A NEW METHOD FOR MONITORING THE DROWSINESS OF DRIVERS

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ABSTRACT

Drowsiness is the intermediate, fluctuating state between alert wakefulness and sleep. It is implicated in many road accidents, but there is no generally accepted method for monitoring drowsiness objectively while driving. **Objective**: to describe a new method for monitoring the drowsiness of drivers continuously (Optalert™) using a new scale of drowsiness (The Johns Drowsiness Index or JDI). **Methods**: eye and eyelid movements were monitored by an infrared reflectance method using transducers housed in a light frame, such as would be worn with prescription lenses or sunglasses. The JDI (range 0-10) is based on a combination of variables characterizing eyelid movements during blinks, particularly the ratios of amplitude to maximum velocity (AVR) of eyelid closure and reopening. These are newly described patented variables that do not require individual calibration. Optalert™ recordings were made while 8 volunteers drove in a simulator for 45 min when alert and after sleep deprivation for up to 30 hr. Other recordings were made in commercial truck drivers, driving their usual routes and schedules at work. **Results**: In alert drivers, driving without incident, the JDI varied between about 0.5 and 4.0. Driving was impaired after sleep deprivation, and there were 61 drive-off-the-road “crashes” in the simulator, all of which could have been preempted with a warning when the JDI reached 4.5, particularly >5.0. A truck driver was also recorded on the road with a JDI >5 when he reportedly fell asleep at the wheel without crashing. **Conclusion**: trials in a driving simulator and with trucks on the road have shown that Optalert™ can monitor the drowsiness of drivers continuously and could potentially prevent crashes by prompting drivers to implement a drowsiness management strategy before they fall asleep at the wheel and crash.

Keywords: Drowsiness, velocity of eyelid movements, blinks

INTRODUCTION

Drowsiness is the intermediate state between alert wakefulness and sleep that usually lasts only a few minutes when we are falling asleep intentionally, but which can last much longer when we are struggling to stay awake, as for example when driving. Drowsiness is a fluctuating state of reduced awareness and impaired performance, to be distinguished from fatigue, although many people fail to make that distinction. Drowsiness is believed to be a major factor in about 20 per cent of road crashes *(1)*, but that may be an underestimate because there is currently no method for measuring the drowsiness of drivers objectively and continuously.

Several methods have been used for monitoring sleep and wakefulness in patients or volunteers in sleep laboratories. Those methods include monitoring the electroencephalogram (EEG), electrooculogram (EOG), and electromyogram (EMG). However, the need for electrode attachments makes these methods inappropriate for monitoring drivers routinely. In addition, when such methods have been used for research in drivers, they have not detected drowsiness very well *(2)*. In recent years, video-camera methods have been advocated, particularly PERCLOS *(3)* which gives an overall measure of eyelid closure, and presumably sleep onset, based on the proportion of time that the pupils are at least 80% covered by the eyelids over a few minutes.

Despite their early promise in laboratory experiments, video camera methods have problems. They have difficulty capturing images reliably when the environmental light conditions are highly variable, as when driving in sunlight with shadows, or when prescription glasses or sunglasses are worn. In addition, video-camera methods are based on false assumptions. In the drowsy state, failure in the performance of a visual task is caused not only by eyelid closure that blocks vision, but also intermittently when the eyelids are open, by a process of visual suppression or neglect *(4)*. In addition, the dangers of drowsy driving probably begin before involuntary long eyelid closures occur (lasting >500 msec), which video-camera methods depend on for their measurement.

Sleep Diagnostics Pty Ltd, Melbourne, Australia, has developed and patented a new method (Optalert™) that uses infrared oculography for monitoring the drowsiness of drivers continuously. This method has led to the recognition of new parameters of drowsiness, particularly the relative velocity of eyelid movements, derived from ratios of the amplitude and maximum velocity of blinks *(5,6)*. A new scale for measuring drowsiness, the Johns Drowsiness Index (JDI), has been developed and validated, as will be outlined here. It is based on a combination of many variables that characterize the duration and velocity of different components of eyelid movement during blinks.

