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Drowsy Driving is Not Simply a Matter of Fatigue:
Clarifying the Nature of a Problem at Mine-sites

Murray Johns

Sensory Neuroscience Laboratory, Swinburne University of Technology, Hawthorn,

and

Optalert Ltd, Richmond, Melbourne, VIC, Australia

Address: Dr MW Johns, Optalert Ltd,

Level 3, Building 5, 658 Church Street,

Richmond, VIC, 3121

mjohns@optalert.com

It has been estimated that 93 per cent of accidents and incidents involving haul trucks at mine-sites are caused by human error. Of those, 60-70 per cent have been attributed to drivers being drowsy or fatigued at the time.[1] Even minor crashes can be very costly, not only in terms of human health and safety, but also the continuity and cost of production.

Fig 1. A relatively minor crash in a haul truck can be very expensive in terms of repairs and loss of production, even if there is no personal injury.

What is interesting in this and many other related reports is that drowsiness and fatigue are neither defined nor distinguished. Does this mean that there are two different states, drowsiness and fatigue, each of which is associated with increased crash-risk for drivers? Alternatively, does it mean that the two words refer to the same thing? Or are we just confused about the nature of this problem and don't know which word to use? If so, does it matter? Our aim here is to answer those questions.

Background

About a century ago, applied psychologists began to study fatigue as a cause of impaired performance in the work-place, mainly as a function of the “hours of work”. The idea that fatigue was a major cause of road traffic accidents arose later, but nonetheless has a history going back several decades.[2] Throughout those years there has been difficulty in reaching a consensus about what fatigue is. When developing Australian guidelines and regulations for heavy vehicle drivers, the National Transport Commission assumed that fatigue includes ‘feelings of drowsiness’[3] ie. they assumed that drowsiness is part of fatigue. Alternatively, some prominent researchers have suggested that fatigue is a state resulting specifically from sleep deprivation, poor quality sleep, or sleep at times of circadian rhythm dysregulation.[4] Others say that fatigue is simply the state of reduced ‘alertness’, whatever its cause. Others again imply that fatigue is that which causes impairment of performance over time, which seems to involve a circular argument. There has been very little discussion about these different definitions. This is not unique to Australia.[5] Nor is it unique to the mining industry.

After reviewing the published literature and having personal discussions with many researchers around the world, it appears to the present author that most of them assume they know what fatigue is and how it relates to impaired performance. However, they often seem to be talking about different things without recognizing that other people do not share their ideas and assumptions, couched almost exclusively in terms of fatigue. Some have expressed the opinion that if we used an alternative word such as drowsiness, which may be more accurate and appropriate in relation to road safety, the general public would be unnecessarily confused. A cynic might conclude that the word fatigue belongs to the world of Alice in Wonderland, where words mean what we want them to mean. Does this matter? It would seem sensible to want to understand the nature of this problem and how to measure it if we are to manage its risks. Of course, such discussions have far wider implications than for the mining industry alone, including all industries in which impaired human performance can be of critical importance.

This report highlights the confused state of thinking about this problem, especially as it relates to the risks of drowsy driving at mine-sites. We shall try to clarify the nature of the problem by examining the different definitions of the terms used and the conceptual framework from which they emerged, and placing a new emphasis on the state of drowsiness rather than fatigue. Finally, a new method for detecting and measuring drowsiness in drivers is described briefly. This is already helping to address the problem of drowsy driving at mine-sites.

