Drowsy Driving and the Law

A Submission to the Tasmania Law Reform Institute
re: Issues Paper No 12

Prepared by Dr Murray W Johns, Sleep Diagnostics Pty Ltd, Melbourne.
November 2007

Aim of this Submission

The aim of this submission is to highlight the confused state of the scientific evidence that is currently used as the basis for making legal decisions about “drowsy driving”. This has been one of the author’s main topics of clinical and research interest and expertise for the past twenty years. It is not intended that the legal arguments about the culpability of “drowsy drivers” be canvassed here. That is beyond the author’s area of expertise. However, it is hoped that others may be able to make better decisions based on a clearer understanding of the nature of the problem.

Summary

Driving while in the drowsy state is acknowledged to be a common cause of road crashes. However, much of the discussion about this problem is being conducted with a very limited understanding of the nature of the drowsy state. In particular, there is widespread misunderstanding that the states of fatigue and drowsiness are the same. The distinguishing features of these two states are briefly described here, highlighting the fluctuating nature of the drowsy state and its periods with lack of awareness of the here-and-now that make “drowsy driving” so dangerous. Some experiments are described that illustrate the nature of drowsiness, but more research is needed on this topic that has been largely neglected previously. A detailed report about the various methods for assessing drowsiness in drivers (commissioned by VicRoads in 2001) is attached as Appendix A, to be read as back-ground information as required.

Introduction

There is a broad consensus among researchers and regulators of road safety that "falling asleep at the wheel" is among the most important causes of road crashes (1). These crashes typically involve a single vehicle that departs the driving lane and collides with another object, such as a tree beside the road or another vehicle. The driver is often alone, having been driving for some hours, often between midnight and 6 am. A unique characteristic of such crashes is the absence of evidence that the driver had taken evasive action to prevent the crash or to mitigate its consequences, eg. a lack of skid marks indicating that the brakes had not been applied (2). This suggests that the driver was not aware of the crash about to happen. The consequences of "drowsy driving" crashes are often unusually severe in terms of deaths, injuries and property damage.

Various estimates suggest that about 20% of all highway crashes are due to "drowsy driving" (1). However, there is great confusion about how to quantify this problem or, indeed, how to define it. This extends to confusion about the legal implications of "drowsy driving". If you do not understand the nature of a problem and cannot measure it, it is very difficult to arrive at meaningful decisions about its management.

Much of this confusion seems to arise from a very limited understanding of the nature of the state of the drowsy state and, in particularly, from a failure to distinguish drowsiness from fatigue. Even the National Sleep Foundation in the USA, in their most recent report about "drowsy driving", use the terms fatigue and drowsiness as if they were synonymous (3). One reason for the confusion appears to be a reluctance or inability to define the words and concepts being used. Another reason is that, although sleep researchers have taken giant steps over the past 50 years towards understanding sleep and wakefulness, the state of drowsiness has been almost neglected. There has been a lack of appropriate tools for detecting and measuring different levels of drowsiness, as opposed to sleep. The methods traditionally used in sleep laboratories for monitoring sleep and wakefulness (especially the electroencephalogram or EEG) have proven not to be the most appropriate for detecting drowsiness, especially in its earliest stages.

Definitions of Drowsiness and Fatigue

When defining such terms as drowsiness and fatigue, an English dictionary such as the Shorter Oxford English Dictionary can establish their common usage. To be drowsy, therefore, is to be "inclined to sleep, heavy with sleepiness, half asleep, dozing". This is synonymous with the adjective "sleepy". Drowsiness is therefore the state of being drowsy or sleepy. By contrast, in common English usage, fatigue is "weariness resulting from bodily or mental exertion", which is synonymous with "tiredness". There is no confusion here between "drowsiness/sleepiness" on the one hand and "fatigue/tiredness" on the other hand.

Contrast these with the definitions used by many road safety authorities and others who have almost always chosen to centre their discussions around "driver fatigue" (4-6). Brown (7), who has had a dominant influence on such discussions, defined fatigue as “the subjective experience of tiredness and a disinclination to continue performing the current task”. While that definition is compatible with the common English usage of the word fatigue, Brown went on to claim that the main effect of fatigue in a driver was “a progressive withdrawal of attention from the road and traffic demands,” [and] “probably the most frequent cause of general attentional impairment is the eye closure that accompanies sleepiness” (7). Without any explanation or justification, Brown equated the state of fatigue/tiredness with that of drowsiness/sleepiness. This confusion continues to this day in many quarters, particularly in discussions about road safety in Australia and elsewhere (5, 6). Even when some people use the word drowsiness correctly, they simply assume that this also refers to fatigue, and then claim that fatigue and drowsiness are indistinguishable (4).

