are implications for drivers outside the normal range of the ESS (>10).

- These findings have possible screening implications for commercial drivers, particularly at a test-retest level, since they may be more at risk from SRVAs, and we cannot assume that they are within the normal ESS range (0-10).

- The recruitment procedure should perhaps ask for more information about previous experience with driver sleepiness, knowledge of countermeasures and normal amounts of sleep. These additions should be based on recent UK drivers surveys (Maycock, 1996; 1997).

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Transport, Local Government and the Regions (DTLR).

7.0 INDIVIDUAL DIFFERENCES II

Sex

7.1 SUMMARY

While it may be possible to identify those at risk from driver sleepiness using simple measuring techniques such as the ESS, there could be other factors affecting an individuals risk of falling asleep at the wheel which have yet to be identified. Gender differences are well documented in psychological literature, including sleep architecture, EEG, sleep disturbance, sleep disorders and problems related to shiftwork. This may be relevant to driver sleepiness also, because male drivers are thought to be far more likely to have SRVAs than females, based on studies of accident data, although this has not been directly addressed in experimental work. While the difference may simply be due to greater exposure to driving and/or to driving in situations where sleepiness may be more likely (e.g. at night, or in working situations), there are no data with which to normalise this ratio. There may be physiological differences between the sexes, or fundamental differences in driving behaviour and *attitudes* to driver sleepiness which have so far been undetected since gender comparisons are typically an afterthought in experimental studies such as those described in the previous chapters. Do males suffer more from driver sleepiness as the accident statistics would suggest ? Does this extend to driving performance when sleepy ? How do males and females differ in their *perception* of increasing sleepiness, and likelihood of actually falling asleep at the wheel ?

The aim of this study was to examine equal groups of male and female drivers for subjective and objective sleepiness, as well as driving performance (measured by lane drifting), in order to directly assess any apparent sex differences. Data from 30 participants, aged between 20-30yrs, with a mean age of 22.97 (±2.54 yrs), was chosen, to represent equal numbers of each sex (15 male, 15 female), for normal and restricted sleep conditions (i.e. non-treatment sessions without intervention). All drove the interactive driving simulator under monotonous conditions, for 2 hours in the afternoon following a night of normal and a night of restricted sleep (5 hours, between 0200-0700 – verified by overnight actimetry). Subjective sleepiness (as measured by the KSS and LHoFA scales), EEG and lane drifting were measured throughout as described in previous chapters, and data were compared between the two groups for both normal and restricted sleep conditions.

The male and female driver groups demonstrated similar levels of and changes to subjective sleepiness over time in the normal sleep condition. However, under restricted sleep, female drivers perceived themselves to be more sleepy than males. This was demonstrated significantly on both the KSS and likelihood of falling asleep scales. The EEG also showed a trend for females to experience more sleepiness than males, although this difference was not significant. Analysis of lane drifting data demonstrated significant differences between the two groups with females making more driving errors following sleep restriction. These findings show that although male drivers may be more at risk from SRVAs, this may actually be more of a result of exposure, attitudes and awareness than physiology. That is to say that females may be more prone to sleepiness and the resulting impairment to driving, but also much more able to recognise this and stop driving. As well as this, the study demonstrates most importantly that there may be interesting elements still to be uncovered in terms of gender differences. While much work is concerned with anecdotal, experimental and accident statistic investigation of driver sleepiness, few studies have directly addressed the issue. With modestly increased subject numbers and more strict gender balancing within studies, straightforward and statistically robust comparisons may be made. In particular, this should focus on differences in attitudes to driving, and willingness to stop when tired – the psychological elements involved in the driver sleepiness problem, with obvious legal implications.

7.2 INTRODUCTION

While the ESS may be useful in predicting accident risk, particularly for higher scoring individuals and to identify pathological sleepiness, there are other aspects of individual differences which have yet to be directly addressed. This chapter describes an additional study designed to directly investigate sex differences in driver sleepiness, using an existing database of experimental driving data (including that collected in the previous chapters).

Individual differences have been extensively researched in many areas of psychology, focussing largely on age and sex. These extend to many different elements of sleep research, although investigations into sex generally tend to be secondary observations under the broader heading of individual differences.

Females experience physiological and emotional changes in several defined phases each month due to the menstrual cycle, which may include increased sleep disturbance and daytime sleepiness (Manber & Bootzin, 1997). While early research acknowledged the potential confounding effect of this, little since then has directly controlled for it, or investigated further. However, several studies have demonstrated sex differences in various aspects of human sleep:

Looking at circadian rhythms, Campbell et al. (1989) examined body temperature and sleep quality in elderly subjects. They concluded that age-related changes are dependent on gender, and in particular, women were phase-advanced by 1.25 hrs. There is also some evidence for a general tendency of women towards *morningness* in terms of mood and personality – possibly as they are more dependent on environmental zeitgebers (Adan & Sanchez-Turet, 2001). This is supported also by the greater incidence of seasonal variations and seasonal affective disorder (SAD) in females (Blazer, 1995).

Reynolds et al. (1986) studied recovery sleep, to find that females experienced better sleep quality following 36 hours of deprivation. Females also seemed more able to sleep, with an increase in TST extending to the second recovery night which was not present in males. Armitage et al. (2001) also examined SWS levels following sleep deprivation, concluding that females show a greater enhancement of slow wave activity than males. This difference in SWS has also been demonstrated under normal conditions, in studies focussing on sleep architecture. Mourtazaev et al. (1995) found that slow-wave amplitude was greater in females, but noted that anatomical differences between the sexes, particularly skull size and thickness, can affect the EEG. Dijk et al. (1989) also demonstrated higher power density in females from spectral analysis, and again, this was related to cranial differences (Pfefferbaum & Rosenbloom, 1987). However, as noted by Ehlers et al. (1993), increased SWS in females has also been demonstrated in animal studies where EEG is measured from the cortical surface (i.e. *unaffected* by skull thickness), suggesting that these differences may not be due to cranial characteristics.

While it is generally found that males suffer more from sleep disorders such as apnoea, Valencia-Flores et al. (1992) studied differences in *sleep architecture* in male and female patients. Females were found to have longer sleep onset latencies, greater amounts of SWS, and fewer awakenings than males. They also reported more daytime fatigue and night time sleep disturbance. Most interestingly, these differences *continued* to be present under CPAP treatment.

Ehlers & Kupfer (1997) studied the effects of sex and ageing on SWS, demonstrating that males show a greater decline in the percentage of SWS experienced with age (20-40yrs). Similarly, Carrier et al. (2001) found higher EEG power density in females – as well as better sleep, although they *complained* more about insomnia. Therefore it was suggested that men and women age differently in terms of changes to sleep.

Wilkinson's (1984) review of the literature on noise and sleep disturbance summarised 3 experiments, all showing females to be more susceptible than males. Similarly, Rediehs et al. (1990) found that women tended to report longer sleep onset latency and more sleep disturbance than males. Pankhurst & Horne (1994) used actimetry and sleep logs to examine the influence of bed partners and movement during sleep. Males showed more movement, but females reported being disturbed more by their partners, had a greater total sleep time and went to bed earlier. Lindberg et al. (1997) studied sex differences in sleep disturbance, related to psychological status in young adults. Females were found to experience longer TST, but more importantly the difference in TST relative to reported sleep *need*, was even greater among females. DMS, EDS and absence of feeling refreshed in the morning were also more commonly found in females. Drawing some of this literature together, a review by Bliwise et al. (1992) concluded that women *generally* have more sleep complaints than men.

Harma (1995) conducted a review of individual differences in sleepiness and shiftwork. Female workers generally tended to suffer more sleep debt and complain more about problems falling or staying asleep, than males. He also noted that household and childcare duties can often make females suffer more (Harma 1993). These findings are supported by Dirkx (1991), reporting that females complain more of awakenings, tiredness, irritability and fatigue, as well as experiencing more injuries, and suffering more drowsiness at work. These ideas were also supported by a study of age, gender and shiftwork intolerance. Again females reported more sleep disturbance, drowsiness during work, and generally more symptoms associated with "intolerance syndrome" (Oginska et al., 1993), once more supporting Bliwise's conclusions.

Looking more closely at *driving*, several studies have examined differences in accident types, driving ability and attitudes, although not related to *sleepiness*. Laapotti & Keskinen (1998) studied Finnish road accident data, focussing on the different *types* of accident reported by male and female drivers. Both had equal numbers of accidents caused by 'loss of control', but this tended to result in single vehicle accidents for males, and collision with another vehicle for females. For males, these were usually at night or in the evening, and for females, the most common factor was slippery road surfaces. Thus, the authors concluded that females' accidents are more likely to be due to inexperience, while males are due to risky driving habits. This evidence underlines the representation of males in SRVA accident data, again, typically single-vehicle accidents, occurring at night (see section 1.5). Authors generally agree that risky driving behaviour is more common in males, but most studies to investigate this concern *young* male drivers (these are easily distinguishable from other groups). Little is known about *female* drivers, and any *comparisons* of sex are usually secondary to the main line of investigation.

One study, by DeJoy (1992) measured drivers' self-ratings of relative driving safety, driving skill and likelihood of accidents. Males were more optimistic, particularly when judging driving skill. Although both had similar perceptions of risky driving behaviours, males perceived them as *less* serious. This supported earlier work, by Jessor (1987), who asked drivers if they took risks for fun while driving. 31% of males said yes, compared to only 7% of females. Brown & Copeman (1975) also, noted that young males rated driving offences as less serious than either young females or older males. Generally it seems that young males have more accidents due to optimism, since they overestimate their own driving skill, *and* perceive less risk in various driving situations (Glendon et al., 1996). These two factors combined may account for their high accident rates. It would be interesting to see if this extends to sleepiness, as it does suggest a difference in attitudes.

Clearly there are consistent findings to demonstrate sex differences in most aspects of sleep research. While driving itself has been investigated to compare them, sex differences are yet to be directly examined in the overlapping area.

Accident Rates

While survey work has now been able to successfully normalise SRVA data for traffic flow by time of day, this is not possible for gender. There are no general statistics on this, although it is generally accepted that a substantially greater number of males are driving than females, particularly during the night time hours. For this reason, we cannot truly compare the sexes by controlling for exposure. Therefore we do not know if males are more vulnerable to driver sleepiness than females, if their awareness is simply diminished, or even if they suffer more impairment to driving when sleepy.

While it may seem accepted that SRVAs involve far more males than females, some studies have actually failed to address this. Maycock's (1996) survey of drivers' experience, used a large sample (N=4621), but selected only *male* drivers. More recent research has begun to consider this more directly however, with UK road audits on trunk roads and motorways concluding that 87% of drivers in SRVAs were men (Reyner, Flatley & Horne, 2001). Similarly, Åkerstedt & Kecklund (2001) studied age and gender in early morning driving accidents in Sweden, to find that females had a less pronounced night time peak, while males had twice the risk of females. One reason given for this was the more aggressive, or over confident nature of male drivers (Gregersen & Bjurulf, 1996). This may be a key issue if males have a different *attitude* to driving when sleepy, or if they are less *aware* of increasing sleepiness.

Study Aims

As demonstrated in chapters 4.0 and 5.0, some small sex differences could be seen, with females reporting more serious levels of subjective sleepiness during driving. These findings seem to support overwhelming differences in the sleep of males and females. While females seem to experience a greater quantity of sleep than males, they also complain more of insomnia, sleep disturbance by noise, problems associated with shiftwork, and have a tendency towards morningness and inflexibility in circadian rhythms. This may be due to a greater reliance on environmental zeitgebers than in males, but also possibly due to differences in attitudes to self-health, and awareness of sleepiness. In terms of driving also, the key issue may be the *awareness* of female drivers, and their *attitudes* to driving whilst sleepy.

