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Original article

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Driver impairment at night and its relation to physiological sleepiness

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Objectives Studies of devices detecting sleepiness need reference points of physiological sleepiness. The present study sought to validate the Karolinska drowsiness score (KDS) as an indicator of physiological sleepiness against driving impairment and eye blink duration during a 45-minute drive in an advanced moving-base driving simulator.

Methods Data from 19 persons were used in the analysis. Electrooculography, electroencephalography, and electromyography were administered continuously. Physiological sleepiness was quantified by scoring the percentage (0–100%) of the scoring epoch with alpha and theta activity and slow eye movements (KDS). Lateral position and speed were used as measures of driving behavior. Lane departure was defined as two wheels touching the lane markers. Blink duration was used as a secondary indicator of sleepiness.

Results The results showed that, for young drivers, sleepiness increased with time in the task with higher levels. The variability of the lateral position and the mean and variability of the blink duration significantly changed when sleepiness increased to KDS ≥20%. Furthermore, there was an increase in the risk of lane departure for KDS ≥30%.

Conclusions The results suggest that KDS scoring is a reasonable procedure for estimating physiological sleepiness under conditions of driving. The results also indicate that a younger age is associated with greater sensitivity to sleepiness at the wheel.

Key terms driver behavior; driver simulator study; lane departure; risk; validation.

Sleepiness is common in truck driving, especially during night shifts (1, 2). It also contributes to crashes (3), and it has been suggested that sleepiness is involved in up to 30% of fatal truck accidents (4). These problems have led to an interest in developing driver support systems that can identify sleepiness before an imminent risk of a crash. Such systems often consist of sensors for measuring physiological and behavioral changes, as well as of algorithms for quantifying such changes and predicting increased risk (5).

Several studies have tried to identify the key parameters that best reflect severe sleepiness (6–8). The results show that, among the physiological parameters, increased power in the alpha and theta bands of electroencephalographs (EEG) seem to be parameters of interest (9–11), but also parameters based on blink behavior (12), especially eye blink duration, are sensitive to variations in alertness. Among the behavioral parameters, the standard deviation of the lateral position of the vehicle seems to be very sensitive to sleepiness (13, 14).

These approaches have used either electroencephalographic (EEG) or electrooculographic (EOG) parameters as indicators of sleepiness. Even if there are good arguments for considering them to be sensitive indicators of sleepiness, their use is mainly based on their response to sleep loss or their high correlation with performance lapses—not through validation against established measures of sleepiness. An alternative approach could be to use integrated measures of EEG and EOG, similar to formal sleep scoring (15) but applied only to the process of (involuntarily) falling asleep.

One integrated approach would be the use of the multiple sleep latency test (16) and the Maintenance of Wakefulness Test (17), which were developed from the sleep scoring concept as time taken to exhibit the first epoch of stage-1 sleep. However, this approach

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is discrete in its character and thus is not suitable for continuous monitoring. A more-continuous measure was developed by Valley & Broughton (18) using different levels of stage-1 sleep. A similar method has been developed by Sallinen his and co-workers (19), and Santamaria & Chiappa (20) have been responsible for a more elaborate one.

The Karolinska drowsiness score (KDS) is another method that classifies polysomnographic data according to the presence of alpha or theta activity and slow eye movements (21, 22). The classification is done in 2-second epochs that yield a continuous measure (0–100% out of each 20-second epoch). This approach may be more suitable as a sleepiness reference for the continuous measurement of physiological sleepiness, including tests of parameters for automatic sleepiness detection. Accident data indicate that young people are more sensitive to driving under sleepiness (23–26). This conclusion was also drawn in a simulator study (27). The aim of our present study was to relate changes in driving impairment to the level of physiological sleepiness as indicated by the KDS. As indicators of driving performance, both variables previously related to sleepiness, such as the mean and variability in the lateral position (lp and sdlp) and variables like the mean and variability of driving speed [speed and speed (SD)] were used. Blink duration may reflect early signs of sleepiness not detected with the KDS method, and it was used as a physiological indicator of sleepiness. Line crossings and road departures were used as final end points. EEG parameters were not used since they form much of the bases for the visual scoring method (KDS). To provide sufficient sleepiness during driving, we scheduled the driving session for late at night. The aim was also to investigate the effects of age on people driving while sleepy.