Distinguishing Characteristics of Drowsiness and Fatigue

Drowsiness is the intermediate state between alert wakefulness and sleep (8). It is a fluctuating state that shares some of the characteristics of alert wakefulness and some of sleep. We normally pass through the drowsy state whenever we fall asleep. With intentional sleep onset, lying in bed, drowsiness may last only a few minutes. However, drowsiness that arises involuntarily when we should be alert, as when driving, may last much longer. Drowsiness can alternate rapidly between different levels within a matter of seconds. It is not a single, all-or-nothing entity, and therein lies a potential source of misunderstanding. It is characterised by intermittent periods when there is a lack of awareness of the here-and-now. This applies to all sensory modalities (vision, vibration sense, hearing, etc). Such periods of lack of awareness may last only a few seconds at a time, and are often followed by arousal to greater levels of alertness, often with awareness of the preceding period of more drowsiness as an “absence”. Most people are not usually aware at the time of making this progression into more intense drowsiness, nor of the potential risks of performance failure at that time. Periods of lack of awareness are sometimes, but not always, associated with a microsleep, with the appearance of theta-waves in the EEG. Drowsiness and its associated lack of awareness often involve spontaneous eyelid closure, but about 25% of such episodes occur with the eyes open (9). Hence, the term “driving without awareness” has sometimes been applied to this situation when the driver is apparently looking but not seeing (10).

By contrast, fatigue is a subjective state of weariness, often with muscle aches or discomfort, emotional irritability and a disinclination to continue activities. It is much more difficult to measure fatigue than drowsiness objectively, but the reverse may be true for subjective measurements. Fatigue gets progressively worse the longer the physical and mental activity continues without a rest period. The more fatigued you are, the more aware of it you become, and that awareness does not fluctuate rapidly, over periods of seconds, as drowsiness does. Fatigue is relieved by rest, whereas drowsiness is relieved by sleep, not by rest in the waking state. In fact, drowsiness becomes worse with physical and mental inactivity. Fatigue does not cause a lack of awareness, as drowsiness does intermittently. Many drivers will feel fatigued after driving for several hours, but that does not necessarily mean that they will be drowsy. However, they can be both drowsy and fatigued at the same time, and this may often be the case.

Viewed in this light, drowsiness and fatigue are not difficult to distinguish, yet their confusion has been a major problem for many people involved in road safety. At least some of this confusion has arisen from a lack of understanding of the state of drowsiness which has received much less attention than fatigue. Without an understanding of the differences between these two states, it will remain difficult to manage the risks and problems, including the legal implications of road crashes, associated with either. Unfortunately, that confusion underlies much of the current legal, industrial, commercial and even academic discussion of "drowsy driving" and "fatigue management" in Australia and elsewhere (4-6). Drivers in general can be forgiven for not understanding such matters.

What Causes Drowsiness?

The tendency to become drowsy, whether or not that proceeds to sleep, is known to be influenced by many factors, including

- the duration of prior wakefulness, especially beyond about 17 hours
- the time of day (a circadian rhythm with its main peak in the early hours of the morning and a minor peak in mid-afternoon)
- the quantity and quality of the preceding sleep
- the presence of a variety of sleep disorders (such as obstructive sleep apnea)
- the person's level of physical and mental activity at the time (eg. posture has a major effect. Sleep propensity is increased markedly by lying down and closing the eyes)
- the level of environmental stimulation at the time (eg bright light, noise, interaction with someone else)
- medical disorders affecting brain function
- the effects of stimulant or sedative drugs

Remaining awake for 24 hours does not necessarily make everyone very drowsy, but is does increase the probability of them becoming drowsy under circumstances in which they would not usually do so, and hence increases their risk of a drowsy crash while driving.

Measuring Drowsiness Objectively

Sleep researchers and clinicians record the electroencephalogram (EEG), the electrooculogram (EOG) and the electromyogram (EMG) to monitor sleep in the laboratory.(See Appendix A: "Assessing the Drowsiness of Drivers") for a full explanation of these and other methods for measuring drowsiness). Some have also attempted to use these standardised methods for monitoring drowsiness in drivers while driving on the road (11). Apart from the impracticality of having to apply electrodes to drivers, especially if such monitoring were to be used routinely, the results have been less than satisfactory. In particular, the EEG changes that reflect sleep onset, even briefly during microsleeps, were not observed as frequently as expected according to video images of the drivers' eyes (11). In laboratory experiments, without the complicating factors of real-life situations, there are subtle changes in the EEG with drowsiness, including the presence of spontaneous fluctuations that correspond to changes in psychomotor performance over periods of seconds in the drowsy state (12). However, in general, the EEG does not signal the onset of drowsiness very well.