METHODS

The Optalert™ System of Infrared Oculography

Optalert™ uses pulses of invisible infrared light from an LED positioned below and in front of the eye, housed in a frame such as would be used to hold prescription lenses, if needed (Fig.1). The IR pulses, which are brief (< 100 microsec) and repeated at a frequency of 500 Hz, are directed at the eyelid. The total IR light reflected back from the eye and eyelid is detected by a phototransistor beside the LED. The level of environmental IR light detected immediately before each pulse is subtracted from the combined level during the pulse, thereby removing the unwanted effect of environmental light, even when it is varying over a millisec. The height of each such pulse is directly related to the position of the eye and eyelids in relation to the IR transducers. This method for monitoring eye and eyelid movements is a modification of that described by Leder et al *(7)*, and different from the more widely used scleral reflection method of Torok et al *(8)*.

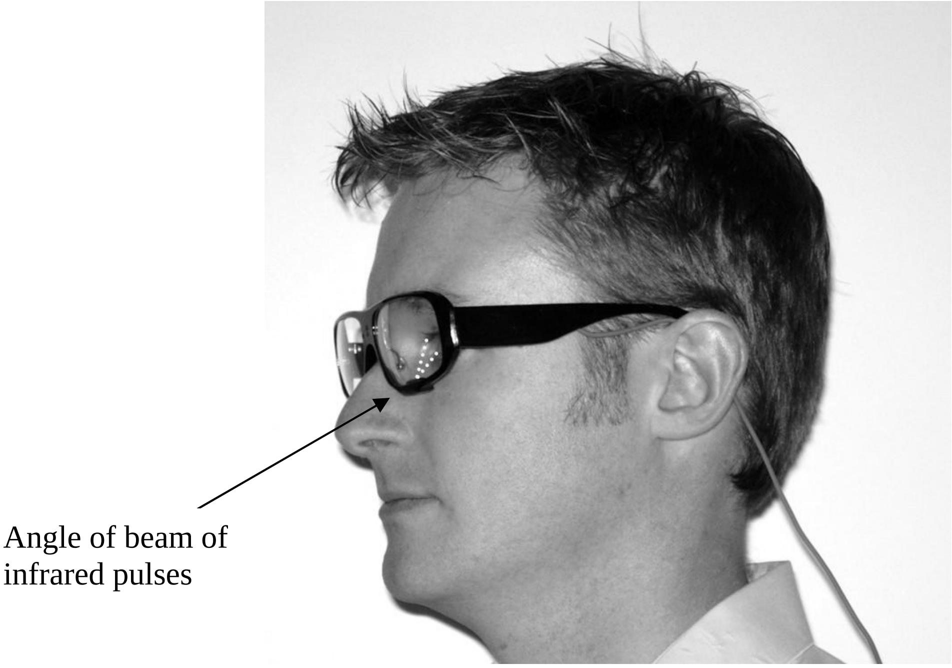

Fig. 1. The Optalert™ system of infrared oculography

A microprocessor, housed in the arm of the glasses, controls the timing and other characteristics of the IR pulses, and digitizes the analogue output from the sensors. The power supply and the serial output from the glasses is via a light cable connected to a processing unit that can be either a bench-top unit for laboratory experiments, or one that is installed in a vehicle for use while driving. This unit provides a variety of different analyses of the recorded signals (reflecting position, and the velocity of movements) and generates the JDI automatically, online or offline.

Johns *(5)* was the first to describe the ratio of the amplitude to the maximum velocity of eyelid movements during blinks to provide a measure of their relative velocity without the need for calibration in absolute terms of either their amplitude or velocity. Initially, this amplitude-velocity ratio (AVR) was based on velocities calculated as the maximum change in position of the upper eyelid per 10 msec *(5)*, but this has been changed to 50 msec to better reflect slow eyelid movements in drowsiness *(6)*.