Since research so far has highlighted the possibility of some minor differences in the sexes, this could be an interesting area for future research. It would of course require more robust sample sizes, with equal male and female participants wherever possible. While this is difficult to do within studies, these last few investigations have yielded good data and more meaningful comparisons can at least be made for *normal* and *restricted* sleep conditions. Using a larger sample size from existing data, and considering the baseline data which has not previously been analysed, together with the non-treatment conditions from each study, a more useful comparison can be made between the groups. The aim of this study was to investigate differences between the sexes, by using existing data to compare two larger groups of drivers using normal and restricted sleep sessions. Given that females are generally found to complain more and report more sleep related problems, it may be that subjective sleepiness at least, is higher in females than males. However, given the higher calculated risk for young male drivers from studies of accident statistics, it will be interesting to see whether males actually experience more sleepiness in the EEG, and if their driving is more impaired because of it.

7.3 METHOD

Participants were 30 volunteers (15 male, 15 female), with a mean age of 22.97 years (±2.54 years), and a mean ESS of 4.92. The two groups were selected from the existing dataset to represent similar age and ESS distributions. The male group had a mean age of 22.8 yrs (±1.82 yrs), and a mean ESS score of 5.57, and the female group had a mean age of 23.1 yrs (±3.16 yrs), and a mean ESS of 4.27. Summaries of participants' details are shown in Tables 7.1 and 7.2. The 'normal' range for Body Mass Index (BMI), as shown, is 20-25 (Heyward & Stolarczyk, 1996). This study compared the subjective, EEG and lane drifting measurements of sleepiness, in two separate groups of male and female participants, for both normal and restricted sleep conditions.

N	Sex	Age (yrs)	ESS	Height (m)	Weight (kg)	BMI
1	M	23	1.5	1.77	78.00	24.90
2	M	23	8.5	1.77	69.85	22.30
3	M	24	1.5	1.86	79.38	22.94
4	M	22	2	1.75	77.00	25.14
5	M	25	9.5	1.72	69.85	23.61
6	M	23	10.5	1.72	73.50	24.84
7	M	23	3	1.80	65.50	20.22
8	M	26	8.5	1.77	67.40	21.51
9	M	20	9	1.77	73.00	23.30
10	M	26	7.5	1.88	73.00	20.65
11	M	21	6	1.80	69.50	21.45
12	M	21	4	1.72	70.00	23.66
13	M	22	4	1.83	71.00	21.20
14	M	22	2	1.91	82.60	22.64
15	M	21	6	1.91	85.00	23.30
MEAN				1.80	73.64	22.78
StDev				0.07	5.64	1.55

Table 7.1

Summary of MALE participants details

N	Sex	Age (yrs)	ESS	Height (m)	Weight (kg)	BMI
16	F	26	9.5	1.60	60.33	23.57
17	F	24	8.5	1.62	54.00	20.58
18	F	22	1	1.80	65.00	20.06
19	F	22	3.5	1.57	60.33	24.48
20	F	29	0	1.62	53.98	20.57
21	F	27	0.5	1.68	70.00	24.80
22	F	21	3.5	1.70	60.33	20.88
23	F	20	8	1.60	65.00	25.39
24	F	20	3.5	1.70	67.00	23.18
25	F	21	8	1.67	57.50	20.62
26	F	29	3	1.67	70.00	25.10
27	F	22	0	1.70	72.20	24.98
28	F	20	8	1.65	68.00	24.98
29	F	21	4	1.70	58.20	20.14
30	F	23	3	1.70	58.00	20.07
MEAN				1.67	62.66	22.63
StDev				0.06	5.93	2.22

Table 7.2

Summary of FEMALE participants details

Statistical Analyses

ANOVAs for sex and prior sleep routine were based on participant's mean values for the 4, 30 minute periods of the 2 hour drive.

7.4 RESULTS

Data is presented here comparing male and female drivers following normal and restricted sleep. However, since the normal sleep (baseline) sessions were not fully analysed as a matter of routine, and some data was lost in transfer from older storage systems, comparison of driving performance and EEG data is limited to the restricted sleep condition only.

Normal Sleep

Subjective Sleepiness

The mean KSS scores for the two groups following normal sleep were plotted against time. This data is summarised in figure 7.1. Self-ratings were taken every 200 seconds. As is clear from the graph, subjects felt increasingly sleepy over the course of the 2 hour monotonous drive, and this was similar for both male and female drivers, reflected in the significant effect of time (F=16.97, d.f. 3, 112; $p<0.0005$). A post-hoc tukey test showed that all drivers were significantly less sleepy during the first 30 minutes of driving than for the remainder of the session ($p<0.0005$).

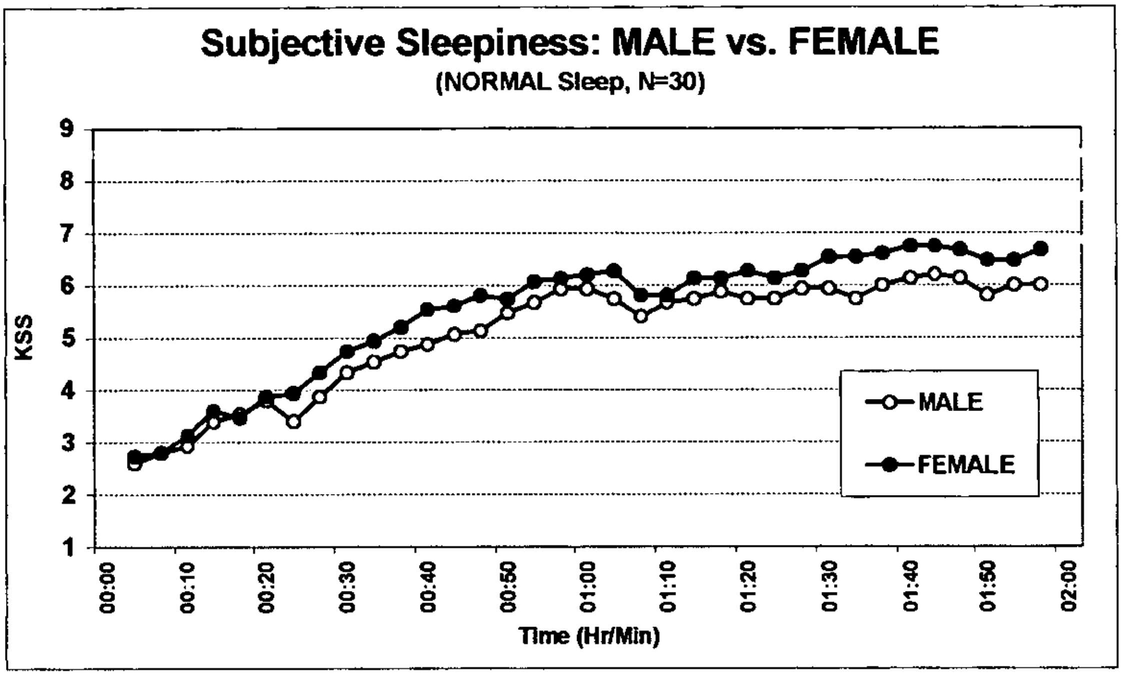

Figure 7.1

Subjective Sleepiness (KSS) over time for MALE and FEMALE drivers following NORMAL sleep.

This data was also plotted in terms of the number of 200 second epochs spent in each level of the scale. This data is shown in figure 7.2. While the two groups show a similar pattern, there is a slight difference with females tending towards higher levels of sleepiness.

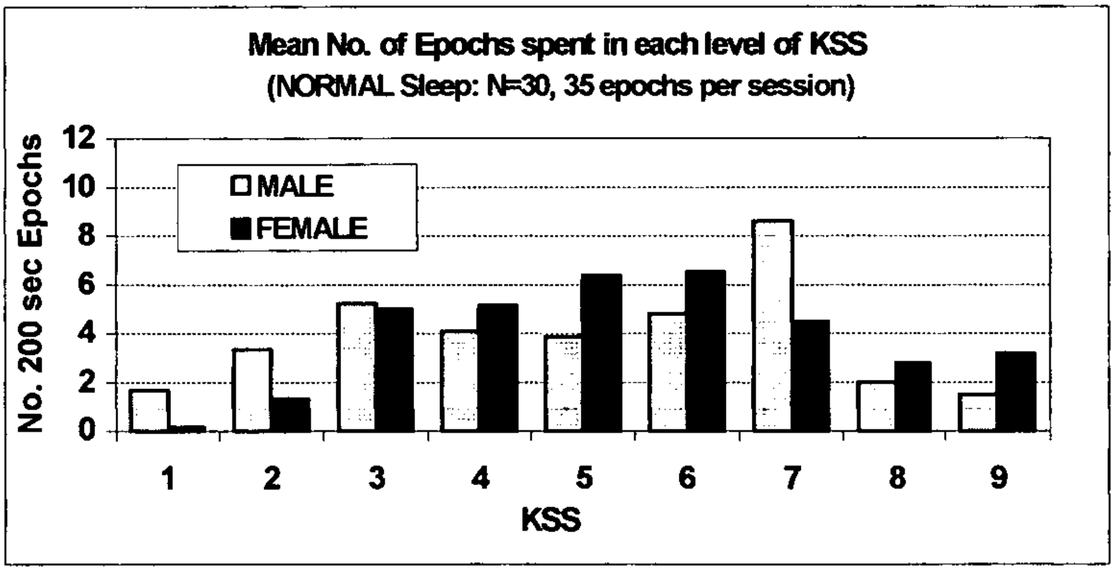

Figure 7.2

Time spent in each level of subjective sleepiness (KSS) for MALE and FEMALE drivers after NORMAL sleep

This similarity also extended to drivers ratings of how likely they were to actually fall asleep. This data is presented in figure 7.3 for both groups during the 2 hour monotonous drive. Again, there was a significant effect of time (F=6.10, d.f. 3, 112; p<0.001), and a post-hoc tukey test demonstrated that drivers were significantly less likely to fall asleep during the opening 30 minute driving period, as compared to the second (p<0.010), third (p<0.007) and final (p<0.001) periods of the test session.

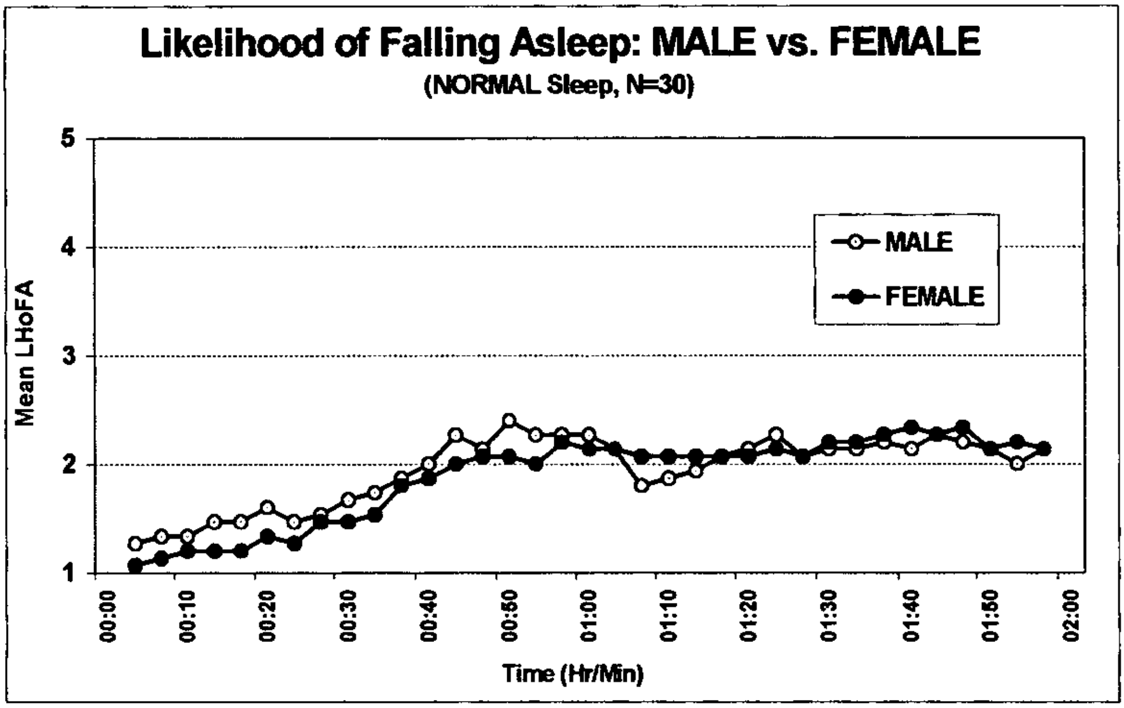

Figure 7.3
Likelihood of Falling Asleep (LHoFA) over time for MALE and FEMALE drivers following NORMAL sleep.