Different levels of drowsiness can be measured objectively by monitoring movements of the eyes and eyelids (See Appendix A). A new system for monitoring the drowsiness of drivers routinely is based on infrared reflectance oculography, using transducers attached to glasses frames (Optalert™, Sleep Diagnostics Pty Ltd, Melbourne)(13). This provides a minute-by-minute measure of drowsiness based on a weighted combination of several variables that characterise each movement of the eyelids and eyes, without the need for electrodes (www.optalert.com). The system can warn drivers when they first show signs of drowsiness, often before they are aware of it and before their drowsiness reaches a dangerous level. By providing objective information to the driver about his/her levels of drowsiness, Optalert™ overcomes the limitations of their subjective awareness of the presence of drowsiness and of the risks associated with “drowsy driving”. This should enable them to manage their own drowsiness and to prevent them dozing at the wheel, even for a few seconds, with the very high crash risk that it entails. Optalert™ is currently being used routinely by some commercial drivers in Australia.

Measuring Drowsiness Subjectively

Much of the previous “drowsy driving” research has involved measurements of drowsiness by subjective scales such as the Stanford Sleepiness Scale (SSS), the Karolinska Sleepiness Scale (KSS), or the Epworth Sleepiness Scale (ESS).

Stanford Sleepiness Scale

The Stanford Sleepiness Scale (SSS) was introduced in 1973(14). It comprises a series of statements, numbered 1 to 7, that range from “feeling active, vital, alert, wide awake” to “almost in reverie, cannot stay awake, sleep onset appears imminent” (Table 1).

The different statements are presumed to represent an ordinal scale that reflects different positions along a continuum of states between alert wakefulness, through progressively deeper levels of drowsiness, to sleep. The respondent is asked to choose which statement most accurately describes his feelings at the time.

The SSS has been widely used, particularly for studying the effects of sleep deprivation (15) , sleep fragmentation (16) and circadian rhythms (17). However, scores on the SSS are not closely related to sleep latencies measured objectively a few minutes later in Multiple Sleep Latency Tests (MSLTs)(18). Another problem with the SSS is that factor analysis suggests that it is not a unitary scale (19). It seems to measure some aspects of sleepiness, in the sense of drowsiness, as well as fatigue, perhaps because so many different poorly defined words are used in the SSS statements, such as “responsive”, “foggy”, “vital”, and “woozy”. The SSS is best used to measure changes within subjects over time, particularly over periods of hours and days. Scores on the SSS often require standardisation (eg to z-scores) to remove differences between subjects.

Table 1: Stanford Sleepiness Scale (after Hoddes et al. (14))

Stanford Sleepiness Scale	
Circle the ONE number that best describes your level of alertness or sleepiness right now.	
1.	Feeling active, vital, alert, wide awake.
2.	Functioning at a high level but not at peak, able to concentrate.
3.	Relaxed, awake but not fully alert, responsive
4.	A little foggy, let down.
5.	Foggy, beginning to lose track, difficulty staying awake.
6.	Sleepy, prefer to lie down, woozy.
7.	Almost in reverie, cannot stay awake, sleep onset appears imminent.

Karolinska Sleepiness Scale

The Karolinska Sleepiness Scale (KSS) is a 9-point scale (or more recently, a 10-point scale) somewhat similar to the SSS (20). In its original format it had word descriptors only for scores of 1,3,5,7 and 9. Those descriptors varied from 1= "very alert" to 9="very sleepy, fighting sleep, an effort to keep awake". However, additional descriptors were later added for all scores (21), as shown in Table 2. The changes observed in the EEG/EOG with drowsiness do not usually appear until KSS scores reach 7 and higher (22). The KSS has been widely used, particularly for describing changes over time within subjects (22-24).The KSS is assumed to be an ordinal scale with a unitary structure, although that has not been confirmed. KSS scores may require standardisation to control for differences between subjects (22,23).