Definitions of fatigue, tiredness, drowsiness and sleepiness

A good starting point for us to clarify the nature of this problem is to consult English Dictionaries, rather than individual researchers, about commonly accepted definitions of the relevant words. According to the Oxford English Dictionary (OED), the noun fatigue means ‘weariness resulting from bodily or mental exertion’. The adjective, tired, is a synonym for being ‘fatigued or weary’. Another dictionary defines fatigue in one sense as ‘temporary loss of strength and energy from hard physical or mental work, and in another sense (when used in conjunction with a modifier) as ‘boredom resulting from overexposure to something' eg battle fatigue, in which there is reduced responsiveness to a stimulus or situation as a result of repeated or prolonged exposure. By contrast, the long-established meaning of the word drowsiness is quite different. The OED defines the adjective drowsy as 'inclined to sleep, heavy with sleepiness, half asleep'. Thus, drowsiness is the intermediate state between alert wakefulness and sleep.

There is no ambiguity in the difference between the common English meanings of these words – fatigue (of which tiredness is a synonym) refers to a quite different state from that of drowsiness (of which sleepiness is a synonym). Consistent with the common usage of these words, people who run marathons say they feel fatigue as the race progresses and for some time afterwards. Yet there is no evidence that they are drowsy or fall asleep soon after they cross the finishing line. As we shall see, one can be very fatigued (in this case with muscular fatigue) without being drowsy. At other times, we may be drowsy without being fatigued and, at other times again, both fatigued and drowsy at the same time.

In the second half of the 20th century applied psychologists began to use the word fatigue in another way. For example, in 1953, Bartlett, who was very influential in this field, defined fatigue as a process (not a state) involving 'those terminable changes in the expression of an activity which can be traced to the continued exercise of that activity'.[6] In other words, fatigue was the process causing progressive impairment of performance during a continuing task, whether physical or mental. How that impairment could be measured would depend on the nature of the task, varying from the progressive weakness of repeated muscle contractions to slowing of cognitive processes in prolonged reaction-time tests. Many people refer to this as the ‘time-on-task- effect’.

There is no doubt that such effects exist, although their mechanisms of causation are not well understood. However, there is a problem if one assumes that fatigue, in the sense of a ‘time-on-task’ effect or in any other sense, is the only reason for changes in performance to occur over time. In particular we cannot assume that, if there are changes in performance of a task over time, they must have been caused by fatigue. Falling asleep, or having one’s brain affected by alcohol or other sedative drugs, or being distracted by extraneous influences, also affects the ability to maintain appropriately focused attention and, consequently, the ability to perform a task such as driving. To confuse matters further, some researchers believe that mental fatigue is quite different from muscular fatigue, presumably because it involves different mechanisms that are less well understood.

The driving task

Driving any road vehicle involves a continuously integrated series of actions based on a variety of sensory inputs. The steering wheel must be turned intermittently to keep the vehicle on track and the accelerator must be depressed so the vehicle moves at an appropriate speed, etc. In a large experiment in the USA, 100 drivers were monitored by video cameras for a year while they drove as part of their daily lives.[7] It was found that if they did not look at the road ahead, and hence did not pay visual attention to the driving task, for more than about two seconds at a time, the risk of a crash increased dramatically. About 40% of their actual crashes and near-misses were attributed to the driver being drowsy or falling asleep at the wheel. Another 40% were due to them looking elsewhere or doing other things, ie. they were distracted from the driving task.

The maintenance of appropriately focused visual attention is essential for safe driving. A major distinction must be drawn between the failure of visual attention while driving, on the one hand, because the eyes are closed as part of the drowsy state or being asleep and, on the other hand, because of failure to maintain appropriately focused visual attention because of distraction. In the former there is loss of visual attention involuntarily, whereas in the latter visual attention remains largely under voluntary control, with the eyes open, but with the focus of that attention misdirected away from the driving task because of distraction. Both conditions, drowsiness and distraction, can have catastrophic consequences while driving. We shall be concerned here mainly with the former.