Restricted Sleep

Subjective Sleepiness

Mean subjective sleepiness for the restricted sleep condition is presented in figure 7.4. As the graph shows, both groups experienced increasing and then decreasing sleepiness across time during the 2 hour drive, to reflect the afternoon circadian dip. This is demonstrated also by the significant effect of time (F=7.09, d.f. 3, 112; p<0.0005), the post-hoc tukey test showing the first 30 minute driving period to be significantly less sleepy than the middle hour (p<0.001) and final 30 minutes (p<0.008) of the drive. However, there was a significant difference between the groups following restricted sleep, with female drivers experiencing significantly greater levels of sleepiness (F=21.35, d.f. 1, 112; p<0.0005).

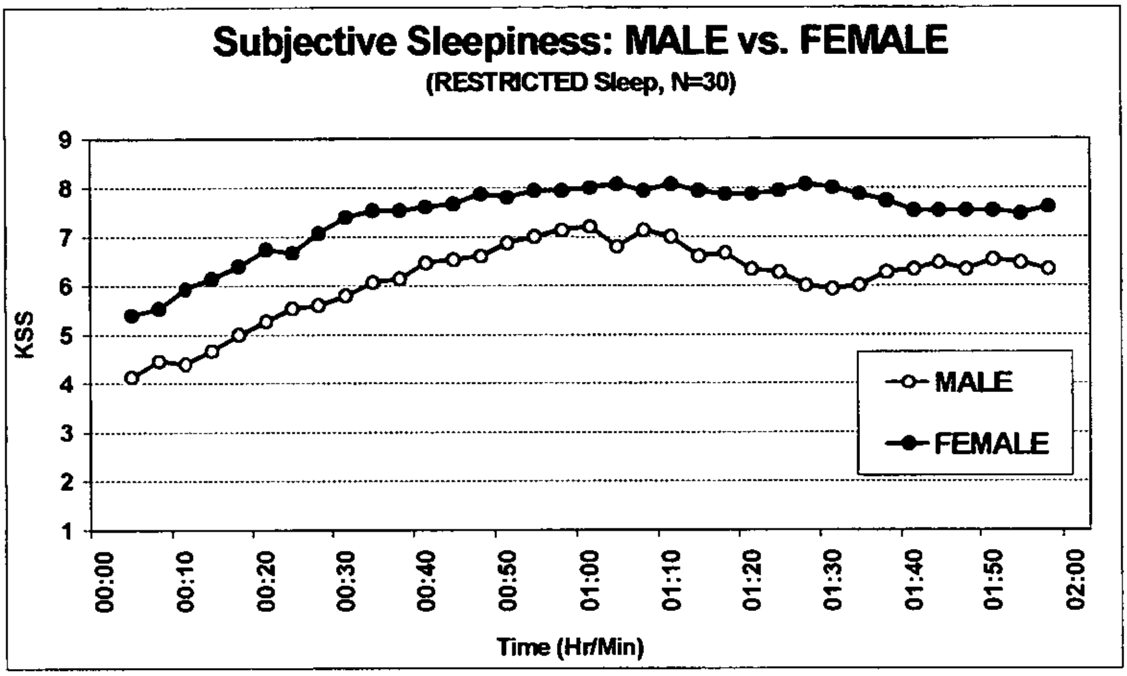

Figure 7.4
Subjective Sleepiness (KSS) over time for MALE and FEMALE drivers following RESTRICTED sleep.

Again, this data was also plotted to illustrate the time spent in each level of the self-ratings scale, as can be seen in figure 7.5.

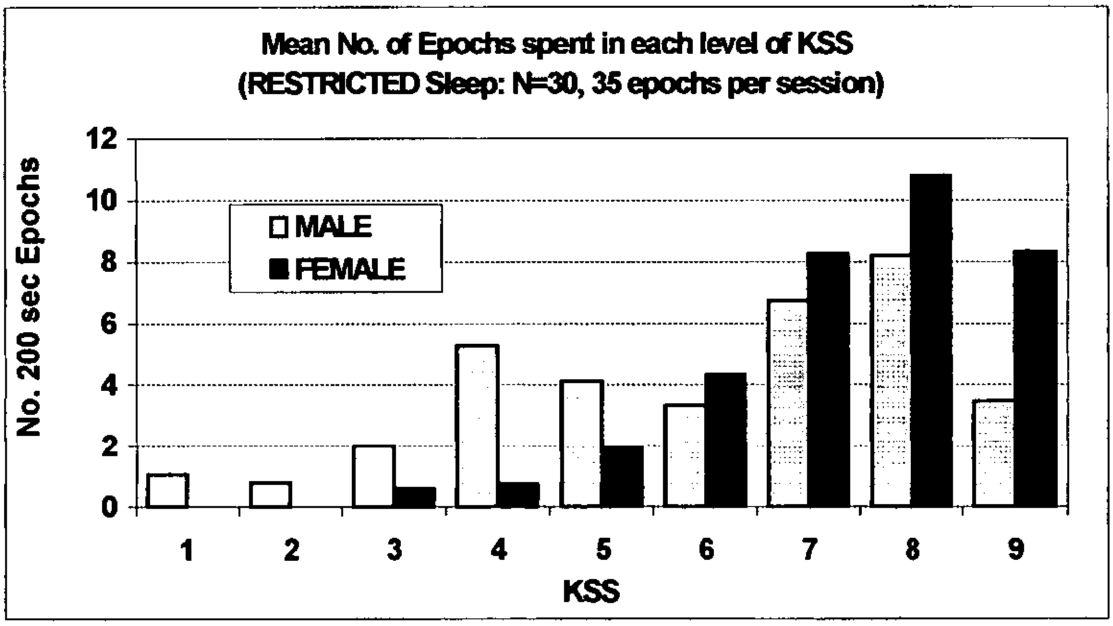

Figure 7.5
Time spent in each level of subjective sleepiness (KSS) for MALE and FEMALE drivers after RESTRICTED sleep

In contrast to the normal sleep condition (see figure 7.2), there is an overall shift to the upper end of the range, together with an increased tendency for females to experience heightened levels of sleepiness. This was also true of the likelihood of falling asleep, as shown in figure 7.6. As the graph shows, there was a trend for females to report more highly on this scale than males. This was found to be significant using ANOVA (F=4.68, d.f. 1, 112; p<0.033). There was also a significant effect of time (F=3.40, d.f. 3, 112; p<0.020), with LHoFA being higher after 60-90 minutes, as compared to the first 30 minutes of driving (p<0.033).

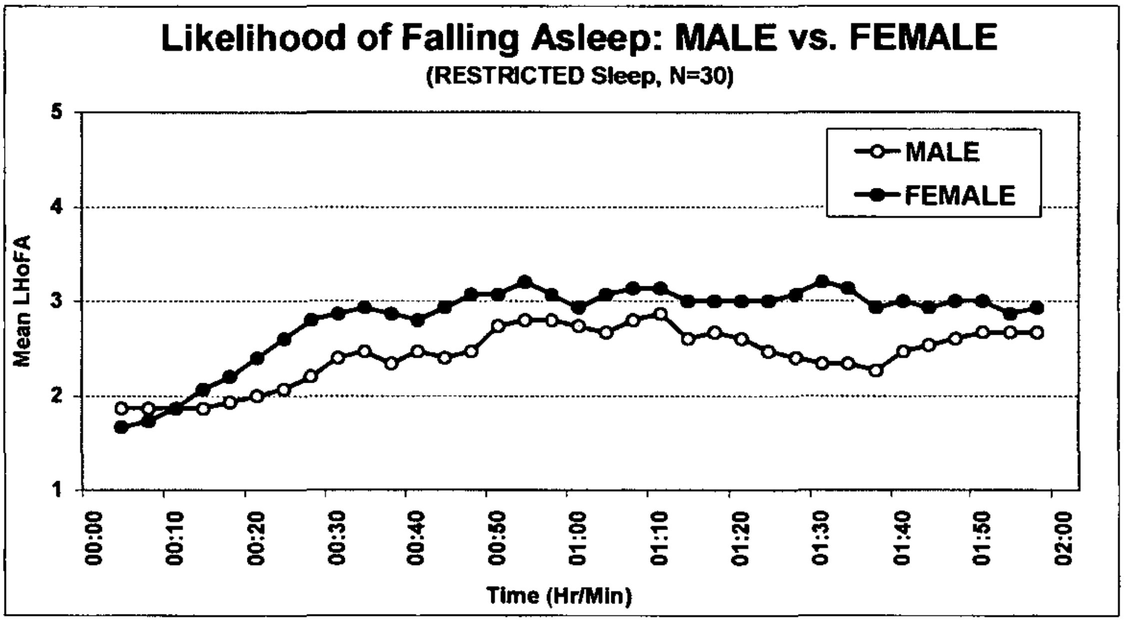

Figure 7.6

Likelihood of Falling Asleep (LHoFA) over time for MALE and FEMALE drivers following RESTRICTED sleep.

Looking at this data in a different form, figure 7.7 is compiled from data in table 7.4, showing the difference in time spent in each level of the LHoFA scale between the sexes. Clearly, females have a tendency to report a greater likelihood of falling asleep than males.

