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ORIGINALARBEIT

Murray W. Johns
Andrew Tucker
Robert Chapman
Kate Crowley
Natalie Michael

Monitoring eye and eyelid movements by infrared reflectance oculography to measure drowsiness in drivers

Monitoring von Augen- und Augenlid-Bewegungen mit Infrarot-Reflektions-okulographie zur Bestimmung der Schläfrigkeit bei Fahrzeugführern

Zusammenfassung *Fragestellung:* Schläfrigkeit am Steuer ist eine Hauptursache für Autounfälle, sie kann jedoch nicht genau erfasst werden. Es wird ein neues System mit Infrarot (IR) Reflektionsokulographie beschrieben, welches mit Sensoren an einem Brillengestell die Schläfrigkeit des Fahrers kontinuierlich auf einer neuen Skala (IDS) bestimmt. *Methode:* Bei 50 Probanden wurden Augen- und Augenlid-Bewegungen gemessen, während sie Reaktionszeit-Tests im wachen und schläfrigen Zustand durchführten. Auf Parameter, die für Augenbewegungen berechnet wurden, wurde eine multiple Regression angewandt und für jede Minute berechnet. Diese diente der Entwicklung einer neuen Schläfrigkeitsskala (IDS). Wenn im Fahrsimulator von der Straße heruntergefahren wurde, war dies ein Zeichen gefährlichen Fahrens unter Schlafentzug. *Ergebnisse:* Die multiple Regression ergab eine hoch signifikante Vorhersage der Schläfrigkeit (r = 0.70; p < 0.0001). Der mittlere IDS Wert und die mittlere Reaktionszeit korrelierten unter allen Testbedingungen hoch (r = 0.70; n = 88; p < 0.001). Acht schläfrige Fahrzeugführer fuhren insgesamt 62-mal von der Straße, 61 Ereignisse konnten durch einen IDS Wert über 5 erkannt werden. *Schlussfolgerung:* Die Schläfrigkeit des Fahrers kann kontinuierlich mittels IR Reflektionsokulographie zusammen mit der neuen Schläfrigkeitsskala IDS bestimmt werden. Eine individuelle Anpassung des Verfahrens ist ebenso wenig erforderlich wie das Anlegen von Elektroden.

Schlüsselwörter schläfriges Fahren – Augenblinken – Sehschaden – Verkehrsunfälle – Schläfrigkeitsskala

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Summary *Question of the study* Drowsy driving is believed to be a major factor in road crashes, but currently cannot be assessed accurately. A new system of infrared (IR) reflectance oculography is described that uses transducers attached to a glasses frame to measure drivers' drowsiness continuously on a new scale (JDS). Driving in a car simulator was investigated in relation to JDS scores per minute. *Methods* Fifty volunteers had their eye and eyelid movements monitored while performing RT-tests when alert and when drowsy. Multiple regression analysis of ocular variables, measured every minute in alert and drowsy conditions, was used to establish the drowsiness scale (JDS). Driving off the road in the driving simulator was the criterion for dangerous driving by 8 sleep-deprived drivers. *Results* The regression predicting conditions was highly significant (R = 0.70, p < 0.0001). Mean JDS scores and mean RTs in all test

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M.W. Johns · A. Tucker · R. Chapman · K. Crowley · N. Michael
Sleep Diagnostics Pty Ltd.
Melbourne (VIC), Australia

M.W. Johns · A. Tucker · N. Michael
Sensory Neuroscience Laboratory
Swinburne University of Technology
Melbourne (VIC), Australia

K. Crowley
Dept. of Psychology
Melbourne University
Melbourne (VIC), Australia

Dr M.W. Johns (✉)
Suite 9
150 Chestnut Street
Richmond
Melbourne (VIC) 3121, Australia
Tel.: +61-3/9425-5000
Fax: +61-3/9425-5001
E-Mail: mjohns@optalert.com

conditions were highly correlated ($r = 0.70$, $n = 88$, $p < 0.001$). There were 62 "off-road" events in 8 drowsy drivers, and 61 of them were preceded by JDS scores > 5. *Conclusions* It is possible to measure drivers' drowsiness continuously by IR oculography using the new JDS scale which does not require adjustment for individuals or the attachment of electrodes.