Study population and methods

Study population

A total of 20 persons participated in the study. One was excluded because of technical problems, and data from 19 were finally used in this analysis. Nine persons were young drivers (18–24 years), and 10 were older drivers (55–64 years). Each age group was equally divided between the men and women.

Among the inclusion criteria were good health, having driven more than 5000 kilometers during the last year, not having passed any time zones during the past 2 weeks, no present sleep disturbances, no shift work during the previous month, and no planned or performed extensive physical activity. The participants rated their normal sleep quality on a 5-grade scale from 1=very good to 5=very bad. The average score was 1.95 (SD 0.60). Among the participants, 16 claimed that they never or almost never had problems with interrupted or disturbed sleep, but 3 reported occasional sleep problems. The experiment was approved by the regional ethics committee (2003 Dnr 03–376), in Linköping, Sweden. The participants received a monetary compensation of approximately EUR 200. They were recruited through an advertisement in a local newspaper.

Design and procedure

Each participant performed two test drives, one early condition (early evening) and one late condition (late night). The first served a purpose different from the focus of the present paper. The second was intended to provide a high degree of sleepiness due to extended wakefulness, low circadian phase, and potential monotony. This paper focuses on the late-night condition. Results for age will be presented elsewhere; however, a description regarding the effects of time on task has been separated for the young and old drivers.

The drivers visited the laboratory at least 3 days before the actual experiment for an interview to verify that the inclusion criteria were satisfied and that the person was informed about the experimental procedure, and also so that the person could practice driving the simulator. They were also informed about how to use the subjective Karolinska sleepiness scale (KSS) (28). The KSS ranges from 1–9, for which 1=very alert, 5=neither sleepy nor alert, 7=sleepy but no effort to remain awake, and 9=very sleepy, an effort to stay awake, fighting sleep. The scale was modified to have labels also on intermediate steps (29). The participants were instructed to give a number that corresponded to how they had felt during the last 5 minutes. The scale was prompted by an instruction displayed on the windshield, with the response given orally. To support the participants, there was a scale pasted to the steering wheel.

The participants were instructed to have a normal night's sleep before the experimental day, to rise no later than 0800, not to drink coffee within 6 hours before arriving at the laboratory, and not to use alcohol for 72 hours before the experiment.

The drivers arrived at the laboratory during the late afternoon. All of the participants started with an early evening drive. They then stayed awake until late night, when the second drive was scheduled. The time between the two drives was approximately 9 hours. Each drive lasted for 1.5 hours, the first part (45 minutes) involved normal driving, but the second part (45 minutes) involved the use of a sleepiness warning system. For this paper, data from minutes 5–45 have been used. All of the participants managed to drive for this period.

During the experiment two participants drove in close sequence. The first participant arrived at 1700, and the second came at 1800. When the first participant arrived, the EEG, EOG, and EMG electrodes were applied immediately. A modified, 3-minute, Karolinska drowsiness test (KDT) (22) was carried out before the driving. During the test, the participants were seated with their eyes open, focusing on a stimulus (dark circle) placed on the wall at a distance of approximately 50 centimeters from the head. Then the participant was taken directly to the simulator for his or her first drive. No food was served before the drive. The participant was ready to drive around 1800, at the same time as the second participant arrived. After the evening condition, the participants stayed in the laboratory during the night, without sleep, supervised by an experimenter. They were served dinner at about 0030, and the first driver drove a second time between 0230 and 0400, followed by the second driver between 0400 and 0530. The participants were sent home by taxi.

An advanced moving-base driving simulator [Swedish National Road and Transport Research Institute (VTI)] was used. The car body consisted of the front part of a Volvo 850 with a manual 5-shift gearbox. The noise, infrasound, and vibration levels inside the cabin corresponded to those of a modern car. There were three channels of forward view a total of 120 × 30 degrees from the participant's position in the simulator. The driving simulator model has been extensively validated (30–32).

Scenario

The participants drove a route on a 2-lane motorway with a posted speed limit of 110 km/h in right-hand traffic. They were instructed to drive legally and as they normally would on a similar road. The road had a smooth curvature with high friction and dry summer conditions. The road was repeated every 18 km. The ambient light conditions corresponded to daylight, cloudy but with good visibility. There was no other traffic, either oncoming or going in the same direction as the participant; hence the participants did not have any reason to change lanes.