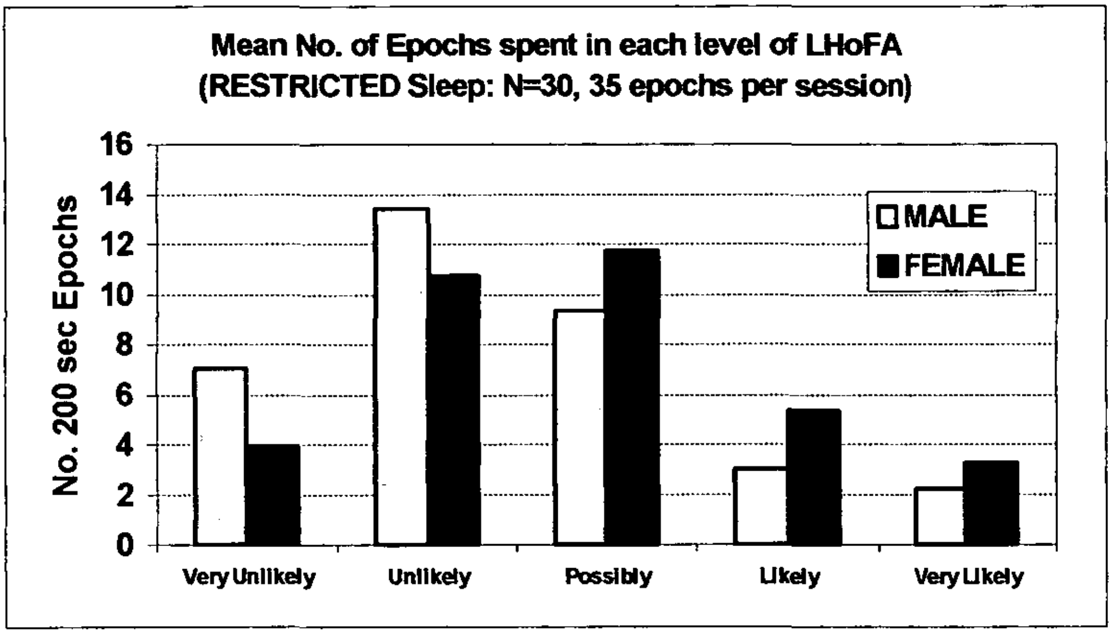

Figure 7.7
Time spent in each level of LHoFA for MALE and FEMALE drivers after RESTRICTED sleep

	NORMAL SLEEP	A	B	C	D	E
	MALE DRIVERS	**Very Unlikely**	**Unlikely**	**Possibly**	**Likely**	**Very Likely**
1	Extremely Alert	25	0	0	0	0
2	Very Alert	46	4	0	0	0
3	Alert	52	25	1	0	0
4	Rather Alert	16	43	2	0	0
5	Neither	17	37	4	0	0
6	Some signs of Sleepiness	12	42	18	0	0
7	Sleepy but no effort to stay awake	20	38	71	0	0
8	Sleepy, some effort to stay awake	0	4	23	1	2
9	Very Sleepy, great effort to stay awake	0	0	17	2	3
	NORMAL SLEEP	**A**	**B**	**C**	**D**	**E**
	FEMALE DRIVERS	**Very Unlikely**	**Unlikely**	**Possibly**	**Likely**	**Very Likely**
1	Extremely Alert	2	0	0	0	0
2	Very Alert	20	0	0	0	0
3	Alert	65	10	0	0	0
4	Rather Alert	52	25	0	0	0
5	Neither	42	44	10	0	0
6	Some signs of Sleepiness	29	33	36	0	0
7	Sleepy but no effort to stay awake	33	13	21	0	0
8	Sleepy, some effort to stay awake	3	14	25	0	0
9	Very Sleepy, great effort to stay awake	0	0	25	4	19

Table 7.3 – Progression of Subjective ratings –
The Subjective Sleepiness Matrix (Normal Sleep)

	RESTRICTED SLEEP	A	B	C	D	E
	MALE DRIVERS	Very Unlikely	Unlikely	Possibly	Likely	Very Likely
1	Extremely Alert	16	0	0	0	0
2	Very Alert	12	0	0	0	0
3	Alert	20	10	0	0	0
4	Rather Alert	12	65	2	0	0
5	Neither	26	35	1	0	0
6	Some signs of Sleepiness	15	25	10	0	0
7	Sleepy but no effort to stay awake	5	32	64	0	0
8	Sleepy, some effort to stay awake	0	33	59	29	2
9	Very Sleepy, great effort to stay awake	0	1	4	16	31
	RESTRICTED SLEEP	A	B	C	D	E
	FEMALE DRIVERS	Very Unlikely	Unlikely	Possibly	Likely	Very Likely
1	Extremely Alert	0	0	0	0	0
2	Very Alert	0	0	0	0	0
3	Alert	9	0	0	0	0
4	Rather Alert	8	3	0	0	0
5	Neither	9	20	0	0	0
6	Some signs of Sleepiness	25	30	10	0	0
7	Sleepy but no effort to stay awake	7	59	58	0	0
8	Sleepy, some effort to stay awake	1	49	87	19	6
9	Very Sleepy, great effort to stay awake	0	0	21	61	43

Table 7.4 – Progression of Subjective ratings –
The Subjective Sleepiness Matrix (Restricted Sleep)

Driving Performance

Lane drifting incidents related to sleepiness (as identified by video analysis) were averaged across participants and plotted in 30 minute periods, as shown in figure 7.8. Clearly there are more incidents occurring in the female driver group. This difference was shown to be significant with ANOVA (F=7.89, d.f. 1, 112; p<0.006). There was also a narrowly significant effect of time (F=2.69, d.f. 3, 112; p<0.049), relating to the first and second 30 minute driving periods, as confirmed by the post-hoc tukey test (p<0.033). There was no significant interaction.

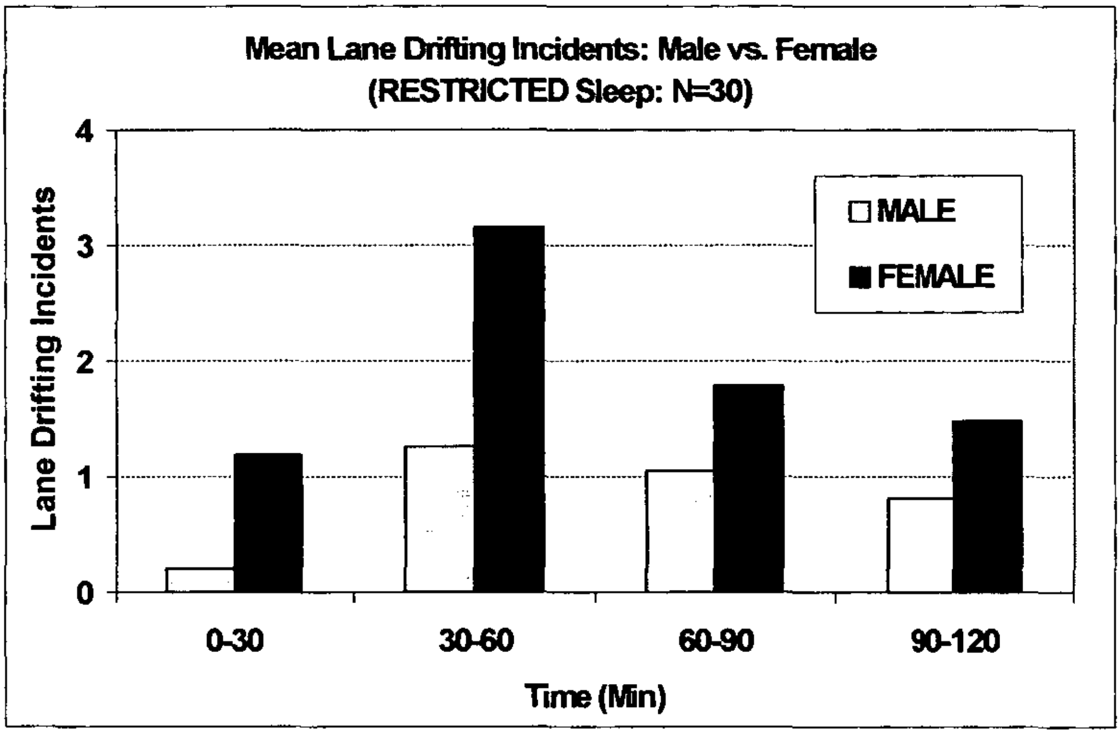

Figure 7.8
Lane Drifting Incidents over time for MALE and FEMALE drivers following RESTRICTED sleep.

EEG

EEG data was spectrally analysed and standardised in one minute epochs before being averaged across participants. Since this data came from different studies, the raw data files were used, spectral analysis redone (using Rhythm – see section 2.3), and all data standardised together in order to ensure identical treatment and minimise errors. The averaged data was plotted against time for alert and sleepier groups, as shown in figure 7.9.

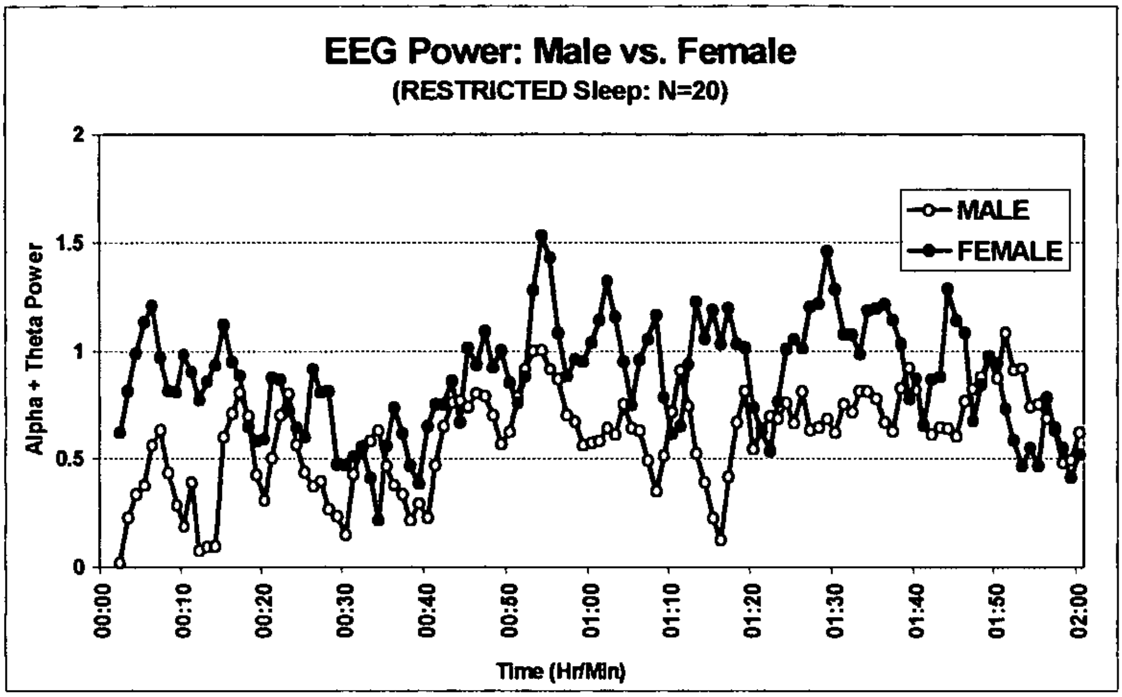

Figure 7.9

Standardised Alpha and Theta EEG power for MALE and FEMALE drivers following RESTRICTED sleep.

There were no significant outcomes, although there was a trend for females to be more sleepy than males, particularly in the second hour of the afternoon drive.

7.5 DISCUSSION

Differences were seen in all measures taken by the driving simulator for male and female participants. While these changes were minimal following normal sleep, they became exacerbated by the sleep restriction of 5 hours prior to the afternoon drive. This supports the suggestion that sex differences are subtle among healthy young adult subjects, but are likely to be more visible in challenging conditions such as sleep restriction (Armitage & Hoffman, 1997; Ehlers & Kupfer, 1997; Armitage et al., 2001). These findings are also supported by the observations made in previous chapters, and suggests a need for further investigation.

Subjective sleepiness in particular, demonstrated this difference. While data from both driving groups was very similar following normal sleep, for both the Karolinska and LHoFA scales (see figures 7.1-7.3), the sleep restriction caused this to become altered. While still clearly illustrating the effects of the circadian dip in alertness, the female group maintained a 1 point difference on the KSS throughout the drive (based on the sample of 30 drivers - see figure 7.4). Again, this related also to the likelihood of falling asleep, with females significantly more likely to do so than their male counterparts (see figure 7.6).