Key words drowsy driving – blinks – saccades – road crashes – drowsiness scale

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Introduction

Drowsiness is the intermediate state between alert wakefulness and sleep, to be distinguished from fatigue [1]. It is a fluctuating state of reduced awareness and impaired psychomotor performance that is believed to be a major factor in about 20 % of road crashes [2]. Several different methods have been used to monitor levels of drowsiness in laboratory experiments. For example, the duration of blinks and the incidence of long eyelid closures, measured from the electrooculogram (EOG), increases with drowsiness [3–5]. By contrast, the velocity of saccades, measured by an eye-tracking system, decreases with drowsiness [6]. The size of the pupil, its spontaneous fluctuations and its response to light stimuli (pupillography) are all influenced by drowsiness [7]. However, none of these methods is suitable for routine use by drivers. Nor are the traditional methods used for measuring sleep and wakefulness in sleep laboratories, with the electroencephalogram (EEG), the EOG, and electromyogram (EMG). Even when such methods have been used in drivers, they have not detected drowsiness very well [8].

In recent years, video-camera methods have been advocated for monitoring drowsiness, particularly for measuring PERCLOS, the proportion of time that the pupils are at least 80 % covered by the eyelids over a period of a few minutes [9, 10]. Despite their early promise in laboratory experiments, video methods have had problems in real-life implementation with drivers. There are difficulties capturing images in daylight, particularly when the environmental light conditions are highly variable, as when driving in sunlight with shadows, or when prescription glasses or sunglasses are worn [11].

We have recently developed a new method for monitoring the drowsiness of drivers unobtrusively and continuously in all light conditions, with or without prescription glasses, contact lenses or sunglasses. It is based on infrared (IR) reflectance oculography, with IR transducers attached to a glasses' frame (Optalert™ Drowsiness Measurement System, Sleep Diagnostics Pty Ltd, Melbourne, Australia). This method has led to the recognition of new variables, particularly the relative velocity of eyelid movements during blinks, and in turn, to the development of a new scale for measuring the drowsiness of drivers continuously.

The amplitude-velocity ratios for blinks

In alert subjects, the amplitude of upper eyelid movement during blinks is known to be very closely related to its maximum velocity [12]. The further the lids move, the higher their velocity. A slightly different, but equally close relationship has been described for the amplitude and maximum velocity of saccadic eye movements, and this relationship has been called the "main sequence" [13]. These relationships have been demonstrated by use of a magnetic search coil on the upper eyelid for blinks [12] and on the cornea for saccades [13]. Search coil methods are the gold standard for these measurements, but they are not suitable for routine or long-term use and they require calibration at each setup.

Johns [14] introduced amplitude-velocity ratios (AVRs) for blinks as a measure of the relative velocity of those movements, measured by IR reflectance oculography. The AVR has the dimension of time and does not require calibration in absolute terms (mm and mm/s) of either the amplitude or velocity so long as they are both measured at the same time and under the same circumstances. The AVRs for eyelids closing during blinks are different from those for eyelids reopening, even though their amplitudes are usually the same. The AVRs for saccades are different again from blinks. The AVRs increase with drowsiness [15], particularly for the eyelids re-opening, i.e. the upper eyelid moves more slowly when re-opening after a blink in subjects when drowsy than when alert. The eyelids may droop with drowsiness, which would decrease the amplitude of blinks, but that does not change their AVR. These ratios are very similar in different subjects when alert, which means they do not have to be adjusted for individuals [14, 15].

Duration of blinks

How long a blink lasts depends on both the amplitude and velocity of eyelid movements, particularly of the upper eyelid. The separate durations of eyes closing, remaining closed and reopening all tend to increase with drowsiness [16]. Consequently the total duration of blinks increases with drowsiness, whether assessed by the present IR reflectance oculography system [16] or by the EOG [5]. However, correlations between the durations of the separate components of blinks are quite low and not always statistically significant (e.g. Spearman's $r = 0.32$, $n = 250$, $p < 0.001$) [16]. The same is true for the relative velocities of eyelid closure and reopening, measured by the respective AVRs [15]. This suggests that the reflex processes that control such movements are partially independent of each other. Drowsiness appears, on the one hand, to loosen the usually tight controls within each 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. Other researchers have reached the same conclusion [3, 4].