Driving behavior

The driving behavior data obtained from the simulator were speed (mean and variability) and lateral position (mean and variability). Driving behavior was recorded at a frequency of 33.33 hertz. Lateral position was defined as the perpendicular distance (at the lane border) between the right-hand side of the right front wheel to the left side of the right lane border (continuous line), and the lateral position was defined as the middle of the car in relation to the right edge line; the unit of measure was meters (see figure 1). Lane departure was defined as two wheels touching the lane boundaries (center line or the right edge line).

Physiological state of the driver

A Vitaport II system (Temec Instruments BV, Kerkrade, Netherlands) was used to record the EOG (electrooculogram), EEG (electroencephalogram), and EMG (electromyogram). The electrodes used for the EOG and EMG were of disposable silver–silver chloride. The EMG signal was used to detect artifacts in the EEG due to facial muscle activity (eg, yawning). The EMG electrodes were placed under the chin. The EEG was measured through three bipolar derivations positioned at Fz-A1, Cz-A2, and Oz-Pz. The electrodes were silver plated and not disposable. Six electrodes were used to record the EOG, four vertical (above and under the left and right eye) and two horizontal. The EOG was DC (direct current) recorded. The sampling frequency was 512 hertz for the EOG and EMG and 256 hertz for the EEG.

The EOG data were analyzed with a MATLAB program developed by the Center for Applied and Environmental Physiology (Dr A Muzet & Thierry Pebayle, CEPA, Strasbourg, France). It essentially involves a low-pass filter to establish a stable baseline for the signal, establishing a threshold that has to be exceeded to score a blink (done visually) with computation of the start and end point of the blink based on the slope and computation of blink duration done at midslope. To reduce problems with concurrent eye movements and eye blinks, blink durations were calculated as half the amplitude of the upswing and downswing of each blink, and then the time elapsed between the two was computed.

The EEG and EOG data were scored visually for sleep-related patterns using conventional criteria (15). Twenty-second epochs were divided into 10 steps of 2 seconds, each scored with respect to whether alpha waves (8–12 Hz), theta waves (8–12 Hz), and slow

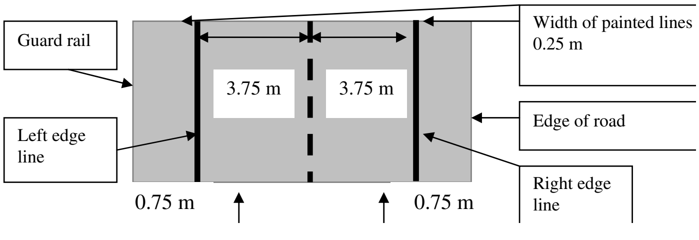

Figure 1. Simulator road measurements and outlines, representing the two lanes visible for a person driving on a motorway.

rolling eye movements occurred. Each epoch was assigned a value between 0% and 100% on the basis of the proportion of signs of physiological sleepiness. For example, an epoch that included three 2-second segments with physiological sleepiness would be represented by the KDS value of 30% (21). For the current analysis, the maximum KDS during a 1-minute period was used.

Analyses

The data were analyzed in 1-minute windows (3 epochs of 20 seconds). "Time interval 1" means that data from 0.0 seconds to 60.0 seconds were used, "time interval 2" covered data from 60.0 seconds to 120.0 seconds, and so forth. In the analysis, a 1-minute window was considered to be a minute with a lane departure if there was at least one departure within that minute. Data from the first 5 minutes of driving was excluded. The analyses were done using SPSS (version 15.0, SPSS Inc, Chicago, IL, USA). The significance level was set to 5% in all of the tests.

Time on task

In order to describe whether there were any effects of the dependent variables in relation to time driven (minutes), an analysis of variance (ANOVA) with a repeated measures design was carried out with time driven (5-minute interval) as a factor and age as a between factor. The used dependent parameters were the mean and variability for speed, lateral position, and blink duration, but also the KDS and KSS. The Huynh-Feldt correction for sphericity was used. In the analysis, all of the participants (N=19) were included.