Table 2. A modified version of the KSS (after Reyner and Horne (21))

Karolinska Sleepiness Scale Here are some descriptors about how alert or sleepy you might be feeling right now. Please read them carefully and CIRCLE the number that best corresponds to the statement describing how you feel at the moment.
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 difficulty remaining awake 8. Sleepy, some effort to keep alert 9. Extremely sleepy, fighting sleep

Epworth Sleepiness Scale

The most commonly used method for measuring a person's average sleep propensity in daily life is the Epworth Sleepiness Scale (ESS), developed by Johns (25). The ESS asks subjects to estimate their usual chances of dozing off in a variety of different situations, such as sitting and reading, watching TV, sitting and talking to someone. The ESS score is the sum of 8 item-scores, and can vary between 0 (low sleep propensity) and 24 (very high sleep propensity). The ESS does not provide a measure of a person's drowsiness at a particular time. However, people who have ESS scores >15, who are said to have "excessive daytime sleepiness", have a significantly increased risk of a crash while driving (26).

Psychomotor performance in the drowsy state

For more than a century, experimenters have been investigating the impairment in psychomotor performance that occurs with sleep deprivation, and by implication, with the drowsy state. In visual reaction-time (RT) tests, subjects are asked to push a button as soon as possible after they see a visual "stimulus". Because driving is first and foremost a visual task, with many other skills and sensory modalities being important but subsidiary to vision, it seems appropriate to use visual RT tests in drowsy subjects as an experimental surrogate for "drowsy driving".

It is well known that after sleep deprivation, beginning after being awake for no more than about 17 hours, subjects take longer to respond (ie. their RTs increase), their RTs become more variable, and they sometimes fail to respond at all (ie. they have errors of omission) (27). However, despite such experiments having been done repeatedly around the world, there has been very little attempt to develop a theoretical explanation for the changes observed. Confusion between fatigue and drowsiness is presumably part of that conceptual void.

Awareness of Being Drowsy

"Drowsy driving" episodes are quite commonly reported by drivers in the general community and by professional drivers. A recent population-based survey in USA indicated that 37% of the driving population had driven while drowsy and dozed off at the wheel, some many times, within the preceding year (3). Only a minority of such episodes had caused a crash or near-miss incident. That experience may lead some drivers to believe, inappropriately, that episodes of "drowsy driving" are readily manageable and are not necessarily associated with greatly increased risks. Combine that with the known impairment of the drowsy driver's ability to make sound judgements about driving risks (or anything else) when in the drowsy state, and the combination becomes potentially lethal. It has not been demonstrated that those risks are associated with the state of fatigue, in the absence of drowsiness.

There are several sources of information from surveys and experiments that can help us understand how aware drivers are of their state of drowsiness. Some researchers, such as Jim Horne from Loughborough University(21), say that drivers always know how drowsy they are at a particular time, but they may not understand the increased risk of falling asleep at the wheel when they are drowsy. For Horne, the answer to the problem of "drowsy driving" lies in further education of drivers about those risks.

In a survey of road crashes in Utah that police investigators had determined were caused by the drivers "falling asleep at the wheel", 41% of those drivers said they were either not drowsy at all or were only "slightly drowsy" before the crash (4). Some may ascribe this to the drivers' reluctance to admit fault. Others may say that the driver's memory of having been drowsy was lost after the crash, for whatever reason. However, the large proportion of drivers who denied being drowsy must raise suspicions that at least some were genuinely unaware of their drowsiness at the time.

Horne and Baulk (28) described an experiment in which 38 young men and women each drove for 2 hours in a car simulator after mild sleep restriction (5 hours sleep) on the previous night. Their driving performance was monitored by the lane position of the vehicle and "incidents" when they drove with two wheels out of the lane. They also had continuous EEG recordings. They gave subjective estimates of their "sleepiness" every 200 sec when prompted by the experimenter, reporting a KSS score between 1 and 9 verbally. The mean KSS scores every 200 sec clearly changed in parallel with changes in the power of the EEG, within the frequency range of 4-11 Hz, and also with the occurrence of lane departures. The authors concluded that their volunteers were clearly aware of their changing levels of drowsiness while they were "driving" in the simulator.

This experiment raises many questions. Were the drivers sufficiently drowsy for them to have stopped driving in real-life driving situations? Subjective ratings of drowsiness may not be very accurate reflections of objectively measured drowsiness, especially when differences between subjects are taken into account. For example, several lane departure incidents occurred with KSS scores in the relatively alert range, less than 6. To what extent did the experimenter's intervention enable the subjects to rouse briefly after they had been prompted and then form an estimate of their behavioural state that they may not have been aware of otherwise? While acute sleep deprivation (eg. missing a night's sleep) is commonly associated with "drowsy driving" crashes, especially in young adults, the question arises whether other people who have a chronic sleep disorder, and who are continually more drowsy as a result, perceive their drowsiness in the same way. Much more research is required before these questions can be answered definitively.