This raises several interesting points. Firstly, the 1 point difference as measured by the KSS is a substantial one, and must be taken into account in future experimental work. Care must be taken to balance samples between the sexes to avoid biasing results. Secondly, as demonstrated in chapter 5.0, these differences may well also be present in studies involving psychostimulant, or other interventions. As this study used only baseline and non-treatment conditions to show some disparity, we must assume that the sexes may also be affected differently by countermeasures. Again, this highlights the need for robust sex-balancing of samples. Finally, and most importantly, the difference itself. It may be that females are experiencing more sleepiness than males, or that they simply complain more about a similar level of sleepiness. Looking at the objective data, we may be able to understand this more clearly. Although the EEG (see figure 7.9) revealed no significant findings (supporting the former conclusion), there was some tendency for greater levels of alpha and theta activity in the female group. Turning to the lane drifting data also (see figure 7.8), there is a more obvious relationship, with females having significantly more incidents related to sleepiness. Clearly there is something interesting happening, but further research may be needed to explain this in terms of physiological or psychological differences between the sexes. Given the lack of significant objective (EEG) data, it seems that the psychological angle is more promising. The conflicting nature of these findings with accident statistics, also supports the suggestion that females are generally more sensitive to external zeitgebers (Adan & Sanchez-Turet, 2001), thus suffering more from driver sleepiness. However this may actually have the result that females are less likely to be involved in SRVAs, as they experience too much sleepiness to attempt driving in a dangerous state. In contrast, the tendency of males to underestimate risk and impairment, and be over confident in their own driving ability makes them more likely to be involved in SRVAs. The key issue then, is a psychological one, as the *attitude* may be where the fundamental difference lies. This supports the view of Aldrich (1989) who suggested that the problem is far more dangerous in those less able to *recognise* or *deal with* sleepiness.

If females are *experiencing* more sleepiness then this may underline the seriousness of the problem of driver sleepiness for males. Far more accidents involve males and this may be due to gender differences in driving behaviour. Men are generally more aggressive in driving (Gregersen & Bjurulf, 1996), and may actually under-rate problems of sleepiness. They may be more reluctant to stop driving and rest, while females are probably more likely to 'admit defeat' and take a break. This could be examined experimentally using some simple modification of our protocol. Drivers may be asked at some point during the drive if they want to have a short break before continuing (until the total drive time is complete), or to push on with the drive. This possibility will be discussed further in chapter 8.0, as general improvements to the driving simulator and protocol may benefit from increased motivation of drivers, and some measure of how drivers decide to continue, or stop.

Further Research

Given the apparent differences between the sexes, it should be possible to undertake a study to directly examine these further. In combination with some improvements to the driving simulator and experimental protocol (see chapter 8.0), the most interesting aspects of male and female driving behaviour could be investigated. While not focussing greatly on the menstrual cycle itself, this protocol should perhaps at least pay some attention to it. Again, some simple additions to the background information questionnaire could be used here:

Additional Questions for Female Volunteers

- Do you have a regular (approximately 28 days) menstrual cycle ?
- Can you tell me the start date of your last menstrual period ?
- Are you taking Oral Contraceptives ?
- Can you tell me the name of the tablets ?

This should make it possible to calculate the phases of the cycle, in particular the *luteal phase* which has been associated with increases in daytime sleepiness, and sleep disturbance (Manber & Bootzin, 1997). Oral contraceptives also, have some effect on hormone levels which change throughout the cycle. At this stage it seems that studies to examine changes in driving with the menstrual cycle itself, or looking at any effects of the contraceptive pill would be too ambitious and would not yield clear results. Before these options can be considered for their relevance, a more substantial experimental examination of sex differences in driving behaviour, attitudes to sleepiness, and awareness of potential driving impairment is necessary. In particular, some measure is required of *when* drivers would consider stopping their journey due to tiredness. This seems to be one of the greatest failings of the driving methodology, as we are measuring *how* sleepy drivers are, but do not have any idea if they are aware of the implications of this and if they would therefore stop driving in a real situation. Clearly this new scenario must be balanced with motivation to continue, as would be the case in the real world. For example, drivers could receive a payment bonus for completing the entire 'journey,' small deductions in payment for cutting the journey short, and larger deductions for continuing when sleepy and making major errors. If the differences between the sexes are due mainly to awareness, and more importantly their *attitude* to this awareness, then clear differences will be seen in their motivations to continue, given the same external motivation.

Given also, that we would be testing two separate groups of drivers, some more attention should be paid to the characteristics of each. Thus, they should be where possible, matched for age and driving experience, as well as ESS and normal sleep routines.

Another interesting issue here is the size of the difference between the sexes. This was minimal following a normal night of sleep, but increased when it was restricted to 5 hours. It may be interesting to examine these same differences under different driving conditions such as in the early morning, or after a night *without* sleep. Females may experience even greater sleepiness relative to males.

Education is required to demonstrate the limits of driving skill, and raise awareness of the potential consequences of sleepiness while driving. This may well be a greater problem for male drivers and campaigns to educate the public should therefore be aimed more towards male drivers. Of particular importance is the difference between their *perception* of skill, and their actual driving *ability*. The ultimate goal of this is to *personalise* the risks involved. Now is an excellent time to do this, while the Selby Rail crash and resulting litigation is fresh in the public's mind.

KEY POINTS

- Sex differences have been demonstrated in many areas of sleep research, including some recognition of the potential effects of the menstrual cycle on sleep quality and daytime sleepiness.
- Sex differences have also been shown to exist in accident statistics relating to SRVAs, and in driving behaviour in general.
- Findings from previous chapters suggest that there may be some difference in driver sleepiness which has not been directly addressed in experimental work.
- Findings from this study show that subjective sleepiness is similar for male and female drivers under normal sleep, but that the subtle differences are exacerbated by sleep restriction.
- Females experience more sleepiness while driving, and their driving is more impaired by sleepiness than males.
- A key issue is differences in *awareness* and *attitudes* to driving when sleepy, since accident statistics actually show that *males* are more at risk.
- Changes to the protocol may be used to examine sex differences in greater detail, particularly in relation to the psychological elements such as motivation to continue and the decision to stop driving.

8.0 GENERAL DISCUSSION

8.1 Driver Sleepiness and Accidents

As indicated in chapter one, vehicle accidents related to sleepiness are generally serious or fatal, and follow circadian variations in alertness. While data varies on the percentage of total RTAs actually caused by sleepiness, it is clear that the early morning (0200-0600) and mid-afternoon (1400-1600) periods carry the highest risk. Driver sleepiness is increasingly recognised as a major cause of accidents across the western world, and is affected by a range of factors better understood through applied research. This thesis aimed to address these issues through experimental studies designed to examine driver sleepiness and the efficacy of potential countermeasures in young adults. This chapter will summarise the findings of these studies, and discuss their further implications.

8.2 Validation of Methodologies

Research Questions

- What is the relationship between subjective sleepiness and driving performance ?
- Are simulator based findings reliable, valid and applicable to the real world ?
- What improvements can be made to the existing driving simulator and protocol ?

The driving simulator was proved to be valid and applicable to the real world, and subjective ratings (as measured by the KSS), a reliable method of assessing driver sleepiness, providing a good guide to driving performance. Although offering increased realism, the logistic complexities of the closed road circuit design as well as any road study, combined with the greater control available in the laboratory, means that simulated experimental work is far more effective.

Summary

- The KSS was a good indicator of increasing sleepiness, and was clearly related to the increasing incidence of lane drifting.
- The simulator and closed road circuit protocol demonstrated similar results, thus validating the simulator as a methodology for investigation of driver sleepiness and potential countermeasures.
- The closed road circuit protocol was successful but logistically complex, more expensive, and offers much less control than the laboratory environment of the driving simulator.
- The study highlighted the lack of realism in the driving simulator, which could be improved with the addition of motorway and night-time driving modes, and perhaps even a full size car.

8.3 Technological Countermeasures

Research Questions

- Is secondary task Reaction Time sensitive to sleepiness ?
- How do changes in Task Load affect sleepiness when driving ?
- What are the prospects for in car devices to detect and warn of increasing driver sleepiness ?

Devices still rely on the driver's judgement to stop driving, so they do not remove or reduce the possibility of human error, and cannot replace the need for common sense and driver education. Drivers may become bored with a device and turn it off, or develop strategies to get around it in the same way that we stand on the bathroom scales in just the right manner so they tell us what we want to hear. If the problem in this situation is *sleepiness* then the solution is *sleep,* and additional devices serve only to complicate matters. As the RT study showed, the secondary task concept seems too problematic and complex to be greatly effective. While this is also true largely of the technological approach as a whole, there may be some promise in new, *combined* or *advisory* systems which are now being investigated.

Of the physiologically-based devices, the percentage of eye closure (PERCLOS) system project seems to have the greatest potential (Stutts, 2000). While the rolling of the eyes and incidence of long blinks have been shown to be a good indicator of sleepiness (Stern et al., 1994), it should be remembered that this is not always the case, and some individuals are able to reach a state of extreme sleepiness with the eyes open (Miles, 1929). Similarly, steering corrections seem most promising from a driver's behaviour viewpoint (Riemersma, 1977; Fairclough, 1997). As I have already noted however, methods relying on changes to driving performance may be too late at recognising sleepiness. It may be therefore that some combination of these two concepts would form the best technological device (Stutts, 2000). The advantages of each approach would compliment each other, and the device would be monitoring 2 separate parameters, thus lessening the potential for false alarms and driver irritation.

Summary

- Reaction time did not reflect increasing sleepiness during driving, showing only small and non-significant fluctuations over time.
- Self-ratings were far more effective than reaction time at assessing driver sleepiness.
- Reaction time is a complex measurement, and a key issue is task load: the nature of driving is dynamic, and spare capacity is needed suddenly. The secondary task concept therefore seems flawed.

- Reaction time may be more useful as a method of increasing driver alertness, though this too is problematic, as drivers feel less likely to fall asleep – effectively relying on the device to prevent this.
- The technological approach to countermeasures is complex, problematic and has been slow to achieve success generally. More practical methods may be more effective.
- Some small sex differences in subjective sleepiness were found, which may be examined further in other studies, since the design employed here does not support statistical comparison. These differences showed that females may experience more sleepiness than males.

8.4 Practical Countermeasures

Research Questions

- Are 'functional energy drinks' effective at reducing sleepiness in the context of driving ?
- Is there any improvement in driving behaviour ?
- What are the implications for advice given to sleepy drivers ?

Practical countermeasures such as short naps and caffeine (in coffee) have previously been examined, and shown to be effective although problematic. In particular, the variation in caffeine content of coffee undermines advice given to sleepy drivers. Functional energy drinks are much more reliable in their caffeine content, increasingly popular and widely available. Providing these are not abused and that sensible advice is given, alongside education of drivers, they should be regarded as a very effective practical countermeasure to driver sleepiness.

Summary

- The 250ml (80mg caffeine) dose successfully reduced subjective sleepiness and lane drifting for about 60-90 minutes, with a trend for a more alert EEG.
- The 500ml (160mg caffeine) dose had a stronger and more sustained effect, and effectively removed subjective sleepiness and lane drifting incidents. This also extended to the EEG, which was significantly improved for at least 90 minutes of driving.
- FEDs are an extremely beneficial countermeasure to driver sleepiness given that they are readily available and convenient, and the variation in caffeine content of coffee. This may be even better in combination with a nap.
- There is however some potential for abuse, so caution must be exercised in giving advice. Drivers who regularly drive long journeys and at difficult times of the day may use FEDs excessively.

- Further research should examine direct comparison of FEDs with coffee, the synergistic effects of the other active ingredients (taurine and glucuronolactone), and the longer term effects on sleep onset and quality, particularly given this potential for abuse.
- Other caffeine sources or other psychostimulants may be introduced in the UK and these may be effectively evaluated in the same way.
- Experimental effects of potential countermeasures may be described using the *subjective sleepiness matrix*.
- Some small sex differences in subjective sleepiness were observed. Again the study design was not sufficient for statistical comparison, but data did support the previous finding that females experience more sleepiness following sleep restriction.