Karolinska drowsiness score

Differences in the sleepiness levels were analyzed using an ANOVA with the KDS levels as a fixed factor and participants as a random factor (table 1). A model including age as a fixed factor and participant nested within age was also tried. It did not influence the results. Interactions were not included in the model. The dependent parameters used were the mean and variability for speed, lateral position, and blink duration but also the KSS. The number of observations included for each person was the number of minutes (41). The distribution according to the KDS level was the result of the experiment. In the analysis, the participants (N=8) that experienced a KDS level of 50 were included.

Of the 19 participants, 8 reached a KDS of ≥50%. Six KDS levels were used (0%, 10%, 20%, 30%, 40%, and ≥50%).

In order to analyze the risk of lane departure at different levels of KDS sleepiness, a Cox regression was performed. Cox regression is a method for modeling time-to-event data, and it includes predictor covariates. The Cox regression is based on a survival function, and, in this case, the event was considered to be the lane departure (2 wheels at least touching the lane boundaries). An enter method was used. To minimize problems with unbalanced data, only data up to and including the fifth lane departure for each participant were used. Data for all 19 participants were used, and 13 of the participants had lane departures. If the participant had fewer than 5 lane departures, all of the available data were included. The time-dependent covariate (T Cov) was set as a function describing whether or not specific

Table 1. Used analysis of variance (ANOVA) models. [N = observations, k = levels of the Karolinska drowsiness score (KDS), j = participant, df = degrees of freedom]

Description	
Observations (N)	328
KDS (k)	6
Subject (j)	8
df (k-1, n-((k-1)-(j-1))-1	5, 315

Table 2. Distribution of the minutes of the different levels of the Karolinska drowsiness score and of the minutes with lane departures (19 participants), also minutes with lane departures and the percentage of the total minutes at each level of the Karolinska drowsiness score (KDS).

KDS	Observed KDS minutes	Lane departures
0%	367	28 (8%)
10%	167	22 (13%)
20%	86	21 (24%)
30%	70	24 (34%)
40%	41	18 (43%)
50–100%	48	13 (27%)
Total	779	126

Table 3. Results of the analysis of variance (ANOVA) with a repeated-measures design. Huynh-Feldt correction for sphericity was used [F-value, P-value, degrees of freedom for minutes (7, 119)]. Age was used as a between-factor. Signficant effects are shown in boldface. (SD = standard deviation, KDS = Karolinska sleepiness scale)

	Minutes (8 levels)		Minute × age		Age (between-factor)	
	F-value	P-value	F-value	P-value	F-value	P-value
Speed	0.97	0.44	0.80	0.55	0.01	0.93
Speed (SD)	1.81	1.47	0.90	0.46	0.47	0.50
Lateral position	0.71	0.61	1.35	0.27	**7.19**	**0.02**
Lateral position (SD)	**8.82**	**<0.00**	0.57	0.64	0.05	0.82
Blink duration	**6.55**	**<0.00**	1.73	0.13	**7.57**	**0.01**
Blink duration (SD)	**6.07**	**<0.00**	0.90	0.50	**10.23**	**<0.00**
KSS	**37.56**	**<0.00**	0.99	0.43	**6.33**	**0.02**