A new scale for measuring drowsiness, the Johns Drowsiness Scale (JDS), has been developed for use with the IR reflectance oculography system [17]. It is based on a combination of several variables including the relative velocity and duration of blinks and other eyelid closures. The purpose of this report was to describe briefly the method of IR reflectance oculography, the development of the JDS and its calibration against an objective measure of psychomotor performance, and then to outline the results of a pilot study in which JDS scores were related to simulated driving performance by alert and drowsy drivers.

Methods

Infrared oculography

A small light emitting diode (LED) was positioned below and in front of the eye, attached to a frame that could also hold prescription lenses or sunglasses (Fig. 1).

Brief pulses of invisible IR light (each lasting 70 µs, wavelength 935 nm) were directed up in a 30 degree cone of light centered on the lower edge of the upper eyelid and repeated at a frequency of 500 Hz. The total IR light reflected back from the eye and eyelid was detected by a phototransistor in the glasses frame beside the LED. There is always some environmental IR light present from daylight or artificial lights. The level of this environmental light at the phototransistor was measured immediately before each pulse and was subtracted from the combined level during the pulse, thereby removing the unwanted effect of environmental light, even when it varied rapidly, as with fluorescent lights.

The height of each reflected pulse (in uncalibrated output units) was related to the reflectance (colour, shape and texture) and proximity of each part of the reflecting surface (cornea, iris, sclera, conjunctiva, skin of the eyelids) in relation to the IR transducers. The characteristics of this complex reflecting surface changed with eye and eyelid movements. For example, when the upper eyelid closed during a blink, the reflecting surface of the cornea, iris and sclera of the eyeball was replaced by the skin of the eyelid. As a result, the amount of light reflected from those surfaces changes because of differences in their reflectance and because the eyelids are closer to the transducers. The additional IR exposure because of the glasses does not pose a health risk, being less than 2 % of the safe limit according to the relevant standard, AS/NZS 2211.1:2004.

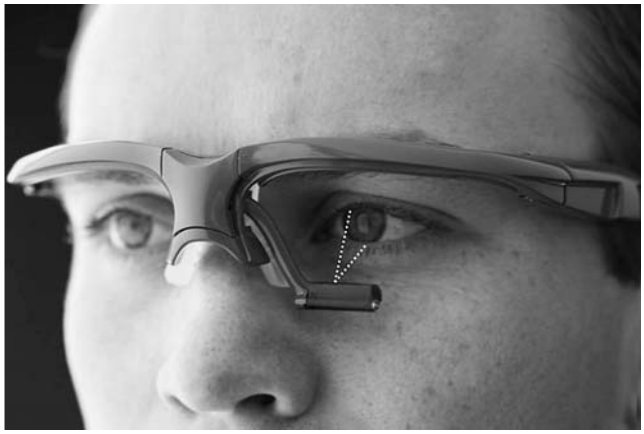

Fig. 1 The glasses frame, shown here without lenses, with IR transducers in the arm attached to the frame, and showing the direction of the IR light pulses directed up at the eye

A microprocessor housed in the arm of the glasses controlled the duration, power and timing of the IR pulses and digitized the analogue output from the phototransistor. The power supply and the serial output from the glasses was via a light cable connected to a processing unit that could be either a bench-top unit for laboratory experiments, or installed in a vehicle for use while driving. The velocity of movements was calculated 500 times per second as the change in position (uncalibrated units) per 50 ms, a method that was devised to measure the velocity of the slowest rather than the fastest movements. The durations of the separate components of blinks and of other eye and eyelid movements, and their AVRs, were measured by software that included period-amplitude analysis of both the position and velocity signals and classification of all periods and amplitudes per minute. This method for monitoring eye and eyelid movements, using IR transducers attached to a glasses frame, is a modification of that described by Leder et al. [18], and different from the more widely used IR reflectance method of Torok et al. [19].