8.5 Individual Differences (I. Trait Sleepiness)

Research Questions

- Are certain types of people more likely to have sleepiness-related accidents ?
- Can we identify drivers at risk from SRVAs using screening measures such as the ESS ?
- What are the implications for the road transport industry ?

As described in chapter 6.0, there is some evidence to suggest that professional drivers are particularly at risk from SRVAs. Since these have also been linked to clinical causes and may even be identified using simple methods such as the ESS (Johns, 1991), it seems that it may be possible to straightforwardly assess the potential for sleepiness-related problems in the road transport industry with some awareness of the problem and basic medical screening. It would be interesting to find out what is asked of professional drivers relating to this, and perhaps more importantly, if this is re-assessed at any point. Changes in lifestyle as well as age can have profound effects on sleep quality and ultimately daytime sleepiness, and it seems that employers have little or no interest in this. However, in situations where drivers are asked to drive for long periods on dull and boring roads, and particularly during the early morning and mid afternoon, some awareness of potential catalysts for sleepiness is necessary. There is clearly some promise in identifying accident risk in more sleepy drivers, though more work is needed using drivers at the higher end of the ESS. The awareness and involvement of employers is very important here, since they must realise that they are now morally and legally responsible in part for the welfare of their drivers.

Summary

- No difference in sleepiness levels was seen under normal sleep, but there was a trend for alert drivers to experience more sleepiness after sleep restriction.

- Sleepier drivers tended to be more impaired by sleep restriction (i.e. make more driving errors) than the alert drivers.
- Alert subjects showed a less alert EEG during the first 30 minutes of the drive following sleep restriction.
- There is an interesting relationship between trait sleepiness, and sleepiness experienced during driving. This seems to depend on the individuals general frame of reference.
- Although results were not greatly significant overall, there are implications for drivers outside the normal range of the ESS (>10).
- These findings have possible screening implications for commercial drivers, particularly at a test-retest level, since they may be more at risk from SRVAs, and we cannot assume that they are within the normal ESS range (0-10).
- The recruitment procedure should perhaps ask for more information about previous experience with driver sleepiness, knowledge of countermeasures and normal amounts of sleep. These additions should be based on recent UK drivers surveys (Maycock, 1996; 1997).

8.6 Individual Differences (II. Sex)

Research Questions

- Are males more at risk from sleepiness-related accidents ?
- Are females more aware of their own sleepiness than males ?
- Do females drive differently because of this perception ?

As a result of observations made during the earlier studies, chapter 7.0 outlined a study to examine sex differences in driver sleepiness directly. This study showed very interesting results and led to more suggestions for improvements to the driving simulator, and for further investigation into sex differences. This is also important given the difference in SRVA involvement between the sexes.

Summary

- Sex differences have been demonstrated in many areas of sleep research, including some recognition of the potential effects of the menstrual cycle on sleep quality and daytime sleepiness.
- Sex differences have also been shown to exist in accident statistics relating to SRVAs, and in driving behaviour in general.
- Findings from previous chapters suggest that there may be some difference in driver sleepiness which has not been directly addressed in experimental work.

- Findings show that subjective sleepiness is similar for male and female drivers under normal sleep, but that the subtle differences are exacerbated by sleep restriction.
- Females experience more sleepiness while driving, and their driving is more impaired by sleepiness than males.
- The key issue here is differences in *awareness* and *attitudes* to driving when sleepy, since accident statistics actually show that *males* are more at risk.
- There is a need to change the setup to include a less abstract driving scenario, with a real beginning and end, effectively changing the motivation. Also give rewards and penalties to simulate a realistic scenario, most importantly to get an idea of how people decide to stop driving.

These studies have demonstrated the importance of drivers' own perceptions of sleepiness. The Karolinska and LHoFA scales have been used effectively to measure this and together this has demonstrated how drivers progress through increasing levels of sleepiness. This progression is a useful tool which can be used to examine experimental effect and could be used more extensively in the future. This is illustrated in the top half of table 4.1, which shows a typical pattern following restricted sleep. However, the bottom half of the table (RT condition) shows a different pattern, caused as the addition of RT displaces sleepiness and drivers feel less likely to fall asleep as characterised by a clustering of data points in the bottom left corner of the matrix (KSS=high, LHoFA=low). This is clearly seen also in table 5.2, which again shows a normal progression under control conditions, but an obvious effect of the 500ml FED treatment, shown by the truncation of the pattern at the bottom right of the matrix. Similarly, under normal sleep, data in table 6.1 shows this truncation in alert subjects, while sleepier subjects continue to the sleepier end of the scales. These subjective scales are central to the methodologies used in this thesis, and yield important information about the psychological aspects of driver sleepiness. In future research they may form part of a variety of subjective measures used to investigate further the question of *why* drivers continue, despite the awareness of sleepiness.

8.7 Changes to Methodologies

As a result of conducting the experimental studies described in this thesis, several limitations of the driving simulator and associated methodologies have become apparent. Since the completion of data collection, the driving simulator has been upgraded to incorporate some of the suggestions below:

- *Recruitment Procedure / Debriefing*

In order to generate more, useful data from respondents, the recruitment questionnaire for drivers should be modified to include questions about prior experience with driver sleepiness, and knowledge of appropriate countermeasures (see section 6.5). This should also include questions about drivers normal amount of sleep, and some assessment of their driving:

Additional Questions

- On average, how many hours do you sleep per night ?

Debriefing Questions

- How well do you think you drove today ?
- Do you think your driving was in any way impaired by sleepiness ?
- Do you think you would have stopped driving in real life ?
- If so, when would you have stopped ?

- *Hardware Configuration*

The interface (see chapter 2.0) is somewhat limiting, since the car has no steering column, and instead uses additional mechanisms for steering, which have very little resistance. This could be improved using a different car. With the steering system still in place, this would give some weight to the controls, and feel much more realistic. The data projector also, is now several years old, and does not give a high quality image. This could easily be replaced with a more powerful model to improve brightness, colour and resolution.

- *Driving Speed and Accelerator Pedal*

The current setup has no sense of speed, due partly to the road-generation software (see below), and partly to the interface controls. The simulators accelerator pedal is usually pushed to the maximum and because no feedback on speed is provided for the driver, he or she may simply drive with their foot on the floor. This is perhaps the most unrealistic element of the simulator, linked strongly to the lack of 'journey' concept. In order to create increased realism and generate reliable speed data, an improved system should output feedback from the simulation computer. This will give an up to date speed reading and may be given in digital or analogue form in the car using appropriate equipment (such as the original speedometer). Once this is provided, the simulation will have an apparent maximum speed, and drivers may be instructed to drive at a fixed speed (below this), or not to exceed a 'speed limit'. For example, if the top speed is 100mph, and drivers are asked to drive at 70mph, there is adequate room for upward and downward variation in the data. This would be far more realistic than the current setup and would also allow the additional performance measure of speed accuracy (Regina et al, 1974).

- *Target Destination and 'Journey' Concept*

Another concern is the greatly abstract nature of the driving simulation. While much of this relates to the issues of driving speed and feedback (see above), the lack of any concept of physical transition also reduces realism greatly. The simulated protocol asks drivers to drive in the left-hand lane of the dual carriageway road for a preset time, overtaking slow vehicles as necessary. At the end of the drive, the program stops without any change to the graphical display, other than the appearance of a blank screen. This, together with the lack of speed, and the primitive audio feedback, makes for a very arbitrary task. In the real world, driving is more complex, and the driver is faced with the basic principles of journey distance, average speed, and journey time. He is also able to constantly monitor changes to these, and their relationship to each other is in his mind as the journey progresses. The current setup does not replicate any of these aspects of the trip, and this is greatly detrimental to realism, and most importantly ignores the drivers perception of the effects of sleepiness on these variables. Ultimately these elements are what make driving 'real' in the mind of the driver, and are as important as all the others. If we go to the trouble of using a real car for our interface, why not begin to replicate some of the conceptual elements of a car journey ?

- *Motivation Issues*

As an extension of these ideas, we must add further elements to account for sleepiness, motivation and the decision of whether or not to stop driving. Again, this is part of the journey concept, but is not accounted for in the driving simulation (see chapter 2.0). The studies described here have shown ultimately that it may be drivers *attitudes* to, and *awareness* of sleepiness that are most important, particularly for male and female differences. If we are to continue to investigate why drivers fall asleep at the wheel, we must find out how they decide whether or not to stop driving and take a rest, and why they decide to *ignore* the need for sleep, and continue. One experimental possibility is to create a progressive system of financial bonuses and penalties to recreate this cost/benefit equation which is part of real driving. For example, bonuses for 'journey' completion, small, progressive penalties for termination, and larger penalties for serious driving errors. Thus we recreate the vital cost-benefit balance in the decision to break one's journey and rest. It may be that this would demonstrate clearly male drivers' perseverance, and female drivers acceptance of sleepiness.

- *Software and Characteristics of Drive*

The program used for the driving scenario is primitive by today's standards, running on an ACORN machine. The lack of graphical texture and definition adds to the lack of realism, and the potential for the system to break down increases with age, as replacements become more difficult to find. This could be improved without major cost using 3D, PC-based graphics software, developed specifically to order. This could be designed to incorporate greater flexibility as follows:

Circuit Design – this should be user defined, to include variable traffic and background scenery levels, as well as road length and shape.

Night-time Driving - while the afternoon circadian dip in alertness brings with it many SRVAs, the night-time peak is also a strong one, especially given the relatively low traffic flow at these times (0200-0600). Despite this, the driving simulator does not currently replicate night driving. Clearly, comprehensive experimental investigation of driver sleepiness should facilitate both scenarios, and their associated characteristics.

Motorway Driving - motorways, trunk roads and other non-urban routes are thought to be most represented in SRVA data (Reyner et al., 2001), while more urban roads may now be thought to have problems (Fell & Black, 1997). It is unclear what the relationship between road type and the incidence of SRVAs is, although this may be affected by traffic density. The driving simulator currently uses a dual carriageway road with 2 lanes, rumble strips and a hard shoulder. An improved system would also facilitate motorway (3 lane) road types. Other possibilities could include investigating lit and unlit roads.

- *Additional Measurements*

Actimetry is an extremely valuable tool in sleep-related research, in this context vital to verify compliance with the restricted sleep conditions, thus removing the need for subjects to sleep under supervision which adds great cost to any study. This method of measuring subjects activity could also be extended to driving, with drivers wearing the monitors throughout the trials. This may provide interesting data to investigate whether sleepy drivers progress through a state of heightened movement or 'fidgeting' at the onset of drowsiness.

8.8 Directions for Future Research

Epidemiology

Data on the incidence and causes of SRVAs is extremely important, and accident and survey work must continue. While accident data investigation in collaboration with the police is needed to account for crashes and in particular fatalities as a result of sleepiness, surveys are also necessary to account for near misses and gauge motorists' attitudes to the problem, as well as how well our advice is getting across. Although several studies have shown that SRVAs occur predominantly on dull and monotonous roads (e.g. Horne & Reyner, 1995), and more so in rural areas (Maycock, 1996; Fell, 1994), a recent survey examined the incidence of driver fatigue incidents in *urban* areas. This included questions on accidents, near misses, and unintentional lane drifting episodes, and concluded that driver sleepiness is also a problem in the city, particularly on trips related to work and involving prior sleep loss (Fell & Black, 1997). This could be an area for future epidemiological research.