In a different experiment reported by Atzram et al (29), volunteers underwent various periods of sleep deprivation from 42 and 88 hours. They performed a 20-minute psychomotor vigilance test every 2 hours and provided subjective reports of their "sleepiness" based on the SSS before the start of each vigilance test. Episodes of performance failure that lasted 30 sec were confirmed by EEG analysis to have been due to them falling asleep, after which they were purposely roused by the experimenters. There was a statistically significant but relatively small increase in subjectively reported "sleepiness" before each subject's first sleep episode. Their "sleepiness" ratings reported a few minutes before their first sleep onset, and after significant sleep deprivation, involved mean SSS scores of 4.0 and 4.3 in different groups of subjects (where 4 = "a little foggy, let down") That is, these subjects did not rate their drowsiness much beyond the middle of the SSS scale within a few minutes of them falling asleep for the first time in the test situation. The authors concluded that their subjects did not appear to appreciate the severity of their drowsiness which they had subjectively underestimated. They had not been prompted to give an estimate of their drowsiness during each test period. We do not know what proportion of drivers in the community would stop driving because of drowsiness under those circumstances.

Experiments conducted recently by Sleep Diagnostics Pty Ltd in Melbourne shed some light on the above results. Volunteers (70 men and 39 women of various ages) performed a psychomotor vigilance tests (the Johns Test of Vigilance or JTV) when alert and when moderately sleep deprived, after remaining awake for 27-30 hours. Their drowsiness was measured objectively during JTVs by infrared reflectance oculography with Optalert™ glasses (16). They reported a KSS score on a 10-point scale as a measure of their drowsiness a few minutes before each JTV test began. This version of the KSS had the same items 1 to 9 as the 9-point version, but included an additional item, 10 = "extremely sleepy, can't keep awake". In the JTV, subjects were asked to push a button as quickly as possible after they saw a visual stimulus (a change of shapes on a computer screen) that lasted only 400 seconds, presented at random intervals of 5 to 15 seconds during the 15-minute test. Their performance was assessed in several different ways - the mean of about 85 RTs, the standard deviation of those RTs, and the proportion of errors of omission, in which there was no response within 2 sec from the start of the stimulus.

All measures of performance changed after sleep deprivation. There was a statistically significant but small increase in mean RTs with increasing KSS scores ($r = 0.38$, $n = 575$, $p<0.001$). There was also a significant increase in the standard deviation of RTs with increasing KSS scores ($r = 0.45$, $n = 575$, $p<0.001$). That is, with increasing levels of drowsiness reported before the tests began, subjects responded more slowly and with more variability in their RTs during the subsequent tests a few minutes later. However, the greatest change was with errors of omission, when they failed to respond at all.

Fig 1 shows the relationship between the percentage of errors of omission and KSS scores, with all test sessions combined, before and after sleep deprivation. Most subjects made very few errors of omission when alert. The more drowsy the subjects were just before each JTV (the higher their KSS score), the more likely they were to make frequent errors of omission during the subsequent test. The regression describing this relationship was not linear, and is shown here as a statistically significant exponential function.

