Blink Parameter as Indicators of Driver's Sleepiness – Possibilities and Limitations.

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In a laboratory study the lid movements of 76 drivers were registered by electro-oculogram while driving a simulation course over 2-3 hours at night. Subjects were asked to rate their subjective alertness every thirty minutes and all fatigue-related mimics were scored by the experimenter. Off-line interpolated subjective alertness was in good accordance with objective signs of drowsiness but blink parameters showed considerable individual differences in their changes during increasing sleepiness. A factor analysis resulted in a stable constellation of five factors controlling blink behaviour in wakefulness and drowsiness. A six step procedure is proposed for a warning device based on blink parameters.

1. INTRODUCTION

The arrival of the American PERCLOS-system (Wierwille, 1999) which is based on the registration of a lid closure >80% once again brought the eye blink and its parameters as possible means of drowsiness detection to discussion. It has been suggested that an increasing blink rate could indicate moderate fatigue and an increase of blink duration severe drowsiness. (Hargutt, 2003) Thus the right time to warn would be an obvious change of blink duration to prolonged durations.

But these suggestions are derived from examining mean curves of mostly small samples of drivers. Two pivotal questions for a future warning system will be first, how often it sets off a *false alarm*, for example when the system cannot track the driver's pupils, and second how often a severe sleepiness is *not detected (misses)* as the driver sleeps with open eyes or the blink parameters deployed by the algorithm do not show the assumed changes in some persons. The underlying general question is: can the individual process of falling asleep be characterised by group means or is it necessary to individualize the diagnosis of drowsiness? We will have a closer look at individual changes in the course of increasing fatigue from two laboratory studies.(Schleicher, 2002)

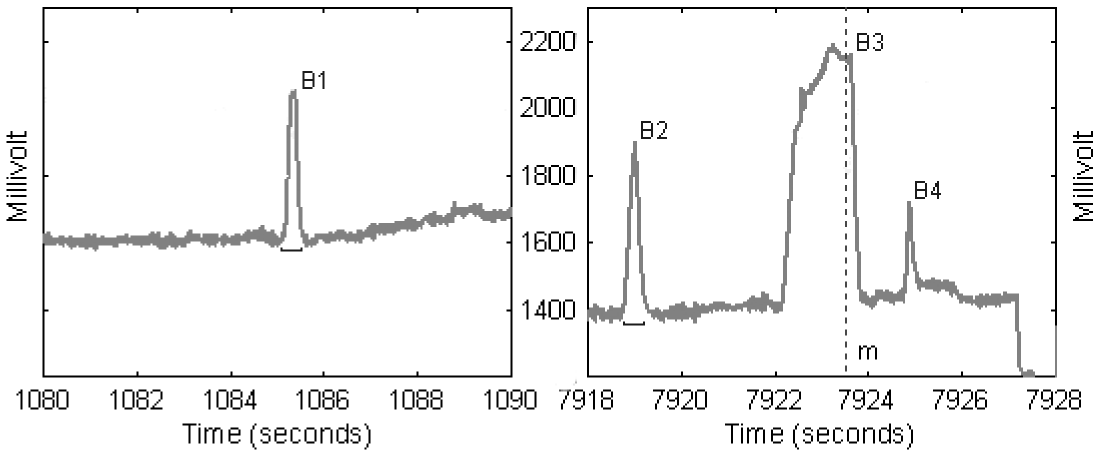
2. SUBJECTS AND METHODS

76 drivers completed a monotonous simulation course in a laboratory setting at night (11 pm or 3 am) for about 2.5 hours. The subjects' face was monitored by an infrared-camera and objective indicators of drowsiness like yawning, staring or long lid closure (i.e. *microsleeps*) were marked online by the experimenter. Every thirty minutes the drivers had to rate their own *alertness* on a scale from 10 (=wide-awake) to 1 (= absolutely not awake, would prefer to sleep). Their electrooculogram was registered by equipment from PAR-Elektronik Berlin and stored on hard disk.