Environmental Countermeasures – Rumble Strips

Rumble strips generally comprise concrete lines at either side of the carriageway, which cause audible noise and some vibration when wheels make contact with them. Thus drivers become alerted by the noise and vibration if they begin to drift out of the lane. Little research has been conducted in this area. This is particularly relevant in countries such as the USA and the UK, which have had rumble strips for some time, but also in countries such as Australia and New Zealand which do not, and may introduce them in the future, particularly as they are now investigating the driver sleepiness problem. Rumble strips are often known internationally by other names, such as 'continuous shoulder rumble strips,' or CSRSs in the USA (Stutts, 2000), or profile edge-lines in Australia (Cairney, 1995). Their advantages include improved visual tracking in wet driving conditions, and cost effectiveness (although more expensive than painted lines, they have a longer lifetime and are therefore cheaper in the long term - Cairney, 1995). Surveys have also demonstrated the positive attitudes of drivers, one study reporting 56% of drivers agreeing that rumble strips had alerted them when drowsy (McCartt et al., 1997; 1998). As noted in the Australian study (Cairney, 1995), the only major study conducted previously was a French study including both experimental and driver survey data (Soulage, 1993). The study evaluated the use of bar- and button-based lines of various heights and spacings. Internal and external noise together with steering-wheel vibration were measured using 3 types of vehicle to include motorcycles, cars and trucks in the analysis. Two different speeds were also studied. Findings showed most notably some difference between noise levels in the different vehicle types, related to the levels and frequencies of background vehicle noise and the resulting audible ranges (Soulage, 1993). Interestingly, this suggests that while effective for example in cars, certain types of rumble strip may be less effective or even useless for other vehicle types. While the Australian study followed a similar protocol, although focussing more on the implications for Australian highways, findings were in agreement with this difference. This suggests that there is a need for further work in this area, with particular reference to HGVs. It should also be noted for the benefit of future work, that these studies used *straight* roadway sections. Since SRVAs may well occur on bending roads as the sleepy driver drifts in a straight line, it would seem sensible to at least address the issue of more acutely angled exposure to rumble strips, and their ability to alert the driver. More recent work in this area in the USA, has addressed more comprehensively the use of CSRSs, covering several different types and some additional possibilities such as centre-line rumble strips and different roadway textures (Stutts, 2000).

Environmental Countermeasures – Rest Facilities

A common reason given by sleepy drivers for not stopping to take a rest on long journeys is the lack of a suitable place to do so, or of appropriate and financially acceptable facilities at service stations. It is not sufficient to advise motorists to take regular breaks and get sleep, without addressing this issue also. Sleepy drivers will be reluctant to pay the price of a room in a hotel/motel if they only intend to sleep for a few hours, and will more than likely try to reach their final destination. Similarly, they will not be able to get good sleep in their cars. It seems that there is a lack of middle ground here, and basic, budget accommodation could provide the answer. If our advice is supported with the provision of cheap and adequate facilities where drivers can rest for a few hours safely, they will be more likely to do so. An example of this is popular French travel motels (Formule1 etc.) now spreading across mainland Europe and beginning to appear in the UK. These are automated and travellers can book in 24hrs a day using a credit card. Similarly, the Japanese have for several years provided budget, basic accommodation for weary travellers and drunken businessmen in the form of *Capsule Hotels.* These were invented by a Japanese architect in the 1970s who used a modified shipping container to make a space-saving room (Inside Japan, 2001). Capsules usually comprise a two metre by one metre room, complete with TV, radio and alarm clock, while the hotels also provide separate shower and washroom facilities. Although these may seem strange to the Western traveller, the underlying concept is one which could help sleepy drivers in the future. Essentially we are already saying – Tiredness Kills, Take a Break. Now we can add the opportunity to do so at low cost, without lengthy check-in procedures – tailored to motorists schedules.

Alcohol and sleepiness

New approaches in sleep research using alcohol as a comparison to sleep loss, and thus equating various levels of BAC with increasing wakefulness have underlined the implications of sleepiness at work (Dawson & Reid, 1997; Williamson & Feyer, 2000; Williamson et al., 2000; Arnedt et al., 2000). In the UK, the legal limit for blood alcohol concentration is 0.08%, compared to 0.05% in many other countries including Australia and parts of the USA. There may be some cause for reducing this limit into line with other countries, given the combined effects of moderate alcohol consumption with sleepiness. Although relatively little research has been conducted on this combination, modest sleep restriction has been shown to increase accident risk when combined with moderate consumption of alcohol (Zwyghuizen-Doorenbos et al., 1988), and in particular, sleep latency was found to be reduced even after alcohol was no longer detected. While alcohol largely affects the CNS as BAC increases, these effects have been found to continue even after alcohol is no longer detectable (Landauer & Howat, 1983). French accident data has also demonstrated that among SRVAs also involving BACs between 0.01-0.08%, the risk factor for death was roughly 4 times that for sleepiness alone (Philip et al., 2000). Of particular interest from the point of view of afternoon sleepiness, are the implications of moderate (i.e. within legal limits) alcohol consumption during lunchtime. That is, the natural tendency for sleepiness brought on by the afternoon circadian dip, augmented by low level BACs, and particularly following modest sleep restriction the night before. In other words – these three elements could quite easily (and legally) combine with the result being a significantly increased risk of falling asleep at the wheel. Again, this can be investigated with some alteration to the methodology described in this thesis, to allow prior alcohol consumption, absorption and breathalisation before testing begins.

Awareness of sleepiness

Increasingly important is the issue of drivers *awareness* of sleepiness. Since this is what will help them to decide whether or not to continue driving, there are legal implications in the event of accidents which are apparently related to sleepiness. It is often difficult to ascertain whether a driver fell asleep at the wheel after an accident, and many drivers will deny this for several reasons. However, it is also possible that they will claim to have 'suddenly' fallen asleep or lost consciousness without being aware of prior sleepiness. This seems unlikely except in cases where the driver was suffering from an undiagnosed sleep disorder, but does require some further investigation. Driver education should focus on this issue, so that motorists are aware that increasing sleepiness can result in actually falling asleep at the wheel. Research also needs to focus on what *motivates* drivers to continue, despite the increasing effects of sleepiness (Nilsson et al., 1997).

Professional Drivers

Using techniques tested in other areas of the transport industry (Reyner & Baulk, 1998), it is possible to assess the potential problems and vulnerabilities of professional drivers in the field. This can help employers to educate their staff, while also improving awareness at higher levels, and highlighting potential problems. Actimetry, sleep logs, questionnaires and interview methods which actively involve professional drivers may be used to achieve this. Although new digital tachographs have yet to come into use, it may be possible in the future to use actigraphy or some similar technology to monitor drivers in the same way. After all, driver sleepiness is a human, not mechanical problem, so why collect data solely from the vehicle ? Actiwatches are small, light and easily worn without inconvenience. They are also completely digital and therefore more difficult to tamper with.

Task Load and Distraction

As demonstrated in chapter 4.0, task load can affect both driver alertness and performance. This may well have implications for issues such as mobile phone usage, which is increasingly popular. In particular the interaction with sleepiness to cause distraction is potentially dangerous. As speech/language may be affected, drivers may compensate and thus driving performance will be further degraded, particularly by intense conversation. Passengers can stop talking when they see that the drivers full attention is needed elsewhere – they can even warn of oncoming danger if necessary, whereas a person talking through a mobile phone cannot (McKnight & McKnight, 1993).

8.9 General Recommendations

Until education and training take a firm hold of the driver sleepiness issue and make some attempt to tackle it, accidents will continue to occur.

Education

As we have seen already from the alterations to the highway code in the UK (November, 1999), and the now familiar roadsigns, advice to motorists is beginning to get through regarding driver sleepiness and the associated dangers. Following successful government road safety campaigns on *speed* and *alcohol*, its attention must turn to sleepiness. These campaigns have effectively caused 'drink driving' and the use of 'excessive speed' to become socially unacceptable, an attitude which can also be achieved with sleepiness through some education of motorists. In particular, the speeding campaign has used hard-hitting television advertisements. This would be very effective in raising awareness of sleepiness, and in particular putting across the severity of the consequences of falling asleep at the wheel.

Education and training for the Police about this is important and in particular case studies where companies are found to be at fault should be presented across forces so that future cases do not go unnoticed. Corporate manslaughter, although not a common charge, may be the result of this, and haulage companies as well as transport bodies must realise that they are at least in part legally and morally responsible for the fitness of their drivers, including their alertness while at work – and will not be absolved of blame if they fall asleep at the wheel. Prosecutions are extremely important because they enable companies to be taken to court when they directly or indirectly cause accidents through failure to monitor their drivers working hours and fitness to work.

The problem of driver sleepiness should now be firmly on the governments list of priorities, particularly following the recent conclusion of the Selby rail crash trial – which saw Gary Hart convicted of 10 counts of causing death by dangerous driving, and sentenced to 5 years imprisonment. This was by far the worst accident seen in recent years to have been caused by falling asleep at the wheel, and has brought the problem swiftly to the fore. This has now lead to the government's 'THINK' campaign on driver sleepiness (April 2002).

Education is therefore advocated at all levels for the public, professional drivers, management and even learner drivers – on the risks, causes and consequences of driver sleepiness, as well as effective and non-effective practical countermeasures.

Management Issues

Employers should also be educated in this area and learn to spot problems earlier. Managers should be made responsible for the welfare of their staff including sleep and rest, and trained to motivate them appropriately without encouraging overwork either directly or indirectly. The current working hour regulations for commercial drivers may also need some attention, since they are currently complex, and do not extend to vehicles other than HGVs such as vans or taxis, whose drivers may also be at risk from sleepiness (Corfitsen, 1993; 1994; 1996).

This thesis aimed to answer questions relating to the further investigation of driver sleepiness, and in particular potential countermeasures to the problem. Having addressed several different experimental approaches, leading to some important findings, it seems that there is still much to be done in order to take a firm hold of the problem, although directions for doing so are now much clearer. Awareness and acceptance of driver sleepiness and the dangers associated with it are ever-increasing internationally. Research into countermeasures is widespread and varied.

8.10 Conclusions

The studies reported here have demonstrated that driver sleepiness is a complex problem, which affects subjective, objective and performance based measures. The interactive driving simulator was found to be a valid and useful tool for investigating this, and several suggestions for changes and improvements were made as a result of this work. Secondary task reaction time was not found to be sensitive to increasing sleepiness, and this has important implications for technological devices designed to detect impairment and warn drivers. Caffeinated functional energy drinks were shown to be greatly effective however, suggesting that such more practical countermeasures to sleepiness are more likely to make a difference to the problem. Individual differences were also found to be important, as there was some suggestion that the ESS could be used to identify problems. Gender also was found to be a likely area for future research. Although male drivers are statistically more at risk from SRVAs, it seems that females experience greater levels of sleepiness while driving.

This suggests that male drivers are even more at risk than was first thought, and that their attitudes to driving when sleepy may be the main obstacle.

Awareness is the best countermeasure to driver sleepiness, fed by further research into *practical* rather than *technological* countermeasures. Much of this knowledge can be applied to other areas of the transport industry, as we move closer to the 24 hour society, and potential for sleepiness at work increases. Work on driver sleepiness will inform and advise the air, rail, shipping and space transport industries in the future. The most important issue seems to be that driver sleepiness is more dangerous in those individuals less able to recognise sleepiness, or less experienced in dealing with it, than those who may be more sleepy, but are able to take appropriate action (Aldrich, 1989).

9.0 REFERENCES

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World Wide Web Reference Material

Capsule Hotel concept	http://www.insidejapantours.com/otheraccom.html
New Scientist	http://www.newscientist.com
PubMed Search Engine	http://www.ncbi.nlm.nih.gov/entrez
Selby Rail Crash	http://www.bbc.co.uk/news

10.0 APPENDICES

Appendix 1

SLEEP RESEARCH CENTRE

BACKGROUND INFORMATION QUESTIONNAIRE

Name: .... Date: .... Subject No: ....

All of the information you give is completely confidential.