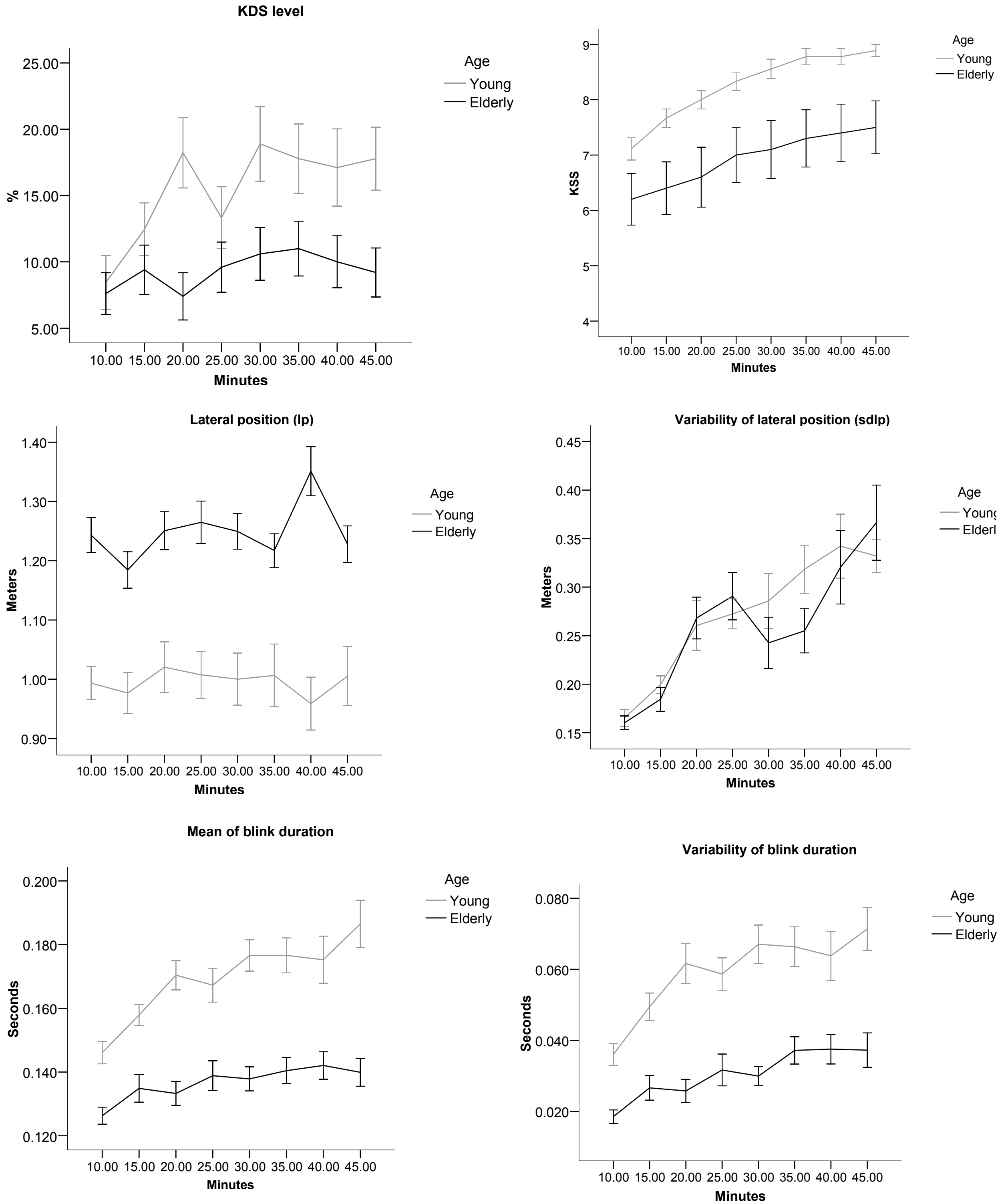

Figure 2. Karolinska drowsiness score (KDS), Karolinska sleepiness score (KSS), mean, standard error of the mean, and variability of the lateral position and blink duration over time (minutes: 8 levels) for young and elderly drivers (N=19).

data were obtained from before the first lane departure, from between the first and the second lane departure, from between the second and third lane departure, and so forth. The covariates were the time driven and the KDS level.

Results

When the 5 first minutes of driving were excluded, 8 participants experienced one or more minutes at a maximum KDS level of 50% or higher, and 7 participants experienced a maximum KDS level of 40%. Moreover, 12 participants experienced a KDS level of 30%, 19 participants experienced a KDS level of 20%, and 17 participants experienced a KDS level of 10%. One participant did not show a KDS at all. The number of observed minutes for each level of KDS is presented in table 2 (see page 145). Altogether there were 412 observations (53%) in which the participants had signs of sleepiness (KDS of ≥10%).

Of the 19 participants, 13 had lane departures in at least one of the 1-minute periods. Altogether there were 126 minutes with lane departures. Six participants experienced 10 minutes or more with lane departures, 3 participants experienced 5–9 minutes with departures, and 4 participants experienced 1–4 minutes with departures.

On the basis of the data from the 19 participants, table 3 and figure 2 (on pages 145 & 146) show that, for the variability of the lateral position, the mean and variability of the blink duration, and the KSS, there was a significant effect of time on task (minutes). In all cases, sleepiness increased with time in the task. In addition, the effect indicated an increased level of sleepiness in the young group for the lateral position, the mean and variability of the blink duration, and the KSS. There was no interaction between time in the task and age.