Differences between fatigue and drowsiness

Without going into details of experimental evidence, research from several quarters has shown that fatigue and drowsiness are different, objectively and subjectively.[8,9] There are several physiological changes that are more or less specific to the drowsy state and which are not a feature of fatigue.[10,11] For example, drowsiness is associated with slow rolling eye movements (SEMs), each lasting 1 - 5 sec, that are poorly coordinated between the two eyes. The drowsy person is seldom aware of these SEMs, but may complain of blurred vision. The SEMs begin before the onset of actual sleep, but after the level of drowsiness has reached a point when there is lack of awareness, usually after the eyes have closed but sometimes while they are still open. The SEMs cease once sleep is established.

Drowsiness also involves changes in the body's system of thermoregulation, including the state of contraction and relaxation of blood vessels in the skin. The temperature of the skin, particularly of the hands and feet, increases with drowsiness because the arterioles in the skin dilate. This facilitates heat-loss which enables the core body temperature to fall as part of the sleep onset process. As the skin temperature rises with progression of the drowsy state, the sweat glands that are also involved in thermoregulation (which is most of them) secrete more sweat. However, the particular sweat glands on the palms of the hands and soles of the feet are actively inhibited then by the brain. The resulting pattern of sweating, which is increased over most of the body at a time when the core temperature is falling, but reduced on the palms and soles, is characteristic of drowsiness, not of fatigue.[11]

In addition, drowsiness fluctuates between different levels over periods of seconds, whereas fatigue is usually more slowly progressive over time. Drowsiness is also associated with perceptual and cognitive impairment due to active inhibition by the brain, which causes periods of lack of awareness of the here-and-now. Vision is inhibited intermittently, not only because the eyelids are closed when the muscles that normally keep them open are actively inhibited by the drowsy brain, but also because vision is inhibited centrally, even when the eyes are still open. That does not happen because of fatigue alone.[12] The more physically and mentally active people are, the more quickly they become fatigued, but the less likely they are to become drowsy at the time. Conversely, their fatigue is relieved by rest and inactivity, but that inactivity makes it more likely they will become drowsy at the time. This is perhaps the most easily understood of the many differences between drowsiness and fatigue.

Sleep researchers often use the word sleepiness instead of drowsiness because the two words are synonymous in their common usage. However, over the past thirty years or so, sleep researchers have also adopted another meaning of the word sleepiness, and that is sleep propensity – how likely a person is under particular circumstances to make the transition from alert wakefulness to the state of drowsiness, and then to sleep.[13] Having two different meanings of the word sleepiness has further confused the issue. The present author has been heavily involved in the measurement of sleepiness, in the sense of sleep propensity, by developing the Epworth Sleepiness Scale which is now a world standard for measuring a person's average sleep propensity in daily life.[9,13] In the present context, however, it seems preferable to use the word drowsiness, with its unique and commonly understood meaning, rather than sleepiness, which now has more than one meaning.

In summary, drowsiness is a unique behavioural state that is an essential part of the daily rhythm of sleep and wakefulness. Drowsiness is dangerous only when it occurs at inappropriate times such as when driving, when its consequences can be life-threatening. Fatigue is different, even though that distinction is not commonly understood.

The drowsiness of drivers

When drivers on Australian highways see an official road sign which says that ‘fatigue kills’, they could be forgiven for thinking that it refers to the feelings of weariness they experience after prolonged exertion, including driving for several hours without a break. In fact, there is little evidence to suggest that fatigue, by itself, kills people. Similarly, there is little evidence to suggest that fatigue causes drowsiness. So where does this confusion come from? It was fuelled in 1994 by a prominent “fatigue” researcher in the UK, I D Brown, who claimed that sleep was the end result of fatigue. [2] He did not provide evidence to support that conclusion. However, it seems unlikely that he considered evidence from another academic discipline, the physiology of sleep and wakefulness, which leads to a different conclusion (above). Many people have evidently agreed with Brown’s idea which, in the opinion of the present writer, is based on a misunderstanding.

The differences between fatigue and drowsiness have received much less attention than they deserve, for they are critically important for our understanding of the broader issues associated with impaired human performance in industry. For example, it may be that current regulations about hours of work actually address the problem of fatigue more than the likelihood of a driver becoming drowsy or falling asleep at the wheel under particular circumstances.