Reaction-time tests

A visual reaction-time (RT) test (the Johns Test of Vigilance or JTV) was developed specially to be part of an integrated system that recorded eye and eyelid movements by IR reflectance oculography during the performance test. The JTV was intended to provide the link between oculometric measures of drowsiness at the same time as objective measures of psychomotor performance. Subjects were asked to push a button held in the dominant hand as quickly as possible after a visual stimulus was presented on a computer screen. The stimulus was a change of shapes, when three circles displayed across the screen changed to become either diamonds or squares for 400 ms at a time, at random intervals between 5 and 15 s. The JTV usually runs for 10 or 15 min and involves about 65–90 stimuli.

Reaction times were measured and categorized automatically in the JTV. For our purposes, a lapse in performance was defined as the absence of a push-button response within 2000 ms from the start of a stimulus. In fact, most lapses were errors of omission (failure to respond), but some were errors of commission, with a response long after the stimulus had disappeared from the screen (in this case at least 1600 ms later). It is common for other researchers to combine all RTs > 500 ms with non-responses, calling them all lapses [20]. We chose to distinguish the many moderately delayed responses (with RTs 500–2000 ms) from lapses. This distinction is not easily made with some other reaction-time test systems such as the PVT in which the visual stimulus remains on until there is a response and it is not possible to tell even approximately when the stimulus was first perceived [20].

Sleep deprivation and reaction-time experiment

Fifty healthy adults (38 M, 12 F, mean age 23.0, range 17–55), with no reported illness requiring current treatment and with normal uncorrected vision, volunteered to take part in a reaction-time and sleep deprivation experiment with the JTV. Subjects gave their written informed consent, and the experiment was conducted in accordance with the standards of the Declaration of Helsinki. Their eye and eyelid movements were monitored during a 10–15 min JTV when they were presumably alert in the morning after a normal night's sleep, and during another 10–20 min JTV the next day, after missing the night's sleep. In fact, their alertness/drowsiness was assessed by their RT performance and lapses, not by their sleep history. Each subject was said to be "alert" during a particular JTV if they had no lapses and had less than 10 % of RTs in the moderately delayed range of 500 to 2000 ms. For data to represent the "drowsy" condition, the JTV had to have more than 5 % lapses and more than 15 % of moderately delayed RTs. These criteria were somewhat arbitrary, but were believed to represent a level of impaired performance that would be relevant to real-life situations such as driving.

Those minutes of each "drowsy" JTV recording that included at least one lapse were separated from minutes without lapses. The oculometric data for these "drowsy and lapsing" minutes were compared with the data from "alert" minutes in a backward stepwise multiple regression analysis predicting those two conditions. The data were analyzed in terms of the mean and standard deviation for each minute of many different variables such as the AVRs for eyelids closing and reopening during blinks, the duration of blinks, the percentage of time the eyelids were closed per minute, and the percentage of time with no movement. Data were log-transformed to normalize distributions where appropriate. The results of this regression analysis formed the basis of the JDS.

Sleep deprivation and driving simulator experiment

In a separate experiment, another 8 healthy volunteers (8 M, mean age 33.3 years, range 23–50) drove for 45-minute test periods in a moving-car simulator based on a normal car. This was a pilot study before a larger independent study was to be undertaken in the same simulator by Monash University Accident Research Centre, Melbourne (see below). Each driver's drowsiness was monitored by IR reflectance oculography and a JDS score was calculated each minute automatically and online. Some recordings were made when the subjects were alert, after a normal night's sleep, others after periods of sleep deprivation that varied from a few hours to 34 hours in different subjects. While subjective reports of sleep duration were recorded, no attempt was made to quantify each subject's sleep and wakefulness objectively. It was considered sufficient that, by voluntarily restricting their sleep to some extent, they would probably become drowsy at times the next day, to the extent that their driving performance was impaired.