There was an effect of different KDS levels on the mean and variability of the blink duration, but also on the variability of the lateral position. Increased levels of physiological sleepiness (KDS of 0–50%) resulted in an increased mean and variability of the blink duration and an increase in the variability of the lateral position (sdlp). [See table 4, and also figure 3 on page 148.] For the KSS, the increase was significant on the 0.10 level.

There was a significant increase in the risk of lane departure for a KDS of 30% and 40%, compared with a KDS of 0% (table 5 on page 149). The overall chi-square was 22.49 (5 degrees of freedom, $P<0.05$). The risk of lane departure [Exp (β)] increased more than 6.0-fold when the participant experienced a KDS level of 40%, compared with a KDS of 0%.

Discussion

The change with time across the drive was significant for the variability of the lateral position, the mean and variability of the blink duration, and the KSS. The increased sleepiness, driving impairment, and long eye blink durations were expected for most of the variables on the basis of prior work (14, 33, 34), and the level of sleepiness at the end of the drive was pronounced.

The age effect was pronounced in some cases in that the young participants were less able to sustain alertness. This result was not due to the groups being different at the start for most of the variables. The results agree with accident data (23–26) and with clinical data that indicate that the multiple sleep latency test shows close to pathological values (around 5 minutes' latency to sleep) for young adolescents (35). However, except for lateral position, performance did not differ between the groups. According to accident data, such a difference could have been expected. The absence of a performance difference could have been due to the difference in sleepiness not being sufficient to affect driving performance. This possibility will have to be determined in future studies. Our study thus confirms that young drivers seem more susceptible during night driving.

The results of the analysis of the KDS data versus those on the other variables showed that there was an effect of KDS level on the mean and variability of the blink duration and the variability of the lateral position. When physiological sleepiness increased (KDS 0–50%), there was an increase also for these variables. Furthermore, when the KDS level increased, there was an increased risk of lane departure, particularly at a KDS of 40% (>6 times). The drivers showed sleepiness signs during more than 50% of the time.

Figure 3 indicates that the lowest level of increase in the KDS did not show any increase in lateral variability or risk of lane departure. Such effects did not occur until a KDS of 20% and first became significant at a KDS of 30%. This finding suggests that performance does not become seriously impaired until the EEG or EOG recording indicates sleep onset processes for more than 6 seconds (30%) out of a 20-second scoring interval. The very high risk at the KDS level of 40% is difficult to interpret, but, since the risk was lower at a KDS of 50%, we assume that the peak in risk at a KDS of 40% may have been spurious and due to a few persons with very high risk, as suggested by the increased confidence interval at a KDS of 40%.

Table 4. Results of the analysis of variance (ANOVA) [Karolinska sleepiness scale (KSS) of 0–50%] [F-value, P-value, degrees of freedom (5, 315)]. Signficant effects are shown in boldface. (SD =standard deviation, NS = not significant, df = degrees of freedom)

	KDS (6 levels)		
	F-value	P-value	df
Speed	2.19	NS	5, 315
Speed (SD)	1.49	NS	5, 315
Lane position	2.12	NS	5, 315
Lane position (SD)	**5.28**	**<0.01**	5, 315
Blink duration	**9.69**	**<0.00**	5, 315
Blink duration (SD)	**8.91**	**<0.00**	5, 315
KSS	1.94	0.10	5, 51