Measuring drowsiness

There are questionnaires for measuring different levels of sleepiness (in the sense of drowsiness) at a particular time, such as the Karolinska Sleepiness Scale (KSS).[14] Respondents are asked to choose which one of nine descriptors, numbered 1-9, best describes how alert or drowsy they have been feeling over the preceding few minutes (eg 3 = ‘ alert’ and 7=’sleepy, but no difficulty remaining awake’). KSS scores have been shown to be valid but often not very accurate, especially when making comparisons between different people. Such reports are not objective and are open to all kinds of misreporting, whether intentional or not. [9]

In recent years a new method has been introduced for measuring alertness/drowsiness objectively and continuously, based on measurements of the neuromuscular function of muscles in the eyelids during their reflex-controlled movements with each blink.[15] A special pair of glasses (Optalert), worn like any other pair of sunglasses, incorporates tiny sensors that enable many different characteristics of those movements to be measured while driving (Fig 2).

Fig 2. Optalert glasses, with and without their sunglasses attachment

A unique ten-point scale of drowsiness has also been developed, the Johns Drowsiness Scale (JDS), with 0= “very alert” and 10 = “very drowsy”.[16] It is based on a weighted combination of several variables, particularly the velocities with which the eyelids close and reopen during blinks, which are very sensitive to the person’s level of alertness/ drowsiness at the time. A JDS score is calculated each minute. Those scores have been calibrated against the relative risk of failure in the performance of various tasks. This is illustrated in Fig 3, from an experiment in which 15 volunteers drove for 70 minutes in a high-fidelity simulator on two separate occasions, when alert after a normal night’s sleep and again when sleep deprived, having missed a night’s sleep. Their risk of driving with all four wheels out of the lane increased progressively as their JDS scores at the time increased, especially above 5. In other experiments involving different tasks and different people, the risk of “performance failure” was very similar in its relationship to JDS scores.