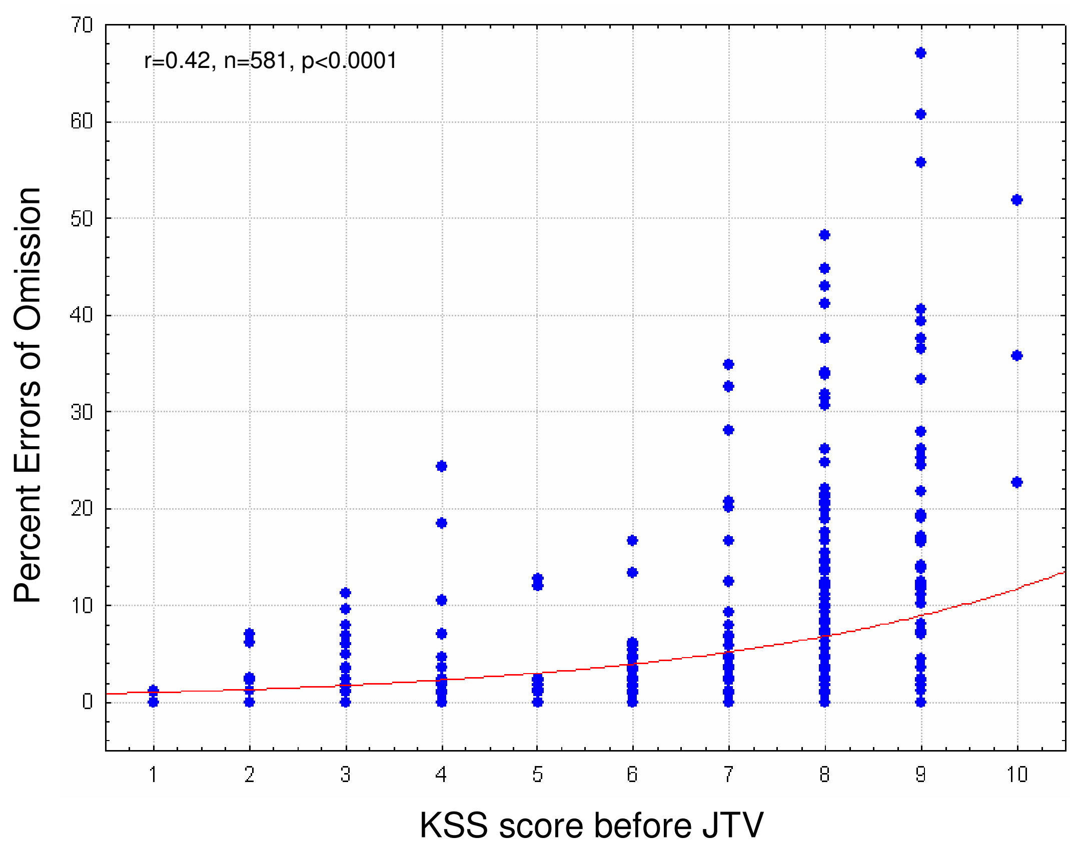

Fig 1. KSS scores reported a few minutes before 15-minute psychomotor vigilance tests (JTVs) versus the percentage of errors of omission in those tests. 109 subjects performed 575 JTVs when alert and when sleep -deprived. An error of omission was defined as no response within 2 seconds from the start of the stimulus.

It was not really until levels of drowsiness represented by KSS scores of 7 and higher were reached that the percentage of errors of omission exceeded that associated with lower KSS scores. The descriptor for KSS = 7 was "sleepy, but no effort to keep awake", which some people might see as the beginning of their drowsiness, but not necessarily the level of drowsiness at which they should stop driving. Even with KSS scores of 8 – 9, many people performed as well as those with scores between 1 and 6. There were very few KSS scores of 10. Subjects were generally not aware of failing to respond to stimuli. Overall, their ability to assess levels of drowsiness as they affected performance a few minutes later was only moderate.

Some subjects with high levels of drowsiness (KSS scores 8-10) did not respond to more than 50% of the stimuli. It can be argued that a level of drowsiness associated with only 5 to 10% of errors of omission in the JTV would not be compatible with safe driving (30). For example, a driver in that state would have a substantial risk of not seeing or responding to the presence of a curve in the road ahead, and running off the road as a result. However, it should also be noted that most subjects that had high levels of drowsiness in this experiment responded within 2 seconds to the majority of stimuli. This emphasises the fluctuating nature of the drowsy state, and the difficulty that it presents in deciding what people can and cannot do when drowsy.

The conclusions arrived at from these and other experiments are as follows:

- the ability of most people to detect their own drowsiness, and to discriminate between its different levels, is moderate so long as they retain awareness of the here-and-now.
- it is normal for drowsiness to fluctuate spontaneously, especially when it is prolonged by the intention to remain awake, as with "drowsy driving".
- the deepest levels of drowsiness involve loss of awareness of the here-and-now, even before microsleeps occur or actual sleep begins.
- it is in this state that drowsy drivers are very liable to make errors of omission, when they fail to respond to a meaningful stimulus during periods that may last only a few seconds. A vehicle travels about 80 metres in three seconds at 90-100 kph, long enough to drive off the road and crash. Drivers who have no awareness of what is happening at that time cannot be expected to take preventive or remedial action during that brief period. That is what is believed to happen often with "drowsy driving" crashes.
- once drowsiness has begun, it may be a matter of chance when a period of more intense drowsiness arises, with lack of awareness of the here-and-now. When such a period coincides with the need to perform some critical driving function (eg turning the steering wheel a few degrees to drive round a curve in the road) the risk of crashing is greatly increased.
- driving while drowsy is not a rare event in the general community or among professional drivers. Because the majority of such episodes do not cause a crash, some drivers may underestimate the risks of "drowsy driving".
- people can usually give a general estimate of their drowsiness over periods of a few minutes, as for example with KSS or SSS scores. However, those subjective estimates are presumably based mainly on their feelings during periods when they are still aware of the here-and-now. Awareness of having recently dozed off is evidently not reached until after the event, when the driver next rouses to become more alert, at least temporarily.
- a driver's own reports of drowsiness may be underestimates of objectively measured drowsiness, particularly at high levels, and this may distort their subjective awareness of risks associated with "drowsy driving".
- drivers should stop driving as soon as they became aware of the first feelings of drowsiness. However, for some people at least, this may not be until after their first episode of dozing off at the wheel on a particular journey.
- much more research is needed on the state of drowsiness and on "drowsy driving" in particular.