Address: ....
Phone No: ....
Email: ....
Nationality: ....
Age: ....
Gender: ....
National Insurance: ....
Approx Weight: ....
Approx Height: ....
Driving Licence: ....
Occupation: ....
Dates Available: ....

1. How many cups of tea/coffee do you usually drink in a day ?

1-2	1	5-6	4
2-3	2	Over 6	5
3-4	3	Don't Know	0

2. Do you Smoke ?

Yes	1	No (Qu 3)	3
Sometimes	2	Don't Know	0

2a. How many cigarettes per day ?

1-5	1
5 or More	2
Don't Know	0

3. Have you ever experienced any of the following medical conditions, and if so, when ?

No = 1
Yes in the past = 2
Yes, sometimes = 3
Yes, at present = 4
Don't know = 0

(a)	Asthma	....	(b)	Hay fever	....
(c)	Eczema	....	(d)	Allergies	....
(e)	Thyroid Problems	....	(f)	Undue anxiety	....
(g)	Sleepwalking	....	(h)	Loud snoring	....
(i)	Nightmares	....	(j)	Bruxism	....
(k)	Difficulty reading/writing	....	(l)	Arthritis/Rheumatism	....
(m)	Depression	....	(n)	Heart problems	....
(o)	Stomach problems	....	(p)	Waking up with a jolt	....
(q)	Waking up excessively early	....	(r)	Difficulty falling asleep	....
(s)	Stress/anxiety at home/work	....	(t)	Epilepsy	....
(u)	Migraine	....	(v)	Colour blindness	....

4. Do you regularly take pills or medicines from the chemist or by prescription.

Yes	1
No	2
Don't Know	0

If so can you tell me what they are ? ....

5. Do you have any diagnosed medical condition which affects your sleep ?

Yes	1
No	2
Don't Know	0

If so can you tell me what this is ?.......... ....

6. Do you have any medical or other reason which regularly prevents you from getting a good nights sleep ?

Yes	1
No	2
Don't Know	0

If so can you tell me what this is ?.......... ....

7. How many times per night do you wake up on average ?

Never	1	5-10 times	5
Hardly Ever	2	Over 10 times	6
Once or Twice	3	Don't know	0
No More than 5 times	4		

8. For how long have you held a full driving licence ? ....

9. On average how many hours per week do you spend driving ?

None	1	5-7	4
1-3	2	Over 7	5
3-5	3		

Thank you, that is the end of the questionnaire.

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Appendix 2

SLEEP RESEARCH CENTRE

OVERNIGHT INSTRUCTIONS

Thank you for taking part in this experiment. Here are some notes for you regarding care of the actimeter and the sleep routine which I would like you to follow.

The actimeter is worn on the wrist like a watch. It does not matter on which wrist you wear it. It is a delicate instrument which should not be banged or dropped etc, nor allowed to get wet. Please remove it when washing, showering, swimming or playing sports (if you do this please also remember to let me know so that I can account for any gaps in the data).

Please start wearing it at **1800 hrs** on .... and continue to wear it until you come to the lab at .... **hrs** on ....

The night before the trial, that is .... you should go to bed at **0200 hrs** and get up at **0700 hrs**. Do not drink alcohol the night before the session, and stop drinking caffeinated drinks (tea/coffee/coke etc.) drinks at 10pm. On the morning of the session, you should not drive a car or ride a bike, and please take extra care when crossing roads etc.

We ask you also to please wash your hair on the morning of the trial, and do not use any additional haircare products such as gel or sprays. This is simply to prevent any difficulty in the application of electrodes.

I hope these instructions help you to understand what is required. If you have any questions or problems, please contact me as soon as possible.

Thank you for your participation in this study.

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Appendix 3

SLEEP RESEARCH CENTRE

TRACK DRIVING STUDY: INSTRUCTIONS

Thank you for taking part in this study. You will be driving in a Peugeot 205, around a test track for approximately 2 hours. The car has dual controls in the interest of safety. We will ask you to drive the car in an anti-clockwise direction around the outer loop of the track, keeping to the left hand side of the road, and following close to the white line on the left. Where the white line is absent, please follow the blue/white cones. Please try to drive at a speed of 25mph, with car in 3rd gear. At regular intervals we will ask you to respond to the prompt: 'sleep check' when you should respond by giving your current feeling according to the two scales, visible in the car, which have already been explained to you. Before we begin the test, we will drive around the track a few times so that you may get used to the car, as well as the route around the track.

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Appendix 4

SLEEP RESEARCH CENTRE
CONSENT FORM

Consent of Subject to be included in Research Trial:

I ....

consent to taking part in a Sleep Research Centre experiment. An explanation of the nature and purpose of the procedure has been given to me by

....

I understand that I may withdraw from the experiment at any time, and that I am under no obligation to give reasons for such withdrawal. I understand also that I may feel sleepy during some parts of the experiment, and undertake to obey the instructions of the experimenter for safety purposes.

I understand that any information about myself which I have given will be treated as confidential by the experimenter.

Videotaped Material

I am / am not* willing to allow the use of extracts of my video recordings which have been taken while I participated in an experimental study for the Sleep Research Centre, Department of Human Sciences, Loughborough University, to be used for:

1. Scientific meetings/conferences*
2. Television documentary programmes*

Signed ....

Date ....

Signature of experimenter ....

* Please delete as appropriate

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Appendix 5

SLEEP RESEARCH CENTRE
SLEEP LOG

Name:... Date: ....

Fill in the details or tick as appropriate.

BEDTIME LOG

I got into bed at .... I turned the light out at ....

MORNING LOG

I woke up at .... this morning. I got out of bed at ....

15 minutes after waking I felt:

a) Very refreshed ☐
b) Refreshed ☐
c) Neither ☐
d) Tired ☐
e) Very tired ☐

Last night I slept:

a) Extremely Well ☐
b) Very Well ☐
c) Fairly Well ☐
d) Rather Badly ☐
e) Extremely Badly ☐

NIGHT DIARY

During the night my partner slept in: *(delete as appropriate)*

the same bed as me / a different bed to me

As far as I can remember it took me .... minutes to fall asleep
As far as I can remember I woke up .... times last night.

Please note the details of any awakenings you can remember in the table below.

Time	**Length of Awakening (minutes)**	**Reason**
....	....	....
....	....	....
....	....	....

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Appendix 6

SLEEP RESEARCH CENTRE

VIDEO ANALYSIS

SUBJECT **CONDITION**
NAME **DATE**

Time	Minor Incident	KSS	Major Incident	KSS	Notes

Appendix 7

SLEEP RESEARCH CENTRE
DRIVING SIMULATOR NOTES

SUBJECT
NAME

CONDITION
DATE

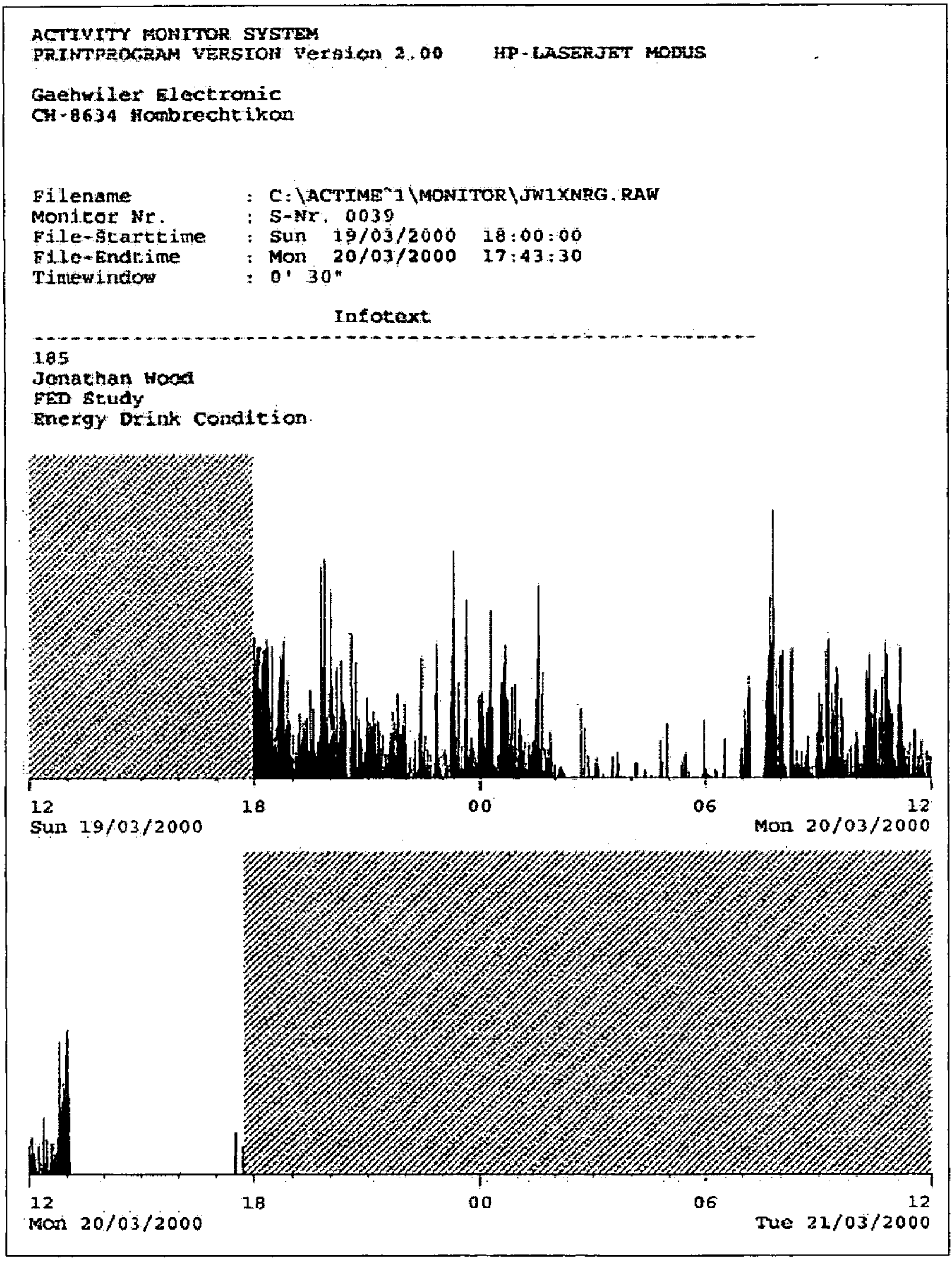
Time (s)	KSS	Time (s)	KSS
200		200	
400		400	
600		600	
800		800	
1000		1000	
1200		1200	
1400		1400	
1600		1600	
1800		1800	
2000		2000	
2200		2200	
2400		2400	
2600		2600	
2800		2800	
3000		3000	
3200		3200	
3400		3400	
3600		3600	
3800		3800	
4000		4000	
4200		4200	
4400		4400	
4600		4600	
4800		4800	
5000		5000	
5200		5200	
5400		5400	
5600		5600	
5800		5800	
6000		6000	
6200		6200	
6400		6400	
6600		6600	
6800		6800	
7000		7000	

Temp.

NOTES

Appendix 8

EXAMPLE ACTIGRAPH



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ACTIVITY MONITOR SYSTEM
PRINTPROGRAM VERSION Version 2.00     HP-LASERJET MODUS

Gaehwiler Electronic
CH-8634 Hombrechtikon


Filename          : C:\ACTIME~1\MONITOR\JW1XNRG.RAW
Monitor Nr.       : S-Nr. 0039
File-Starttime    : Sun  19/03/2000  18:00:00
File-Endtime      : Mon  20/03/2000  17:43:30
Timewindow        : 0' 30"

                       Infotext
----------------------------------------------------------
185
Jonathan Wood
FED Study
Energy Drink Condition
```