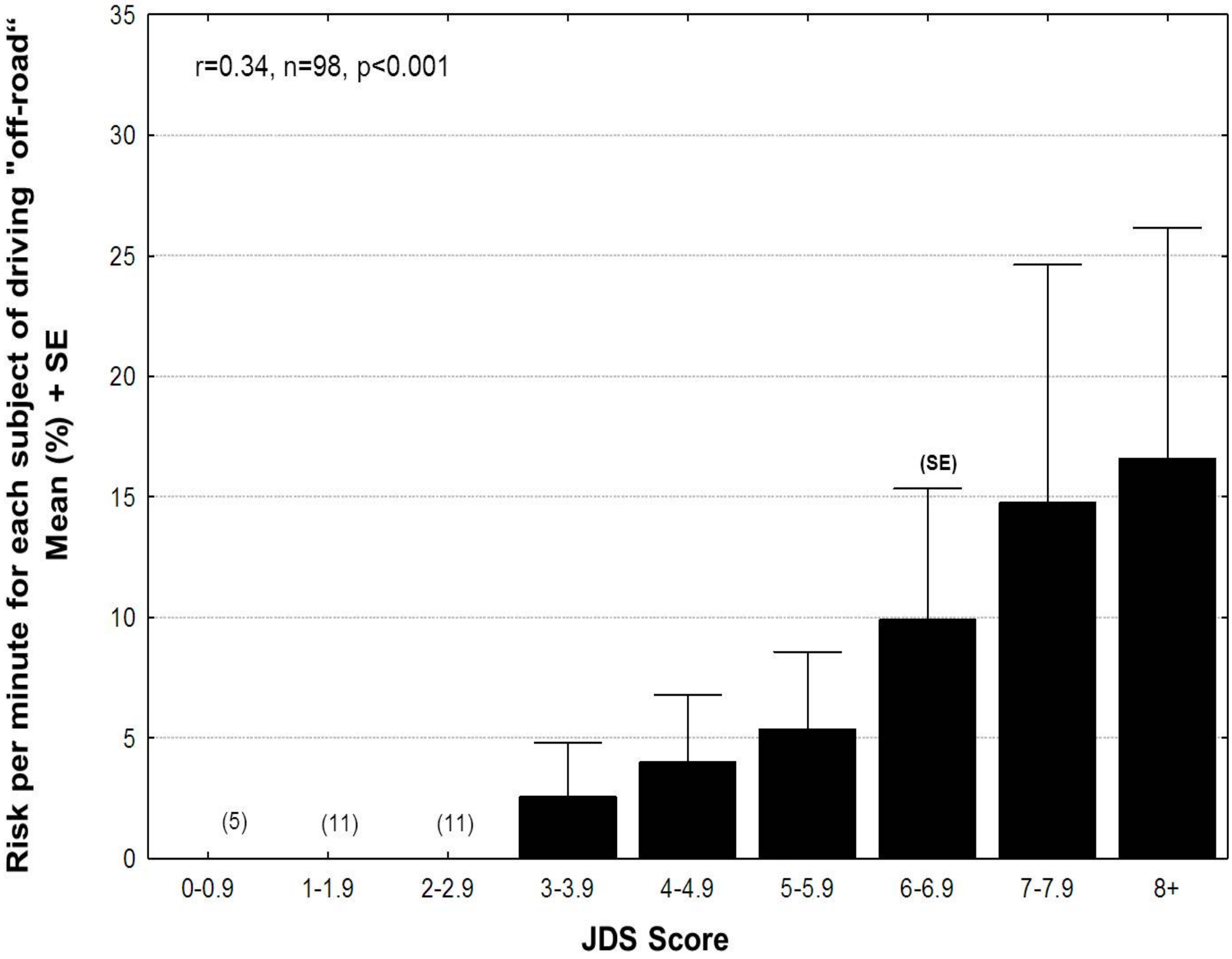

Fig 3. The mean risk (and its standard error) for 15 volunteers of driving with all four wheels out of the lane in a simulator, in relation to their JDS scores at the time, with and without overnight sleep deprivation.

In real-life situations, Optalert drivers see their own JDS scores displayed on the dash-board, updated each minute. Those scores are also be transmitted wirelessly to others, wherever they may be, to make decisions about driving safety in real-time or when reviewed later in terms of particular drivers or work periods. Auditory warnings are given to drivers, first at a medium level of risk, with JDS scores between 4.5 and 4.9, and again at high risk levels with scores of 5 and above. At this point the risk of "performance failure" is several times higher than for an alert driver, equivalent to the risk of crashing when drunk (blood alcohol >0.05%), at which point the driver is considered too drowsy to drive.

Optalert in haul trucks at mine-sites

As an illustration of how Optalert is currently being used at mine-sites, consider the JDS scores recorded from 56 drivers, and the drowsiness warnings given to them, while working on a roster of 12-hour day and night shifts over several months at an Australian mine-site. This involved a total of 4520 hours of recordings (Fig 4). [17]