The 180-degree forward view from the car was of a two-lane country road at night, with curves and inclines and minor traffic but no stops. The drivers' performance was assessed by the maximum deviation of the car to the right and left from the centre of the lane, measured every minute. Off-road events, defined as periods when all four wheels of the car were outside the 3.35 m lane, were taken as the criterion for failure of driving performance. Video camera images of the driver's face were recorded during these simulated driving sessions using of the IR light emitted by the glasses as the main light source.

Results

The output from the IR oculometric system is shown in Fig. 2 for an alert subject over a period of about 2 s, with the position signal above and the corresponding velocity below. The horizontal axis is time, and the vertical axis is in output units from the phototransistor circuit, uncalibrated in absolute terms of the amplitude or velocity of any movement (mm or mm/s). As is the case with EOG recordings that would be familiar to many researchers, saccades and blinks can be clearly distinguished by these waveforms. However, these recordings do not have the "noise" of the EEG or EMG that is usually present in the EOG.

Sleep deprivation and reaction-time experiment

Only 36 of the 50 subjects fulfilled the criteria for "alert" JTVs during the day after they reported having their usual night's sleep, and 25 fulfilled the criteria for "drowsy and lapsing" JTVs after sleep deprivation. There were many minutes of recording in the sleep-deprived condition when there were no lapses (84.7 %). Multiple regression analysis was used to compare the 477 minutes of pooled oculometric data recorded in the "alert" condition (coded 1) with 327 min in the "drowsy and lapsing" condition (coded 9). The regression was highly significant overall ($R = 0.74$, $F(4,799) = 242.15$, $p < 0.00001$). There were significant beta weights for independent contributions to the regression by four variables: log SD of a measure of blink duration (beta = 0.41, $p < 0.0001$), log mean AVR for eyelids reopening (beta = 0.37, $p < 0.0001$), log mean duration of eyelids remaining closed during blinks and other eyelid closures (beta = 0.16, $p < 0.0001$), and log mean AVR for eyelids closing (beta = –0.12, $p < 0.001$). In our experience, the eyelids do not remain closed for more than about a ms during each blink in alert subjects, but this progressively increases with drowsiness.

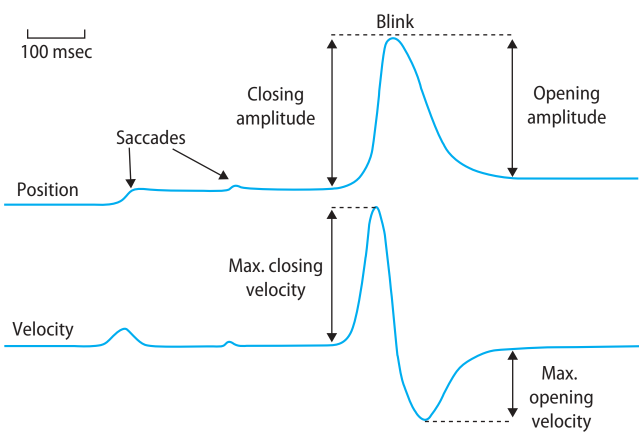

Fig. 2 The outputs form the IR oculometric system for an alert subject over a period of about 2 s, with the position of the eyes and eyelids above, and the velocity of movements, calculated as the change of position per 50 ms, below

Development of the JDS

The regression scores for each minute of recording, derived from the above analysis, were used to generate a scale of drowsiness (JDS) calibrated against the occurrence of lapses in the JTV, an objective measure of impaired performance. It was reasoned that if someone had a level of drowsiness which meant that they had a high risk of not responding to a meaningful and readily visible stimulus (albeit in a laboratory experiment), that level of drowsiness while driving would make them unfit to continue driving. The focus of the JDS was to be on the middle of the scale, i.e. on the earliest stages of drowsiness, rather than on the extremes of alert wakefulness on the one hand and sleep onset on the other.

The regression scores had a mean of 2.5 ± 1.5 (SD) for "alert" minutes and 6.9 ± 2.5 for "drowsy and lapsing" minutes. It was decided to truncate these scores so that negative values were made equal to zero and values greater than 10 made equal to 10. The limits of the JDS then became 0 and 10. The mean JDS scores for "alert" and "drowsy and lapsing" minutes were then 2.5 ± 1.5 and 6.8 ± 2.3 respectively, with a highly significant difference between them (Wilcoxon's test, $p < 0.0001$). Those minutes of data that were recorded after sleep deprivation but without any lapses in the JTV had a mean JDS score of 5.6 ± 1.9, intermediate between the "alert" and "drowsy and lapsing" minutes.