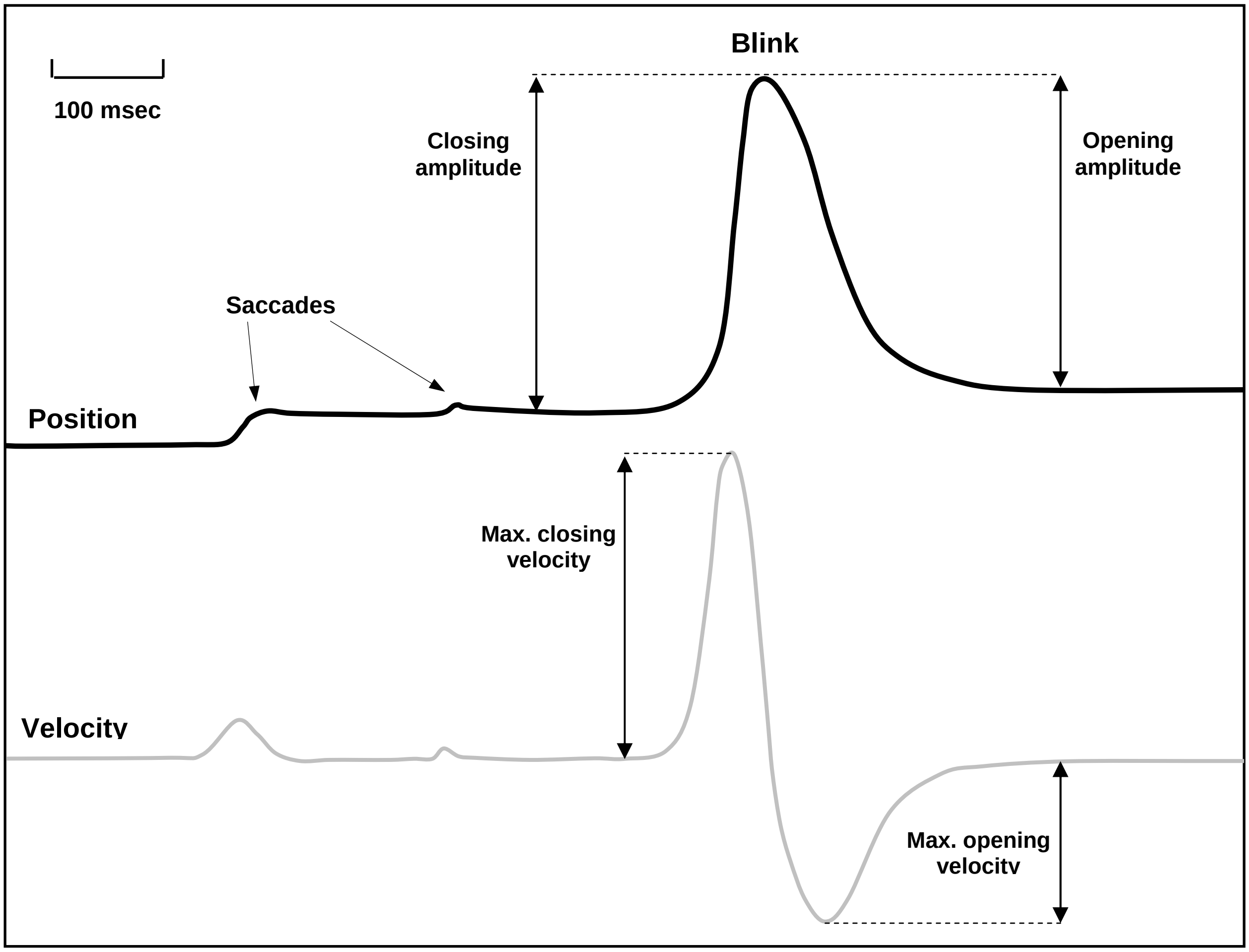

Fig 2. Optalert recording in an alert subject**.** On the vertical axis, position is in arbitrary units (A), and velocity is the change in A per 50 millisec.

Optalert™ recordings (Fig.2) are very similar to the EOG when recorded in the DC mode (not the usual AC mode used in most experiments), but without the unwanted EEG, ocular EMG, and electrode-movement artifacts that are usually present in the EOG of active people. There are two digitized signals from each phototransistor in the frame; the first representing the position of the eye and eyelids, and the second, the velocity of any movement, (the change in position per 50 millisec), calculated 500 times per sec. The durations of eyelid closure, of eyelids remaining closed and of reopening are calculated separately and automatically for each blink, as are the AVRs for eyelid closure and opening.

In summary, Optalert™ uses a “glasses” frame, much the same as would be worn with prescription lenses or sunglasses. Embedded IR transducers enable accurate measurements of eye and eyelid movements to be made. There is no interference with vision and no health risk. The method is not influenced by skin, eye colour or contact lenses.

We have shown previously that the duration of each component of blinks (eyelids closing, remaining closed and reopening) increases with drowsiness *(9)*. However, the correlations between these durations within the same blinks are quite low and not always statistically significant (Spearman's r= -0.11 to 0.30, n= 133). The same is true for the relative velocities of eyelid closure and reopening, measured by the respective AVRs *(6)*. This indicates that the reflex processes that control those movements are partially independent. Drowsiness appears, on the one hand, to loosen the usually tight controls within each such process and, on the other hand, to loosen the relationships between those different processes. Thus, it is important that we do not rely on any one variable alone, such as the duration of eyelid closure, as the sole measure of drowsiness.

