subjective and optomotoric indicators of driver drowsiness

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Abstract

It is well established that subjective and physiological variables change in the course of falling asleep but are not perfectly correlated. Some sleep warning systems deploy lidmotoric parameters. Subjective indicators are often used as criterions to evaluate physiological parameters. In two studies the interrelation between various optomotoric parameters of the lid and eye ball were analysed referring to a subjective ten-point alertness score. Lid activity and saccades were recorded be the electrooculogram (EOG) and identified on-line.

In the first study, 67 drivers completed a PC-simulated driving course of about two hours in the lab at night, whereas for the second study, 16 probands were asked to perform oculomotor tasks for more than one hour after taking a benzodiazepine. In both studies drowsiness was well established in subjective and physiological indicators, but subjective alertness scores showed only moderate group correlations with optometric indicators. Nevertheless, on an individual level, several probands showed very high correlations in the theoretically expected direction of deactivation while other had remarkable correlations in the 'paradoxical' direction of activation analogous to a stress reaction. When velocities and durations of blinks and saccades were standardised in order to adjust them to varying amplitudes, only a few paradoxical correlations disappeared.

These results were interpreted in a framework of at least three partially independent processes occurring during sleepiness while performing: decreasing attention (indicated by blink interval), decreasing alertness (represented by blink duration and blink amplitude) and more or less pronounced effort to maintain the required level of alertness (indicated by velocities of saccades and lid movements).

Introduction

When falling asleep, most physiological parameters show remarkable changes in humans. Especially optomotoric changes like narrow lid clefts or closed eyes seem so obvious and unequivocal that they constitute the general idea of being sleepy or being at sleep. Next to this apparent connection, the fact that they can be obtained non-obtrusive (i.e. without requiring any active input from the driver) is one of the main advantages of using eye-movements as an indicator of drowsiness. However, the relation becomes less reliable if a person tries to fight sleepiness and wants to stay awake at any cost.

Under these circumstances, one might not be able to observe the assumed changes in a clear manner, although the subject gives the impression of being sleepy and rates his own wakefulness accordingly. Nevertheless, attenuated forms of the aforementioned changes still occur. These tendencies are described in the first part of our article. In order to predict drowsiness for a single person, individual instead of group courses have to be considered and sometimes show clear deviations from the former. Possible explanations for these individual differences are subject of the second part.

Optomotoric parameters

The favoured parameters for drowsiness detection based on eye blinks are blink rate and blink duration (Hargutt, 2003; Stern, Boyer, & Schroeder, 1994). Sometimes blink *interval*, the time between two blinks is used to describe the same phenomena as blink rate, the number of blinks per minute. When getting tired, most people blink more frequently and the blink interval decreases or respectively the blink rate increases.

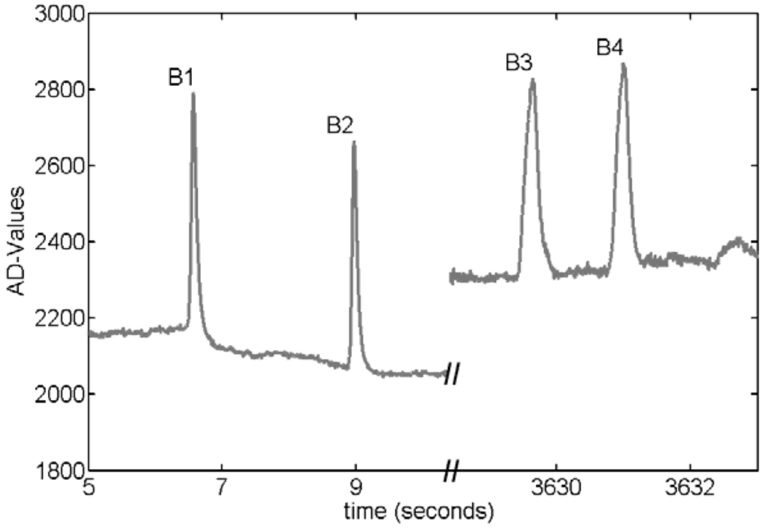

Fig. 1: vertical EOG at the beginning and after an hour driving in a simulator course. Blinks are identifiable as peaks (B1-B4). For further information see text.