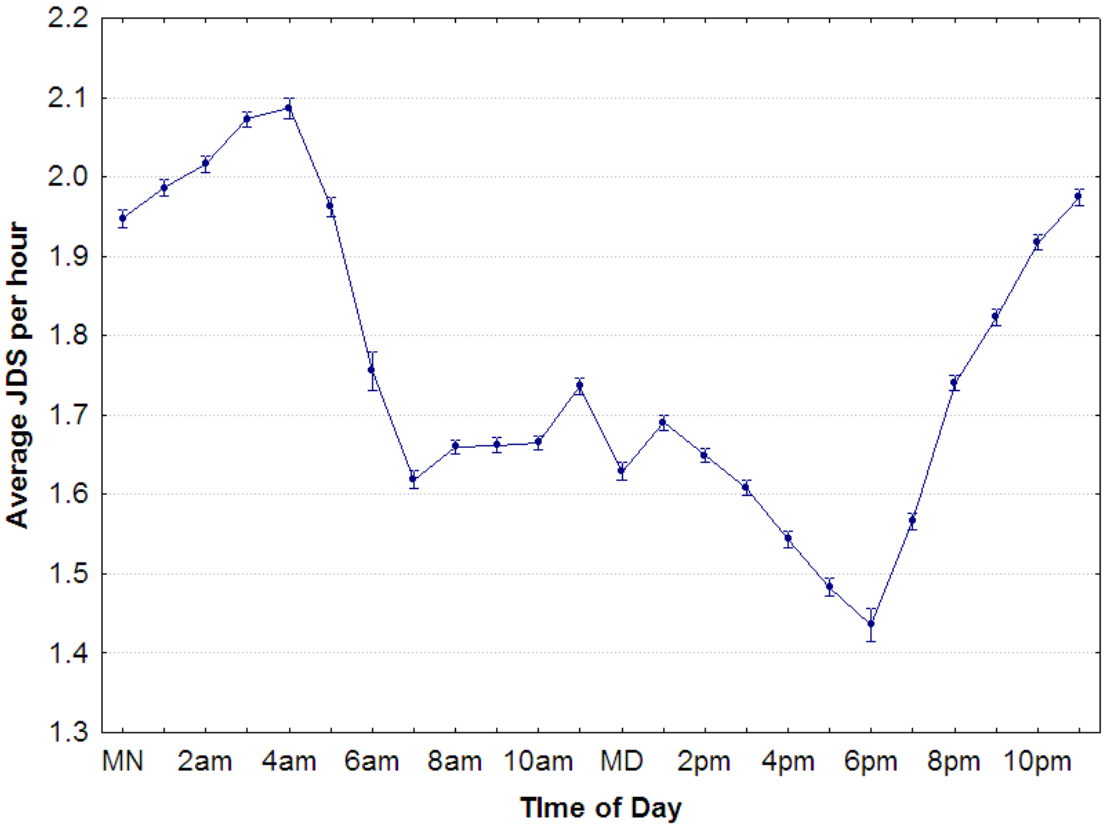

Fig 4. The mean (+/- standard error) of JDS scores recorded from 56 haul truck drivers during night and day shifts for a total of 4520 hours.

During the day-shift, from 6 am to 6 pm, mean JDS scores were higher at the beginning than the end of the shift. This is the opposite of what we would have expected if we had been measuring fatigue and the time-on-task effect. Mean drowsiness scores were higher during the night than the day and there was an obvious circadian rhythm, with a maximum at 4 am and minimum at 6 pm. This presumably reflected the circadian rhythm of core body temperature, as expected, but that was not measured here.