There was a high correlation between the mean of RTs that were less than 2000 ms and the mean of JDS scores recorded during 88 JTVs in all 50 subjects, regardless of their condition (Spearman's $r = 0.70$, $p < 0.0001$). That is, drowsiness increased RTs when subjects did respond, in between lapses, and also increased the frequency of lapses. Both effects were reflected in the pattern of eye and eyelid movements and hence JDS scores at the time.

Driving simulator experiment

A typical example of the results for a driver who was driving in the simulator for 45 min when alert is shown in Fig. 3.

The vehicle was on the left hand side of the road, moving from left to right in this figure. The maximum deviation of the car to the left and right from the centre of the lane and the driver's mean JDS score is shown for each minute. The JDS remained below four and there were no "off-road" events during this drive, as expected with an alert driver.

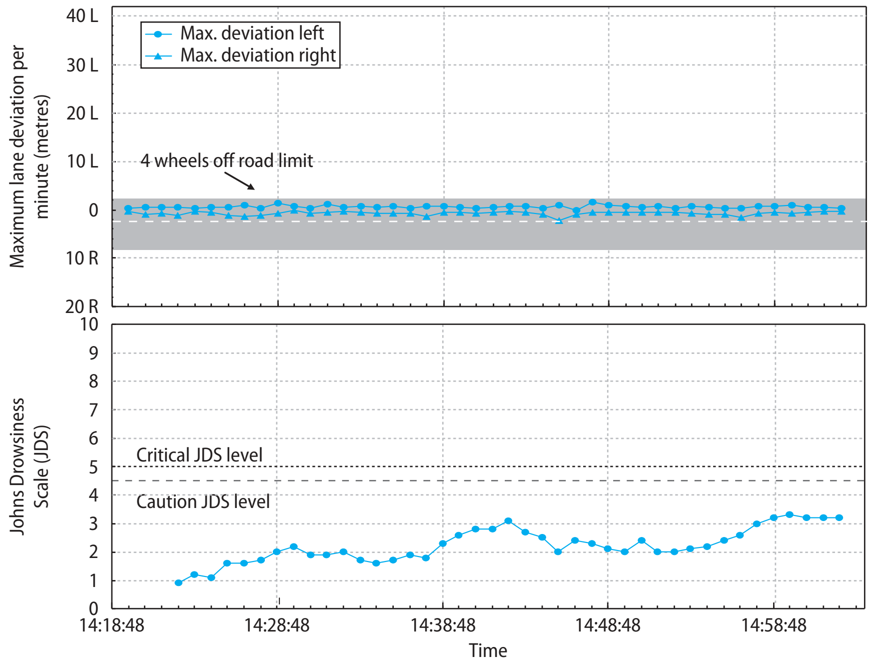

Fig. 3 The results for an alert driver driving for 45 min in the simulator, with the maximum deviations of the car to the right and left of the centre of the road and the driver's JDS score calculated each minute