The Johns Drowsiness Index

The JDI is a composite measure of drowsiness based on many variables characterizing blinks, including the AVRs for closing and reopening of the eyelids, as well as the duration of eyelids closing, of remaining closed, and of reopening during blinks. The weighting for each variable in the JDI was derived from multiple regression analysis, comparing results of Optalert™ recordings before and after sleep deprivation for 24- 40 hr in otherwise normal subjects. The JDI is calculated each minute on a scale of 0-10. Normal values are 0-4, which do not require adjustment for individual subjects.

Recordings of eye and eyelid movements while driving show a variety of movements, in addition to saccades and blinks which would otherwise predominate when sitting and doing a computer-based performance test. When driving, there are also frequent vestibulo-ocular and smooth pursuit movements because the vehicle is moving horizontally and vertically and because there may be voluntary head movements, all of which require reflex-controlled, corrective eye movements to maintain fixation. These movements do not obey the same laws of amplitude and velocity that apply to blinks and saccades, so they must be distinguished by Optalert™ software, before the JDI is calculated.

The Johns Test of Vigilance (JTV) was developed specifically for recording eye and eyelid movements during the performance of a simple reaction-time test, which was used for the validation of the JDI. The subject pushes a button, held in the dominant hand, as quickly as possible after a visual stimulus is presented, which is a change of shapes lasting 400 millisec and appearing at random intervals between 5 and 15 sec on a computer screen. The reaction time is measured automatically with an accuracy of 1 millisec. The JTV usually runs for 10-15 min, involving about 60-90 stimuli.

The JDI has been validated against changes in the performance of the JTV as a result of sleep deprivation that causes drowsiness to differing degrees in different subjects. The mean JDIs during JTVs in alert and sleep-deprived subjects were highly correlated with their mean reaction times, for responses made within 500 msec (Spearman's r= 0.70, n= 97 in 31 Ss, p<0.0001), and also with the percentage of lapses (no response or delayed >.500 msec) (Spearman's r = 0.77, n=55 in 35 Ss, p<0.0001). In other volunteer subjects, mean JDIs during JTVs were significantly related to blood alcohol concentrations, from zero to 0.15 mg% (ANOVA, p<0.0001) (Johns, MW, Tucker, AJ, & Chapman, RJ, 2005; unpublished results).

Driving with Optalert

Recordings were made with Optalert™ while 8 healthy volunteers each drove for 45 min in an advanced, moving-car simulator at Monash University Accident Research Centre, Melbourne. Some recordings were made when subjects were alert, others when they had been sleep deprived for periods ranging from a few hr to 34hr in different subjects. The 180 degree forward view from the car was of a two-lane country road at night with curves and inclines, but with no other vehicles and no traffic lights or stops. Subjects were instructed to stay in the one lane, even when there were occasional extra "passing lanes". Their driving performance was assessed by the maximum deviation of the vehicle to the right and left from the centre of the lane, per minute of driving. "Off-road" events were defined as minutes of the recording when all 4 wheels of the car were outside the lane which was 3.35 m wide.

In another experiment, commercial truck drivers volunteered to use Optalert™ while driving their usual routes and schedules for periods which varied from a few days to a few months. The JDI was calculated automatically for each minute of those driving sessions. However, at this stage of our developments, drivers were simply being recorded by Optalert™ and were not alerted by auditory stimuli at particular "critical" JDIs, as intended later.

RESULTS

Driving in a Simulator

Fig. 3 shows a typical example of the results from one driver when alert and driving in the simulator for 45 min. His JDI and the maximum deviation to the left and right from the centre of the lane were calculated each min. The JDI remained normal (<4) throughout, and there were no “off-road” events.