Fig 1 shows the vertical electrooculogram (EOG) of a proband at the beginning (5th-9th second) and after an hour driving the simulator course. The interval between blink 3 and 4 (B3 & B4) is shorter than the one between B1 and B2. In addition, B3 and B4 appear less tapered: their duration, the gap between their sides, is increased.

Both parameters are either used equally (Morris & Miller, 1996) or associated with light (blink rate) resp. severe fatigue (blink duration) Tietze and Hargutt (2001; s.a. Hargutt, 2003) attribute the changes in blink rate to a decrease in vigilance, the increase in blink duration to fatigue. Saccadic parameters are less frequently mentioned, probably due to measurement problems.

Methods

The reported results are based on data from 65 subjects who drove a PC-based simulation course at night, mostly at 11PM or 2:30 AM in the morning. On average, the driving time was about 140 minutes with a standard deviation of 20 minutes. The following indicators of drowsiness were collected:

- **behavioural and performance measures** like yawning, staring or overlong lid closures (lasting more than 0.5 seconds), in this text also referred to as *microsleeps*[1], and driving errors. All probands were filmed by an infrared camera and their face was monitored by the experimenter on a B&W screen. When leaving the lane and hitting a safety post, a short sound was played. Thus the experimenter could record every occurence of these incidents online
- **subjective alertness ratings** were asked every 30 minutes by the experimenter. When the probands perceived a distinct change in their alertness they could tell this of their own accord.

Eye movements were recorded by the EOG. After identifying all blinks and saccades off-line, 13 parameters for each blink, like blink interval, blink duration, delay between end of lid closure and beginning of lid-reopening etc. were determined (for a detailed description see Galley, 1993).

Results

Fig. 2 shows the average subjective alertness during driving time: self-assessed wakefulness decreases with time-on-task. The subjects at the early appointment were a on average little bit more alert than the late ones.

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[1] strictly speaking, they are only behavioural manifestations of microsleeps: to identify a micro*sleep*, one needs evidence from the EEG, too

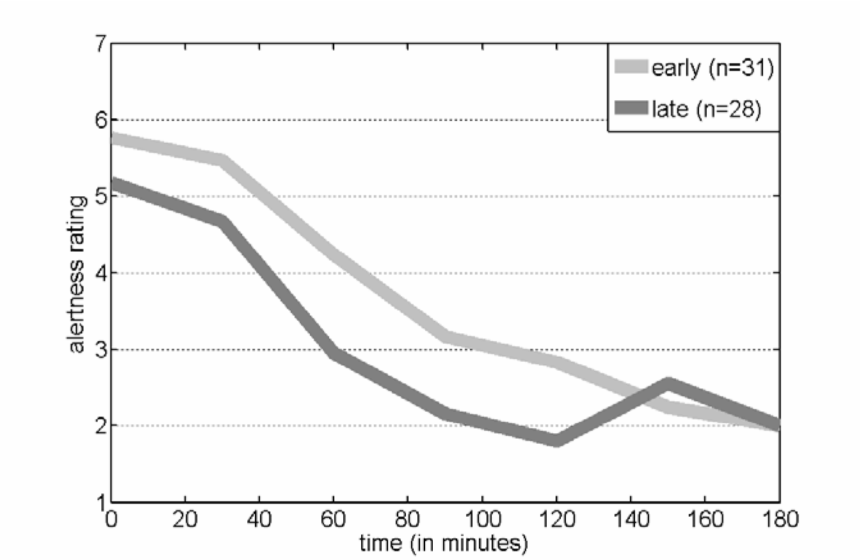

Fig. 2: average subjective alertness with time on task for the early (11 PM) and late (2 AM) appointment

The rise after the second hour is a drop-out-effect: if a proband had more than five overlong lid closures in connection with severe driving errors, the experiment was stopped. As a consequence, the sleepiest persons left and the average alertness increased apparently