3. DATA ANALYSIS

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 et cetera were determined (for a detailed description see Galley, 1993).

These measures were correlated with the subjective alertness resp. sleepiness ratings. Subjective alertness scores were continuously interpolated with respect to time. Figure 1 shows increasing blink rate and blink duration as the drivers gets sleepier with time-on-task.



Blink events in the vertical EOG of proband 15 after 18 (left) and 132 (right) minutes time-on-task. Blink rate increases and compared to B1, B2 and B3 take longer. B3 was marked as a microsleep event (m) by the experimenter.

Figure 1: Blink events in the vertical EOG of Pb 15

4. RESULTS

For the whole group subjective alertness decreased over time and reached a critical value of <3 after 1,5 hours (see figure 2).

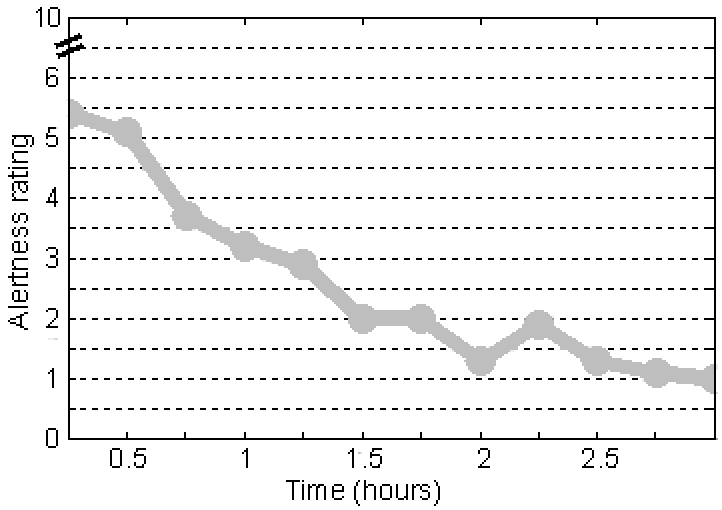


Figure 2: Mean subjective alertness ratings over driving time (n=76)

As can be seen in fig.3, the objective signs of sleepiness were accumulated during periods of low alertness ratings and were very seldom seen during higher values, therefore validating these subjective scores as a quantitative criterion for drowsiness.

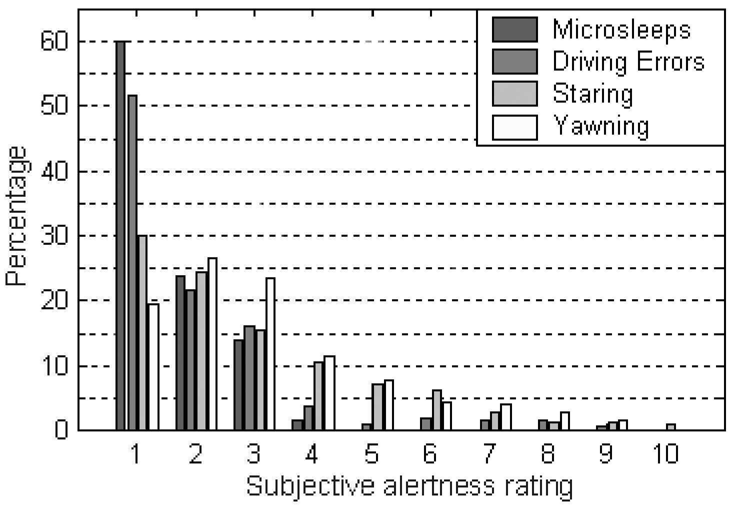


Figure 3:Objective signs of sleepiness in relation to subjective alertness ratings (n=70)

Thus it seems justified to use the interpolated subjective alertness scores to evaluate the oculomotor parameters as possible indicators of sleepiness.