Some Problems with the Current Management of Drowsy Driving

Most people seem to be aware that, if they remain awake for prolonged periods, especially longer than 24 hours, their sleep propensity will increase, ie they will become drowsy and fall asleep more quickly than usual when they lie down. They will also be more likely to doze off under circumstances in which they would not normally do so, especially when they intend to remain awake, as with driving. Unfortunately, the relationship between the duration of prior wakefulness and sleep propensity is very variable between different people. Some do not become very drowsy after remaining awake for 24-30 hours, as others do. By contrast, other people become drowsy after remaining awake for only 17 hours. Drowsy driving episodes often occur within the first hour or two of driving (4) and they would presumably not be controlled by existing regulations to do with the hours of work.

The impairment in driving skills caused by drowsiness is not the same as that caused by alcohol intoxication, but there are some similarities. Drowsiness generally increases as the blood alcohol concentration (BAC) increases, but alcohol has more widespread affects on psychomotor performance than can be attributed to drowsiness alone. It is possible to measure a driver's BAC soon after a crash and to arrive at a reasonably accurate estimate of their BAC at the time of the crash. Hence the widespread use of breathalysers and blood samples for the measurement of BAC in drivers after they have crashed. By contrast, it is not possible to measure accurately and objectively what a driver's level of drowsiness was at the time of a crash by some later measurement of their drowsiness under different circumstances. It will require the continuous monitoring of drowsiness in drivers, such as that now available with Optalert ™, to provide an objective and accurate measurement of drowsiness at the time of any crash.

The general public in Australia, and particularly professional drivers, are being educated about "fatigue management" but not much about "drowsy driving". Various lists of symptoms and signs of early drowsiness (usually called fatigue) have been disseminated but, unfortunately, they are not well-founded scientifically. For example, yawning is often cited as an important sign of drowsiness, and it is not. Having monitored drowsiness and sleep in many thousands of people in sleep laboratories, including video recordings and objective measurements of their sleep and patterns of breathing, it is evident that most people do not yawn as they go to sleep. On the basis of misinformation about drowsiness and yawning, drivers could be forgiven for not having a clear understanding of "drowsy driving" and its risks.

One's awareness of being drowsy, in contrast to being fatigued, may depend to some extent on the experience within the preceding few minutes of dozing off, without awareness at the time of doing so, and then rousing and becoming aware in retrospect of a period of "absence". Without such a dozing episode, drivers may be less aware of their drowsiness than their fatigue. This may make it difficult for drivers to anticipate their first dozing episode while driving at a particular time. However, more research on this topic is required.

Acknowledgement
Dr Kate Crowley helped with the preparation of this submission.

Murray Johns, BSc MB BS PhD
Director & Chief Scientist
email: mjohns@optalert.com

Sleep Diagnostics Pty Ltd
Suite 9, 150 Chestnut Street
Richmond, Melbourne, VIC 3121