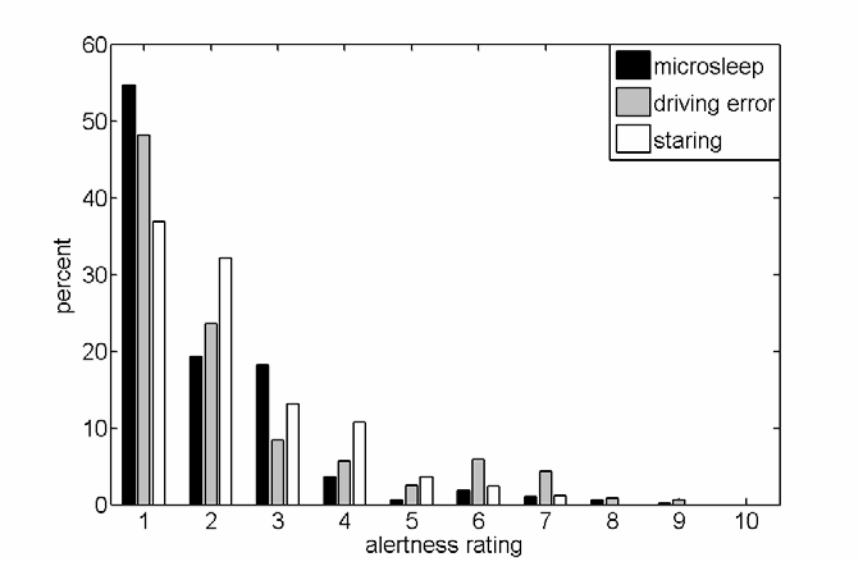

Fig. 3: Occurrence of behavioural indicators of fatigue and subjective alertness rating

Next the subjective ratings were set in relation to objective signs of drowsiness. As you can see in fig. 3, the frequency of behavioural signs of fatigue increases with lower alertness ratings. Indicators of severe sleepiness, driving errors and overlong lid closures, here called 'microsleeps' abruptly rose from alertness level 4 to 3. They were very seldom seen during higher alertness values, thereby validating self-evaluations as a reliable criterion for drowsiness (Horne & Baulk, 2004). In addition, the subjective ratings were used to analyse changes in oculomotoric parameters.

Overall analysis blink parameters

As found in previous studies (Barbato et al., 1995; Stern et al., 1994), the blink interval decreases with increasing fatigue (s. fig. 4).

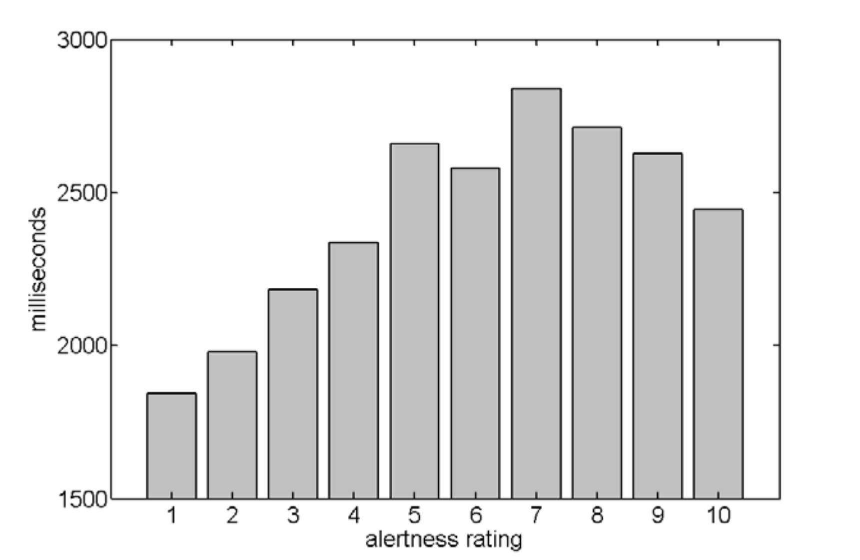

Fig. 4: Blink interval (median) over subjective alertness

The other afore-mentioned indicator, blink duration also shows the expected change (s. fig. 5), namely a rise with increasing drowsiness (Häkkänen, Summala, Partinen, Tiihonen, & Silvo, 1999):