4.1 Blink parameters and alertness

Whereas overall correlations between blink parameters and subjective or objective measures of alertness-sleepiness are low (<.3), individual analyses obtained often correlations in the range of high to perfect correlations. Seven subjects were chosen to show the broad spectrum of individual correlations of blink parameters with alertness (see table 2).

Table 2: Rank correlations between selected blink parameters and range of subjective alertness ratings

Subject Nr.	Alertness range	Intervall	Duration	Amplitude	Closure speed	Delay Clos.-Op.	Opening Time	Max. speed opening
All 76		.29	-.17	.14	.13	.10	-.28	-.03
1	7	.75	-.57	-.5	.29	-.56	-.18	-.63
2	8	.95	-.85	.98	.98	-.95	.89	.97
3	5	.30	-.90	.90	1	-1	.9	.58
56	6	.14	-.81	-.60	.60	-.77	.66	-.99
61	6	.83	-.1	.94	.94	-.97	-.77	1
62	6	.77	.09	.09	-.14	.77	-.83	-.62
115	5	-.10	.70	.30	-.60	-.30	.05	-.45

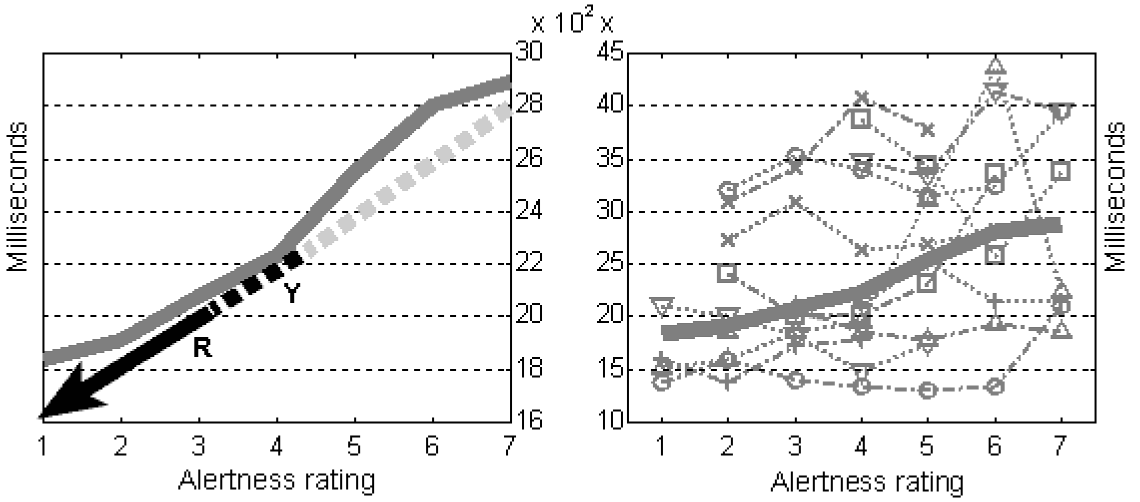
Alertness range: range of subjective rated alertness decrease. A decrease from 7 to 1 or 8 to 2 would yield a range of 7.

Note that sometimes there are sign reversals: in subject 2 the *maximal* v*elocity of lid reopening (max. speed opening)* correlates positive with alertness (.97), while in subject 56 an almost perfect negative correlation (.99) can be found.

The sign reversals in the correlation between some blink parameters, e.g. velocities, and alertness necessitate the assumption of counterregulations: apparently, some persons mobilize considerable effort to overcome their fatigue and the physiological parameters rather represent these increasing attempts to stay awake than the decreasing alertness.