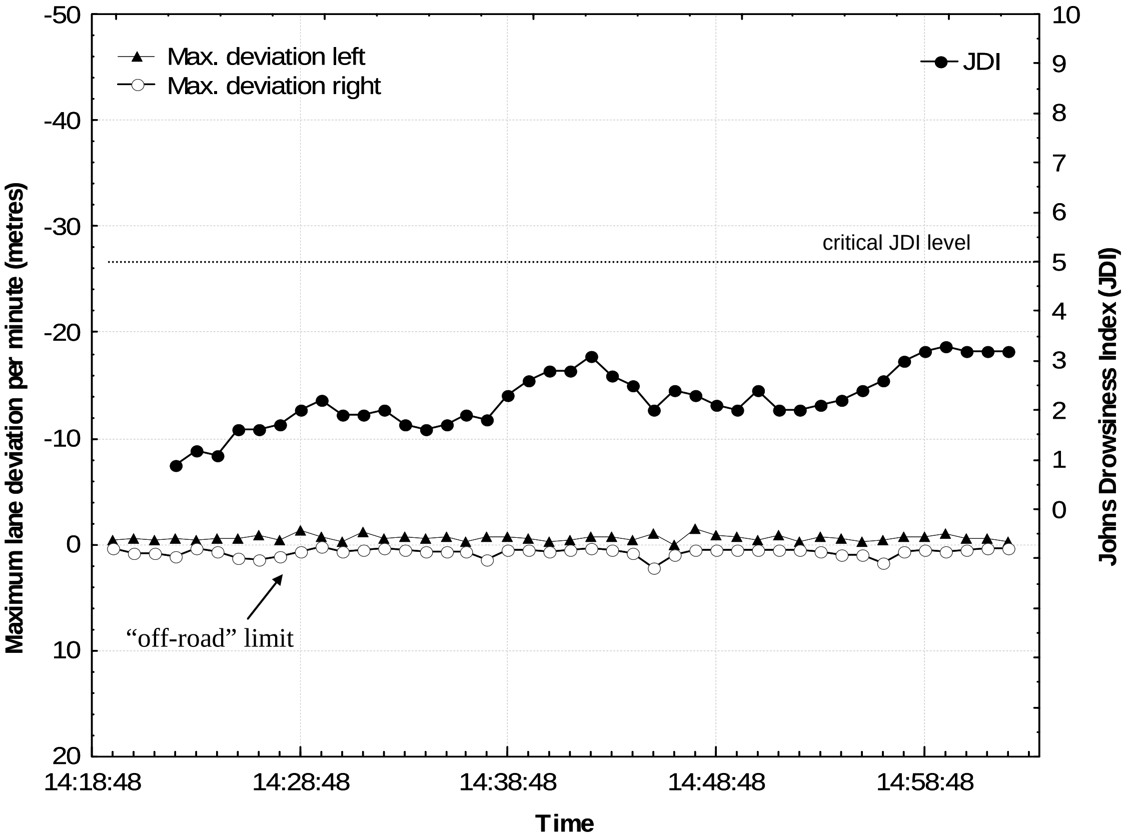

Fig. 3. The JDI and the maximum lane departure to the left and right (per minute) for an alert subject driving in a simulator. The grey band is the “off-road” limit

After going without sleep for another 24 hr, this subject began driving again fairly normally (Fig. 4). However, he then drove off the road several times, to both right and left sides. Initially, his JDI was <4, and this decreased for a few min, presumably with the stimulus of the task. It then increased progressively, reaching 4.5 after 13 min, at which point we would have given a level-1 warning that drowsiness was beginning. The JDI increased above 5.0 after 14 min, when a level-2 warning would have prompted the driver to stop driving as soon as it was safe to do so.