References

1. Lyznicki, J.M., Doege, T.C., Davis, R.M., and Williams, M.A., Sleepiness, driving, and motor vehicle crashes. Council on Scientific Affairs, American Medical Association. **JAMA**, 1998. 279(23): 1908-13.
2. Pack, A.I., Pack, A.M., Rodgman, E., Cucchiara, A., Dinges, D.F., and Schwab, C.W., Characteristics of crashes attributed to the driver having fallen asleep. **Accident Analysis and Prevention**, 1995. 27(6): 769-75.
3. National Sleep Foundation, State of the States Report on Drowsy Driving. 2007, US National Sleep Foundation.
4. Schultz, G.G. and Young, H.T., A safety analysis of fatigue and drowsy driving in the State of Utah. 2007, Utah Department of Transportation, Research and Development Division. Report No. UT-07.07.
5. National Transport Commission, Guidelines for Managing Heavy Vehicle Driver Fatigue. 2007, National Transport Commission: Melbourne. 2007-11-16.
6. Monk, T.H., Practical consequences of fatigue-related performance failures. **Sleep**, 2007. 30: 1402-3.
7. Brown, I.D., Driver fatigue. **Human Factors**, 1994. 36(2): 298-314.
8. Johns, M.W., A sleep physiologist's view of the drowsy driver. **Transportation Research**, 2000. Part F 3: 241-249.
9. Chapman, R., Johns, M.W., and Crowley, K., In the drowsy state, errors of omission in a visual reaction-time test occur with eyes open or closed. **Sleep**, 2006. 29(Abstract Supplement): A364.
10. Karrer, K., Briest, S., Vohringer-Kuhnt, T., Baumgarten, T., and Schleicher, R. Driving without awareness. Proc 3rd International Conference on Traffic and Transport Psychology. 2004. Nottingham: Elsevier, Amsterdam.
11. Mitler, M.M., Miller, J.C., Lipsitz, J.J., Walsh, J.K., and Wylie, C.D., The sleep of long-haul truck drivers. **New England Journal of Medicine**, 1997. 337(11): 755-61.
12. Makeig, S., Jung, T.P., and Sejnowski, T.J., Awareness during drowsiness: dynamics and electrophysiological correlates. **Canadian Journal Experimental Psychology**, 2000. 54(4): 266-73.
13. Johns, M.W., Tucker, A., Chapman, R., Crowley, K., and Michael, N.J., Monitoring eye and eyelid movements by infrared reflectance oculography to measure drowsiness in drivers. **Somnologie**, 2007. 11: 234-242.
14. Hoddes, E., Zarcone, V., Smythe, H., Phillips, R., and Dement, W.C., Quantification of sleepiness: a new approach. **Psychophysiology**, 1973. 10(4): 431-6.
15. Dinges, D.F., Orne, M.T., Whitehouse, W.G., and Orne, E.C., Temporal placement of a nap for alertness: contributions of circadian phase and prior wakefulness. **Sleep**, 1987. 10(4): 313-29.
16. Stepanski, E.J., The effect of sleep fragmentation on daytime function. **Sleep**, 2002. 25(3): 268-76.
17. Monk, T.H., Leng, V.C., Folkard, S., and Weitzman, E.D., Circadian rhythms in subjective alertness and core body temperature. **Chronobiologia**, 1983. 10(1): 49-55.
18. Pressman, M.R. and Fry, J.M., Relationship of autonomic nervous system activity to daytime sleepiness and prior sleep. **Sleep**, 1989. 12(3): 239-45.

19. MacLean, A.W., Fekken, G.C., Saskin, P., and Knowles, J.B., Psychometric evaluation of the Stanford Sleepiness Scale. **Journal Sleep Research**, 1992. 1(1): 35-39.
20. Akerstedt, T. and Gillberg, M., Subjective and objective sleepiness in the active individual. **International Journal Neuroscience**, 1990. 52(1-2): 29-37.
21. Reyner, L.A. and Horne, J.A., Falling asleep whilst driving: are drivers aware of prior sleepiness? **International Journal Legal Medicine**, 1998. 111(3): 120-3.
22. Gillberg, M., Kecklund, G., and Akerstedt, T., Relations between performance and subjective ratings of sleepiness during a night awake. **Sleep**, 1994. 17(3): 236-41.
23. Casagrande, M., Curio, G., Ferrara, M., Tricarico, M., Urbani, L., and Porcu, S., Subjective ratings of sleepiness: Sensitivity of different measures in revealing time of day effects. **Sleep Research Online**, 1999. 2(Supplement 1): 226.
24. Ingre, M., Akerstedt, T., Peters, B., Anund, A., Kecklund, G., and Pickles, A., Subjective sleepiness and accident risk avoiding the ecological fallacy. **Journal Sleep Research**, 2006. 15(2): 142-8.
25. Johns, M.W., A new method for measuring daytime sleepiness: the Epworth Sleepiness Scale. **Sleep**, 1991. 14(6): 540-5.
26. Stutts, J.C., Wilkins, J.W., and Vaughn, B.V., Why do people have drowsy driving crashes? 1999, American Automobile Association, Foundation for Traffic Safety: Washington D.C.
27. Dinges, D.F. and Kribbs, N., Performance while sleepy: Effects of experimentally-induced sleepiness, in **Sleep, Sleepiness and Performance**, Monk, T.H., Editor. 1991, John Wiley & Sons: New York. 98-128.
28. Horne, J.A. and Baulk, S.D., Awareness of sleepiness when driving. **Psychophysiology**, 2004. 41(1): 161-5.
29. Atzram, M., Chow, C., Price, N.J., Rogers, N.L., Van Dongen, H., and Dinger, D.F., Can sleep attacks occur without feeling sleepy? **Sleep**, 2001. 24(Abstract Supplement): A428.
30. Johns, M.W., Chapman, R., Crowley, K., and Tucker, A., A new method for determining when a driver is too drowsy to drive. **Somnologie**, in press.