4.2 Group versus individual values

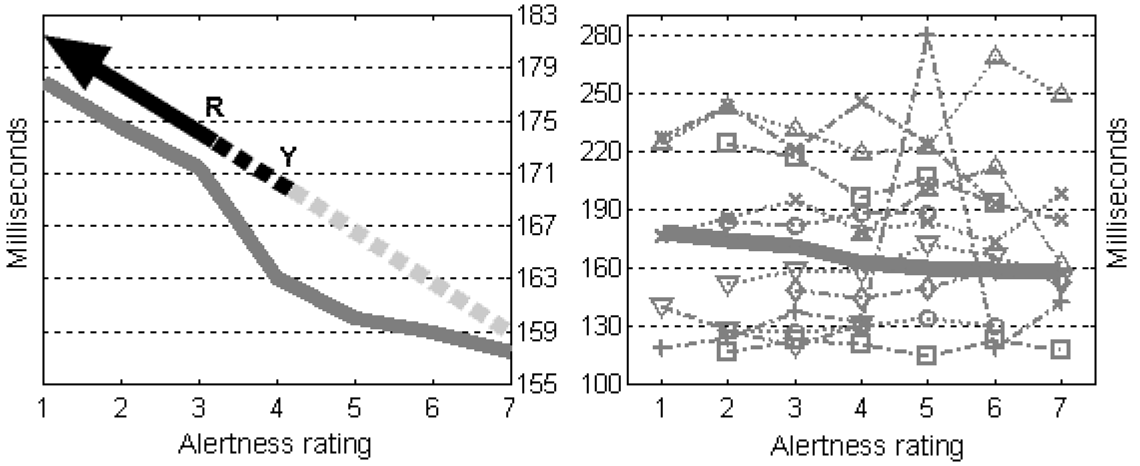
Diverse correlation patterns like these imply that in order to predict sleepiness, the use of individualized parameter combinations might be more promising than one global indicator. For example, on the level of group values, the blink interval declines by 175ms for each step of subjective alertness decrease (s. fig. 4 left) and reaches values below 2100 ms for severe fatigue (alertness <3, state 'R' for 'red' in fig. 4).



Left: Group medians of blink interval in the course of decreasing alertness. **Y:** 'yellow' warning state in propo-sed warning system; **R:** 'red' warning state in proposed warning system (see Discussion). **Right:** Curve of group medians (from left) contrasted to individual median curves of selected subjects. See text for further explanation.
Figure 4: Blink interval over subjective alertness ratings

But when applied to individual cases (fig. 5 right), neither the gradient of decrease in blink intervals nor an absolute threshold derived from group medians would work for many subjects that have nevertheless reached a critical alertness score.

The same holds for *blink duration* (defined as the time between the start of the lid closure to the moment of highest velocity in the lid reopening): the group value curve shows an increase of 2.7 ms for each step of decreasing alertness and critical values may be 165 ms for light and 175 ms for severe drowsiness (see fig.5 left).



Left: Group medians of blink duration in the course of decreasing alertness. **Y:** 'yellow' warning state in propo-sed warning system; **R:** 'red' warning state in proposed warning system. **Right:** Curve of group medians (from left) contrasted to individual median curves of selected subjects. See text for further explanation.

Figure 5: Blink duration over subjective alertness ratings

Again, individual curves differ to such an extent that neither slope nor absolute values of a group mean course are usable for warning (see fig.5 right).

4.3 General structure of blink parameters

In order to identify relevant neuronal networks for blink control, we run a factor analysis on all blink parameters (>210.000). To obtain a model independent of the driver's current wakefulness, the state of full alertness (subjective ratings >=7) and the state of severe fatigue(subjective alertness <=3) were analyzed separately.

Table 2: Factor loadings of blink parameters (PCA with VARIMAX rotation)

	Factor				
Variable	**1** A/S	**2** A/S	**3** A/S	**4** A/S	**5** A/S
Blink Interval					**.80/.79**
Blink Duration				**.96/.96**	
Delay Clos.-Op.			-.29/.23	**.89/.93**	
Blink Amplitude	.48/.49	.50/.33	**.57/.65**		
Opening Duration			**.92/.89**		
Opening Speed		**.92/.93**			
Stand.* Opening Speed		**.72/.83**	-.61/-.46		
Closure Speed	**.91/.92**				
Stand.* Closure Speed	**.94/.94**				