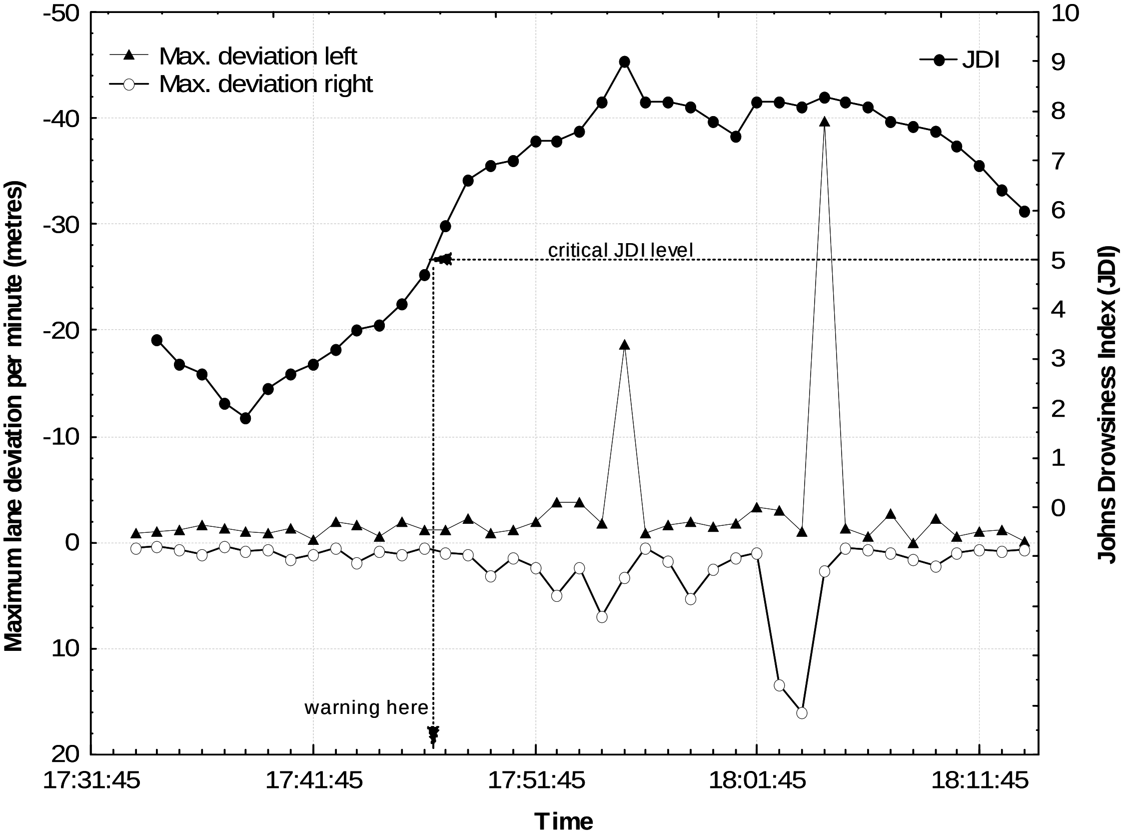

Fig. 4. The JDI and the maximum lane departure to the left and right (per minute) for a sleep deprived subject driving in a simulator. The grey band is the “off-road” limit.

The important point is that, with these warnings, all his “off-road” events would have been preempted by several min. That was also true for all 61 such events in the whole group of 8 drivers in that experiment.

Commercial Truck Drivers on the Road

Fig.5 shows typical JDIs measured over a one hour period in a commercial truck driver who was one of several who volunteered to use Optalert™ while driving his usual routes and schedules. When ostensibly alert, this driver's JDI was <4 and did not change much during this and other driving sessions. Similar JDIs were recorded in other drivers when alert, none of whom found Optalert™ inconvenient or intrusive when driving.