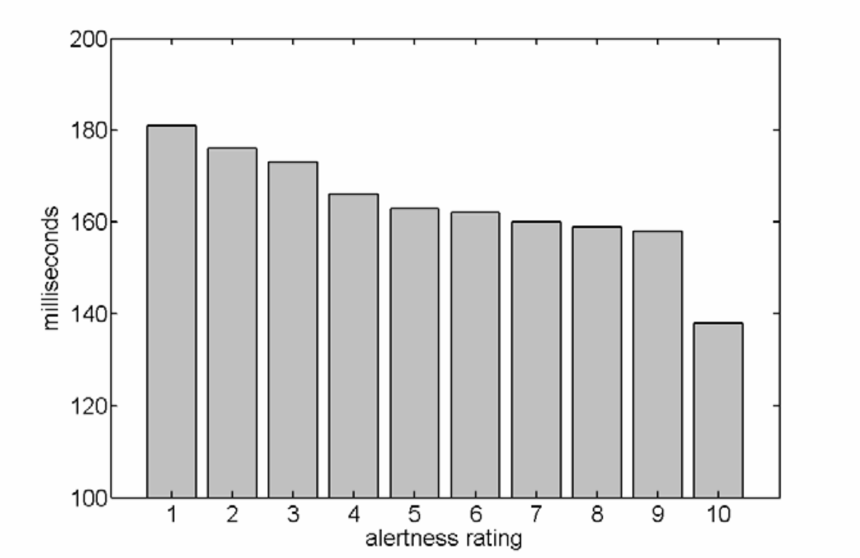

Fig. 5: Blink duration (median) over subjective alertness

Taking a closer look at single events, the prolonged blink durations could be caused by increased closure- and reopening-times (i.e. lower velocities) as well as by longer delays between closure and reopening. Actually, both contribute to the increase in duration and do so *independently*. This means that velocities and delay are controlled by different processes or neuronal networks (Galley, Schleicher, & Galley, 2004). As with closure and reopining time, also blink rate and duration constitute their own factors, which indicates a separate control process for each.

The anecdoticly described phenomena of 'driving without awareness' or 'sleeping with open eyes' provides further evidence for independence of lid-reopening from other oculomotoric effects of fatigue: although the driver is very sleepy and shows remarkable alterations in his gaze behaviour, he still manages to keep his eyes open – unlike during a microsleep, where the eye remains shut (Karrer, Briest, Vöhringer-Kuhnt, Baumgarten, & Schleicher, 2004).

Discussion

At first sight it might seem paradoxical that sleepiness as a general deactivation causes an active behaviour, eye-blinks, to increase. But one aspect of drowsiness is fading interest in the environment: visual processing can only occur with eyes open and during times of high visual load (e.g. reading), eye-blinks are actively suppressed (Orchard & Stern, 1991). As interest in surrounding visual stimuli decreases, the inhibition of spontaneous eye-closures becomes no longer necessary. The increasing blink rate can therefore be understood as a dis-inhibition caused by the subject's fading interest in its environment.

Individual Analysis

Switching from group- to individual values in order to predict fatigue for individual drivers, one has to acknowledge that increasing sleepiness correlates with

1. increase in blink rate
2. increase in blink duration
3. decrease in lid- and saccadic velocities

where order reflects reliability. The latter means that some of our subjects showed no or even a reverse relation between the parameter blink rate and subjective rating or objective indications of severe fatigue. For the remaining, baseline values, thresholds and gradients in change differed substantially (Galley et al., 2004).

A proportion of nearly 30 % showed a paradoxical increase of saccadic and lid velocities. If sleepiness is understood as a general deactivation, velocities should slow down, but for a subgroup of probands, velocities did not show that effect. In our view, this behaviour suggests a stress reaction or an effortful attempt to reestablish the required level of performance. The phenomenon seems to occur phasically and was not sufficient to maintain higher arousal levels for a longer time.

In his model of compensatory control of performance regulation Hockey (1997) states two loops to regulate overt performance. The first, loop A, applies for well-learned skills or routine tasks like driving a car. Here, adjustments occur automatically and require no conscious effort. However, if the discrepancy between actual and desired performance becomes too large, a second loop is activated and will lead to conscious corrections of either the task goals or expended effort (loop B). This increase in effort also causes an elevated sympathetic activation.