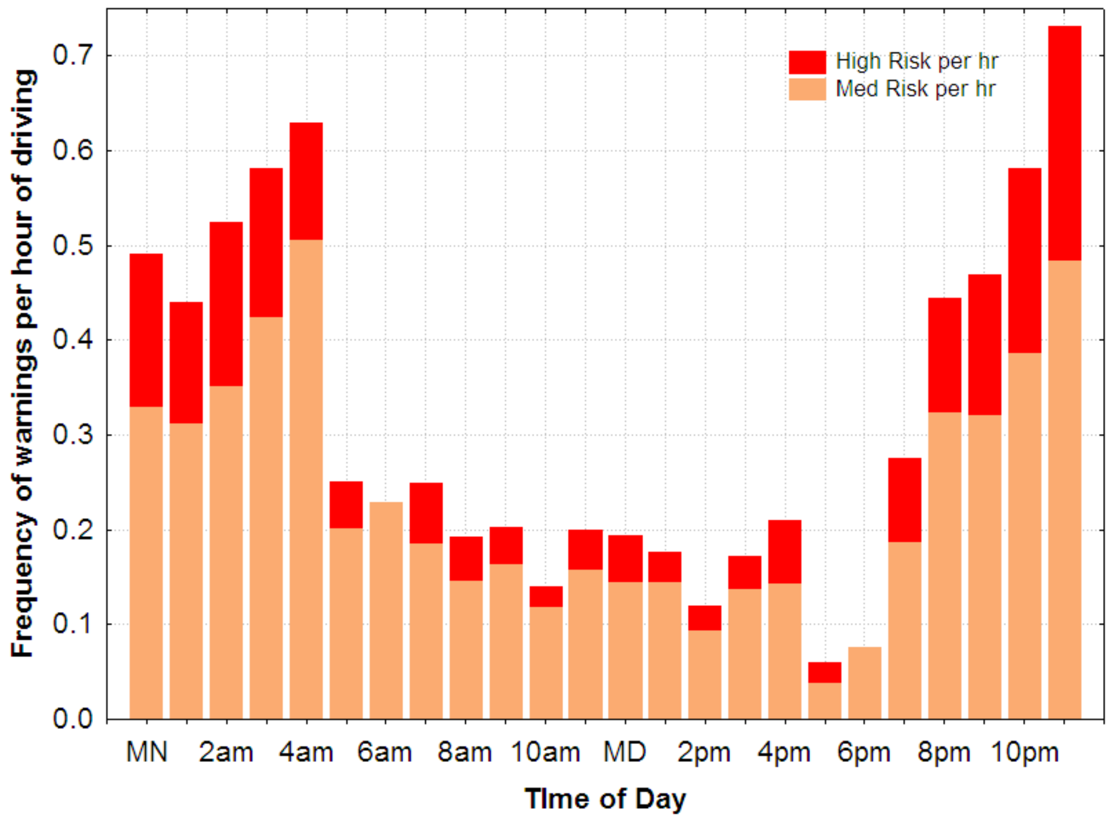

Fig 5. The frequency of Optalert warnings (medium and high risk) per hour of driving issued to the same 56 haul truck drivers working 12-hour day and night shifts as in Fig 4.

The frequency of Optalert warnings per hour of driving are shown for each hour of the day in Fig 5. Warnings were more frequent during the night than the day. There was a circadian variation in the frequency of warnings which generally followed that of the mean JDS scores, although there were two separate peaks, at midnight and 4am. Individual drivers often showed a decrease in their JDS scores immediately after they received a warning, suggesting that they changed their posture or behaviour in some way as a result. It has been shown experimentally in drowsy people that, even after a minor changes of posture or engaging in a brief conversation, JDS scores often decrease for at least a few minutes At the mine-site in question, a single warning was sufficient in the majority of cases to enable drivers to continue driving at a low risk level. If not, the next step was to take a break from driving and have some coffee and/or a brief power-nap.

The fact that drivers had an objective measure of their own alertness available to them continuously, and were able to observe changes over time, seemed to help them manage their own alertness/drowsiness. There were no incidents or accidents reported during that time. The pattern of drowsiness warnings across the 24 hours was consistent with that for the occurrence of fatal haul truck accidents reported from other mine-sites around the world where Optalert was not used.[18]

Conclusions

The experimental evidence indicates that drowsiness and fatigue are not the same. Drowsiness can occur with or without fatigue at the same time. It is important that we understand the difference because drowsiness is more dangerous than fatigue for drivers, and needs to be managed differently. We can now measure the alertness/drowsiness of drivers continuously on a scale that is calibrated in terms of their risk of "performance failure" (crash-risk). This provides a new way of managing the risks of drowsy driving at mine-sites and elsewhere. However, we need more research and more discussions among the broad range of people involved in these matters, especially researchers and regulators, for they must accept much of the responsibility for the current state of confusion. Finally we need better-informed public education about drowsy driving, directed at drivers and employers.

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