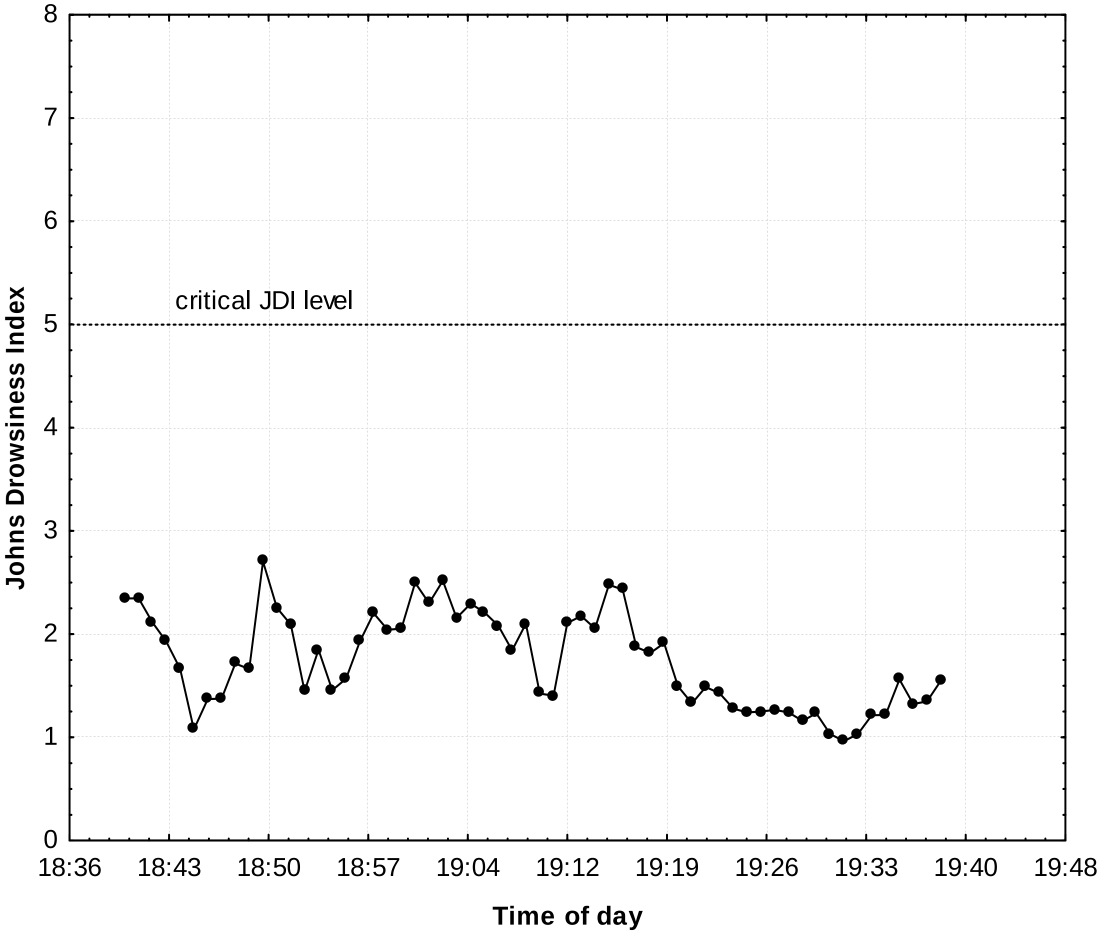

Fig 5. Johns Drowsiness Index (JDI) of a truck driver, measured every minute when alert and driving for about an hour

Two weeks later, when driving between 22:30 and 01:10, this driver pushed a button, provided for the purpose, to indicate that he was drowsy (Fig.7). But he did this only after he “woke up” and found himself driving on the wrong side of the road. By good luck, there was no on-coming traffic and no curve in the road to be negotiated at the time, so no crash occurred. The driver began this session with normal JDIs (<4) which soon increased to >5. By this measure, he was dangerously drowsy and at risk of a crash long before he pushed the button to notify that he was aware of being drowsy. This episode would have been prevented by an Optalert™ warning approximately 50 min earlier, at 23:24.