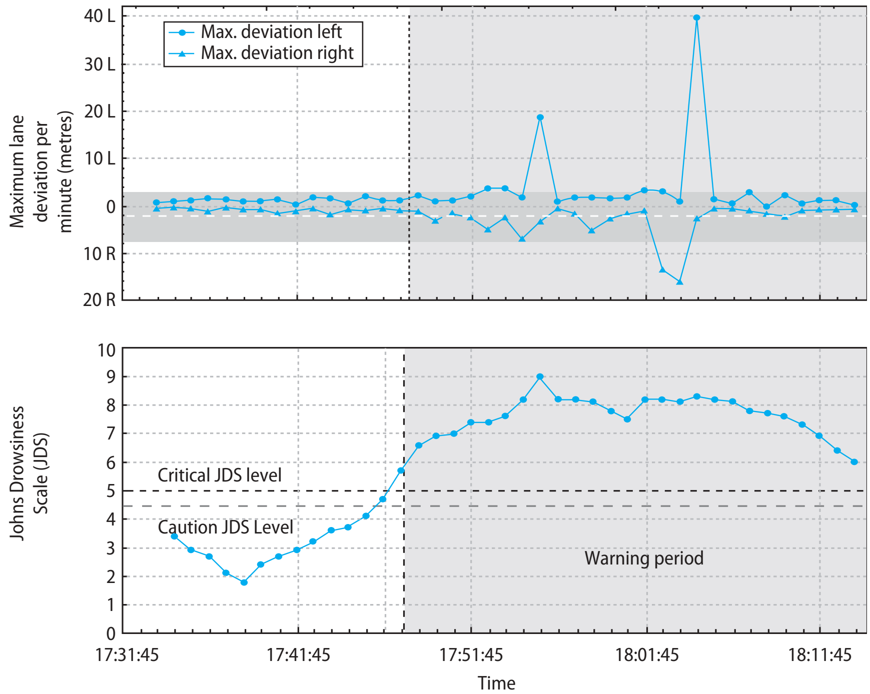

Fig. 4 The same driver as in Fig, 3 driving the simulator after sleep deprivation, showing "off road" events when all four wheels of the car were out of the lane, to the left or right side

After remaining awake for another 24 h, when he had then been awake for about 30 h, the same subject began driving again fairly normally (Fig. 4). However, after 17 min he began to drive off the road for brief periods, and he did this repeatedly over the next 25 min. At one stage he was 40 m off the road and had to be instructed via the intercom on how to get back on the road. This interaction with the experimenter seemed to reduce his drowsiness and improve his driving for the last few minutes. After the first 14 min, his JDS had increased above 5 (which we propose as a critical level of drowsiness) and it remained high throughout the period when he was driving off the road repeatedly. His drowsiness had increased above our proposed critical level 3 min before his driving performance became dangerously bad.

There were 62 "off road" events in total for the 8 subjects of this experiment. In 61 of those events, the JDS score was above 5 for at least a few minutes beforehand. The other event was preceded by a JDS score of 4.5 which we propose as a cautionary level of drowsiness. This suggests that, if drivers were given a cautionary warning when their JDS reached 4.5 and a critical warning when their JDS reached 5, the majority of such "off road" events may be prevented. This conclusion has been supported by a larger study with 20 subjects, performed and reported independently [21] and mentioned below. Video camera images here clearly showed that "off road" events sometimes happened with the driver's eyes wide open, staring straight ahead, and sometimes with the eyes closed for seconds at a time. However, the JDS scores had increased because of more subtle changes in blinks before most of those events occurred.

Discussion

The results indicate that it is possible to measure the drowsiness of active people continuously by IR reflectance oculography without the need for any electrodes to be attached. The subjects of this investigation wore a special pair of glasses, incorporating IR transducers, while they engaged in either a visual RT test or a simulated driving test. Our experience in these and other situations, including driving on the road, indicates that many people are willing to wear such a device and that it does not interfere with their vision or driving. The scale of drowsiness (JDS) was calibrated against lapses in psychomotor performance, an objective measure of the effects of drowsiness that can be related in principle to the task of driving. If the driver cannot see and respond to a meaningful and readily visible stimulus, even intermittently because of drowsiness, he is unlikely to be fit to drive at the time. Calibration of the JDS did not rely on subjective reports of fatigue or drowsiness that are difficult to standardize between different subjects. The ocular measurements that formed the basis of the JDS were not adjusted for individual subjects.

The JDS was based on a combination of oculometric variables, including several that have not been used by other researchers, such as the relative velocity of eyelid movements during blinks, as assessed by their AVRs. The results are consistent with the idea that drowsiness is not a unified state that can be characterized by any one variable. It is noteworthy that the frequency of blinks per minute was not included in the JDS although others have used that variable [3, 4]. We have found that it is too task-dependent and too subject-specific to be useful as a measure of drowsiness. Several other investigations have shown that drowsiness is reflected in a combination of variables related to eye and eyelid movements [3–5, 22, 23]. However, none of those investigations led to the development of a scale of drowsiness that was calibrated against objective measures of psychomotor performance without the need for individual adjustment, that could be derived unobtrusively and without electrodes while driving, and had the potential to be widely applicable as the JDS does.