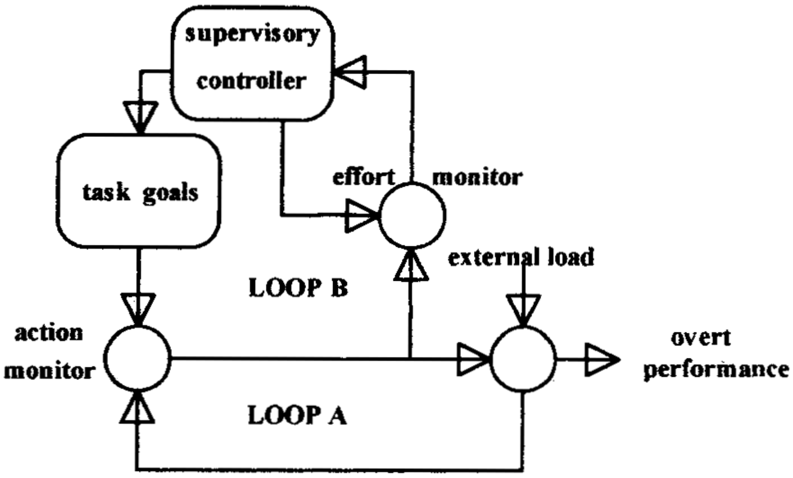

Fig. 6: Compensatory control of performance regulation. Taken from Hockey (1997).

Under normal conditions driving performance is monitored by automatic control processes, in Hockey's model labelled loop A which also compensates for gradual deterioration due to fatigue. To switch from automatic control to conscious monitoring, a clear evidence of goal-deviation like steering errors or perceived microsleeps is needed. In the described subgroup we could observe a phasic increase in velocities, interpretable as an attempt to restore the appropriate activation state.

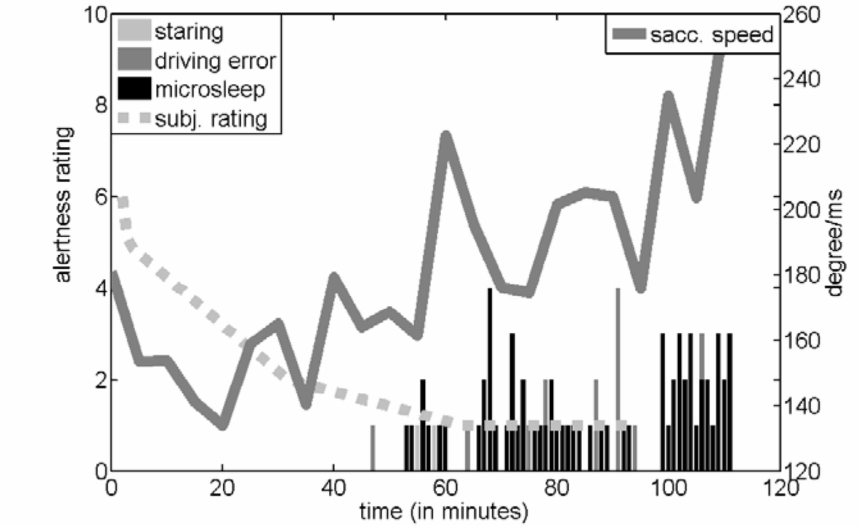

Fig. 7: Saccadic speed (solid line, right y-axis) and subjective alertness (dotted line, left y-axis) of a subject over driving time. Bars indicate the occurrence of fatigue-related incidents (frequency also left y-axis). See text for further explanations.

As you can see in fig. 7, although subjective alertness decreases, the average saccadic speed as a whole rises, often subsequent to fatigue-related incidents like driving errors and microsleeps. Nevertheless, this rise is not constant, but alternates with returns to lower levels.

Conclusions

For a model of driver drowsiness our results suggest at least three processes that can be identified by opto-motoric parameters:

- decreasing interest in the environment: indicated by increasing blink rate and associated with cortical processes.
- increasing sleepiness/tendency to sleep, accompanied by increasing blink duration and delay, which denotes the tendency to keep the eyes shut.
- optional compensatoric effort resulting in increasing velocities for lid and saccadic movements, in most cases only temporarily.

These processes can be partially decoupled. For the last component we assume a relation to consciously perceived loss of control leading to hazardous situations (i.e. driving errors) as most microsleeps without consequences remain unnoticed by the driver.

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