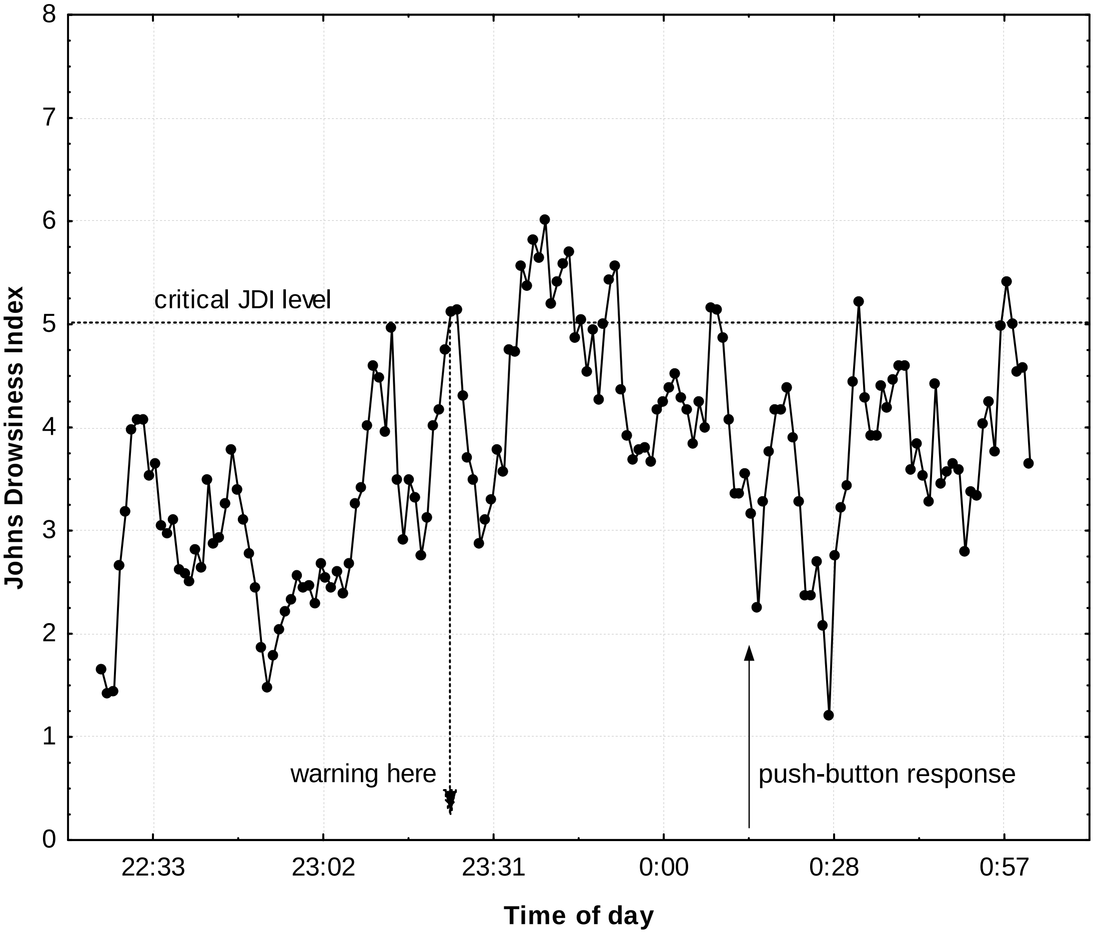

Fig. 7. Johns Drowsiness Index (JDI) of the same truck driver as in Fig 5 when drowsy. The push-button response was when he “woke up”, driving on the wrong side of the road, when he first indicated that he felt drowsy

DISCUSSION

Optalert™ uses a weighted combination of several variables to measure drowsiness that have not been used previously, particularly the relative velocity of upper eyelid closing and opening movements, as assessed by their amplitude-velocity ratios (AVRs). Optalert™ does not depend simply on detecting long eyelid closures as the measure of drowsiness, as used with video camera methods *(3)*.The AVRs in this investigation were similar in different subjects when alert, and did not require individual calibration, confirming an earlier report *(5)*.

We have previously shown that AVRs for eyelid closure and reopening, as well as the durations of the different components of blinks, change with drowsiness *(6,9)*.Those changes reflect the impairment of vigilance, as manifested by longer reaction times and more frequent lapses in a 10-15 min psychomotor vigilance test (JTV) .The JDI promises to be the first calibrated measure of drowsiness that is widely applicable.

Optalert™ has been used by truck drivers for many hours per day and for many weeks, without inconvenience or interference with their driving. Because Optalert™ removes the effects of environmental light, it works equally well in daylight or darkness. The IR transducers are close to the eyes and move with the subject's head, so there is no loss of signal because of head movements or hand movements in front of the face, as can occur with video-camera methods.

The example of a potentially serious drowsy episode in a driver who did not push the button that was provided to indicate he was drowsy until after he roused and found himself driving on the wrong side of the road raises an important issue. In the drowsy state, people intermittently lose awareness of the here-and-now, and also lose the capacity to make decisions, even in relation to their own safety. This highlights the importance of having a validated monitoring device such as Optalert™ that would save lives by warning drivers when they were becoming drowsy, before they lost awareness and control, and had a drowsy crash.

Not all episodes of drowsiness cause a crash. This was demonstrated previously in a large US-Canadian study of truck drivers in which some drivers had frequent episodes of what appeared to be drowsiness, as detected by video-cameras, but without a crash *(2)*. Presumably this was because those episodes were brief, and because the driving task was relatively simple at the time and could be accomplished "automatically", without awareness intermittently. That may not be the case when, for example, there is a curve in the road that arises during a micro-sleep lasting as little as 3 or 4 sec. Drowsy crashes typically occur at full speed, often without involving another vehicle, and often by running off the road, with no evasive action to prevent the crash or mitigate its consequences *(10)*.

The question of when someone is too drowsy to drive has not been answered satisfactorily in the past. The answer we propose is when their JDI is >5.0. That is when drivers would frequently fail an essential part of the driving task, which is to maintain vigilance and to make correct psychomotor responses almost continually on the basis of changing visual and other sensory inputs. That is not simply a function of how long they have been awake or driving.

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