It is obviously important that a driver's eyes should not be closed for more than a second or two at a time while driving, but having the eyes open is no guarantee that a driver can see when drowsy. In several "off road" events recorded here, the driver's eyes were wide open at the time. This is consistent with our previous report of lapses in RT tests by drowsy subjects with eyes open, monitored by our system of IR oculography and confirmed by video recordings [24]. This may present a difficulty for video camera systems that rely solely on the detection of long eyelid closures, based on PERCLOS [9–11]. This and other difficulties that such video camera methods have because of sunlight, the wearing of prescription glasses or sunglasses, and the loss of data because of head movements, do not arise with the system of IR oculography used here. However, this system can measure the percentage of time that the eyes are closed (per minute), which researchers at the Institute of Breathing and Sleep in Melbourne have shown to be highly correlated with PERCLOS measurements derived from video camera images [25].

We have found that significant levels of drowsiness, represented by JDS scores > 4.5, particularly > 5.0, preceded all "off road" events that occurred during simulated driving in this pilot study. These results have subsequently been supported by other investigators with 20 subjects in the same simulator, with and without sleep deprivation [21]. They reported a sensitivity of 83.3 % and specificity of 60.9 % for predicting that the whole car would leave the lane within the next 15 min under sleep-deprived conditions. Using a less stringent criterion of drowsy driving risk, with at least two wheels and half the car out of the lane, the sensitivity was 75 % and specificity 70.6 %. By such criteria, this drowsiness scale gives both false positive and false negative results. However there is no gold standard method for predicting imminent drowsiness. We are not aware of any other method that could be used regularly by drivers that predicts "off-road" events with greater accuracy several minutes before they happen. Certainly, the standard deviation of lane position (a measure of lane tracking ability) did not predict "off road" events in the above study [21]. There is good evidence from other investigations, both with simulated [26] and actual driving [8], that the EEG cannot be regarded as the gold standard because most drowsy driving episodes are not preceded by theta waves and micro-sleeps detected in the EEG.

A device (Optalert™, Sleep Diagnostics Pty Ltd, Melbourne, Australia, ww.optalert.com) has been manufactured that emits a cautionary warning, with an auditory and visual alarm and a voice message when a driver begins to show signs of drowsiness (at JDS = 4.5), and a different warning when a critical level of drowsiness is exceeded (JDS > 5). It is clearly very difficult to do a real-life experiment with drowsy drivers on the road. However, we have recorded drowsy driving in a volunteer commercial truck driver who reportedly "woke up driving on the wrong side of the road" when driving at about midnight [27]. He was wearing Optalert glasses on a trial basis, but was not receiving JDS warnings at the time. Fortunately, there was no on-coming traffic and no accident occurred. His JDS had exceeded 5 for 52 min before that event but, although well informed about drowsy driving, he evidently did not recognize the potential danger of his situation before dozing at the wheel. He recognized that danger only when he roused after that dozing episode, and then stopped driving.

Many people wear sunglasses at times when driving, and some people wear prescription lenses whenever they drive. Thus, it may be acceptable for many drivers to wear Optalert™ frames that can also incorporate sunglasses and prescription lenses when required, to help them manage their own drowsiness. By stopping driving and having a brief nap before drowsiness reaches a dangerous level, drivers could avoid a drowsy crash, saving their own and other people's lives. The Optalert™ system would simply provide objective advice to the driver about when to stop driving, a decision that drivers evidently find difficult to make on the basis of their own subjective feelings.

Conclusions

It is possible to monitor levels of drowsiness in active people continuously and objectively by a system of IR reflectance oculography using a new scale of drowsiness (JDS) based on a combination of variables. Subjects wear a special pair of glasses frames, but there is no electrode attachment. The JDS does not require adjustment for individuals. Such a system has potential to save lives on roads and elsewhere, wherever performance impairment caused by drowsiness presents a problem.

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