*standarized with respect to amplitude (s. Galley, 1993)

A= awake state (subjective rating ≥ 7); **S**= sleepy state (subjective rating ≤ 3)

In both states 5 factors were extracted and the factor loadings of all blink variables remained stable. The factors can be interpreted in the following manner (beginning with the last one):

- **Factor 5** solely consists of *blink intervals*, which may be controlled by attention, a rather cortical factor representing the driver‘s *fading interest* for his environment. As he reduces his inhibition of blinks, the blink rate increases.
- **Factor 4** is built by the *duration of a blink* and the *delay of reopening*, the last presumably corresponding to the intention to keep the eyes closed. It should be a decoupling of the lid closure and the lid opening reflex, which uses different brainstem systems (Esteban, 1999). Microsleep events are typical examples of prolonged reopening-delays, but it is interesting that this factor remains stable over all states of wakefulness and is not limited to severe fatigue.
- **Factor 3** is mainly made up by *blink amplitude* and *duration of the opening phase* but other variables are loading as well. Factor 3 may represent the sympathically controlled cleft between the upper and lower lid, and the often extended opening period. This parameter is most of all associated with the PERCLOS indicator.
- **Factor 2** represents parameters of lid reopening and
- **Factor 1** parameters of lid closure.

5. DISCUSSION

Analyzing larger groups of drivers, (figs. 6 & 8), we found remarkable individual differences in the blink parameters during the fatigue process. They are obviously not caused by unreliable subjective alertness reports as the latter were in good agreement with the occurrence of objective indicators of drowsiness: Behavioural manifestations of severe fatigue like microsleeps predominately occurred during the lowest states of alertness while they were scarcely registered during wakefulness (see fig.4).

The individual differences are reflected by different correlation patterns between blink parameters and alertness. Blink interval or blink duration are not the prime indicators for *all* individuals, for some persons they seem to have no substantial relationship to sleepiness at all. In some subjects, blink parameters even change in the opposite direction as expected e.g. paradoxically increasing velocities with decreasing alertness (see table 2).

We assume that the underlying process is not an unidimensionally increasing deactivation, but consists of two components: along with an increasing sleep propensity (Lavie, 1991) there is also a maintenance-of-wakefulness component which guarantees further execution of vital operations, understandable as an attempt to stay awake. The physiological parameters reflect both, deactivation as well as the effortful struggle against falling asleep.

The factor structure of all blink parameters is not modified by fatigue processes. This seems to speak against the theory that a rising blink rate first characterizes light fatigue and later on increasing blink durations are typical for severe drowsiness.

As the five factors remain stable throughout different stages of wakefulness, they may represent the underlying neuronal nets of blink control with one attentional/cortical factor and four brainstem factors which may represent the coupling/decoupling of lid closure with lid-reopening, the amplitude or lid cleft, and the lid closure and lid opening process. We suppose that individuals may train some parameters of this control process due to lifelong training: some people are able to block the decoupling of lid opening and closure which can result in 'sleeping with open eyes'. Nevertheless, these people should still show prolonged blink durations and decreasing velocities of closure and re-opening. Thus their drowsiness can be detected by these changes.

Our proposal to identify critical values of drowsiness uses six steps:

1. Determine basic values of each of the five factors of blink control during the first 15 minutes of a drive and assign these values to a declared or computed state of alertness from the time of day.
2. Later on, changes in the blink parameters are assessed using default mean values corresponding to one step of decreasing (or increasing) alertness.
3. Compare the ascribed alertness step of each blink parameter with the others.
4. Reassess a global state by weighting the most sensitive parameters most.
5. Give YELLOW warning if state three is reached.
6. Give RED warning if state two is reached and additional signs like microsleeps or critical delays of reopening were registered.

An assessment procedure like this should NOT give a warning when people try to fake the system by voluntary prolonged lid closure because the velocities of lid movements remain high and no period of YELLOW was registered before.

6. REFERENCES

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