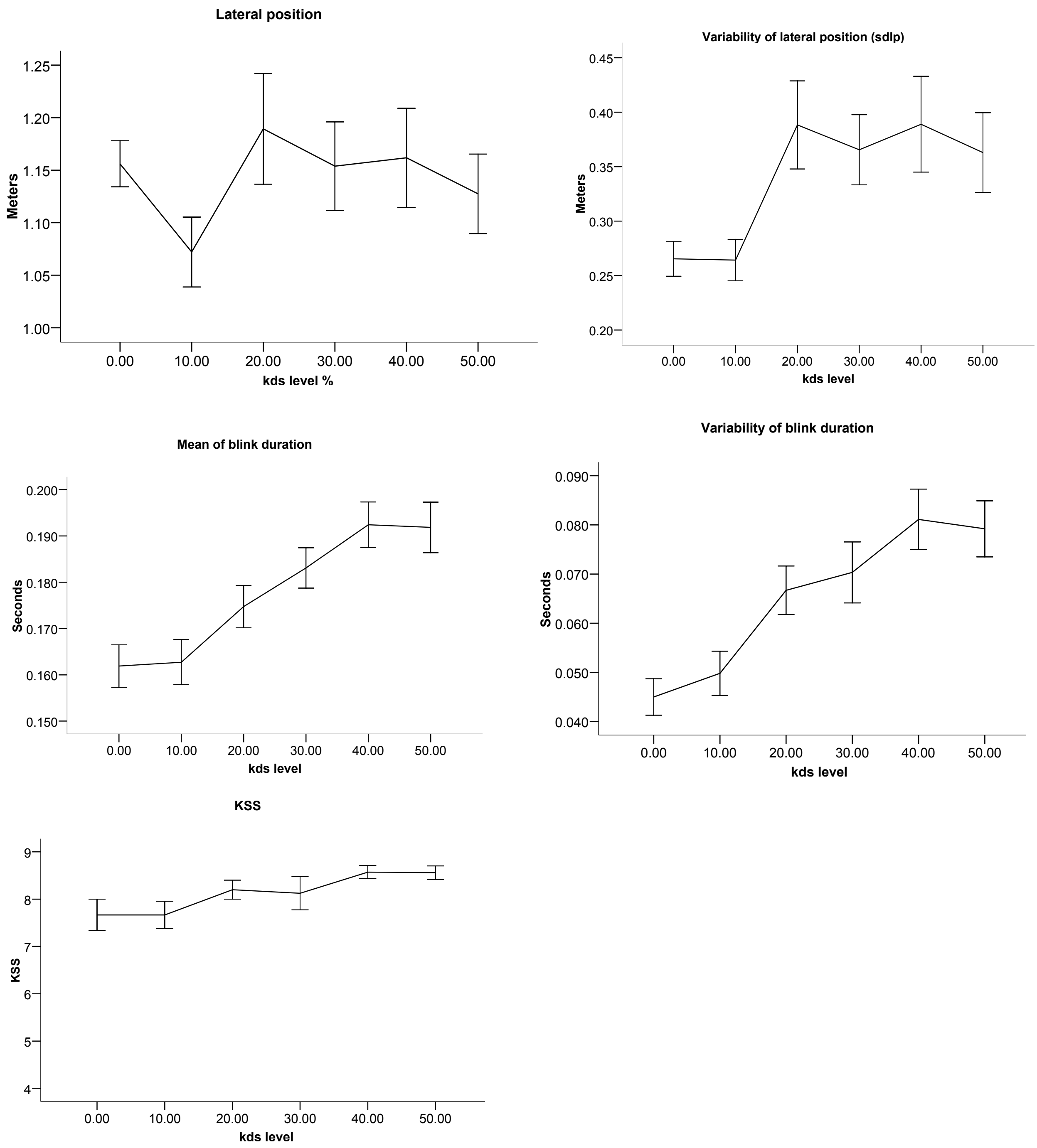

Figure 3. Mean, standard error of the mean, and variability of the lateral position and blink duration and the Karolinska sleepiness score (KSS) for the Karolinska drowsiness score (KDS, 6 level) (N=8).

We also speculate that the lack of a continuous increase in driving impairment above a KDS of 40% could have been brought about by the participants becoming aware of their sleepiness and therefore increasing their effort and taking counteraction. However, activities to counteract sleepiness were not monitored in our study.

KDS applies the traditional criteria of polysomnographical sleep onset to recordings obtained under conditions of wakefulness, the assumption being that “physiological sleepiness” is represented. The latter is, however, only a construction based on inference, and an absolute definition of physiological sleepiness does not exist. Attempts to validate a measure of physiological sleepiness must therefore use other variables assumed to measure the same property. The most well-established one is eye blink duration (12). In our present study, the relation between the KDS and blink duration was one of a gradual increase in both the mean and the variability. This finding seems to support the notion of the KDS representing physiological sleepiness. However, there seems to be little difference between a KDS of 0% and a KDS of 10%, and there also seems to occur a flattening at the highest sleepiness level. This finding could mean that sleepiness is saturated at this level, and sleep is taking over, partly eliminating blinking and making blinks more difficult to identify. The close relation between eye blink duration and the KDS seems to suggest that KDS could possibly be improved by the addition of long eye blink durations to the scoring criteria.

Participant sleepiness (KSS) only showed a trend towards an increase across the KDS levels. An inspection of figure 2 suggests that one reason may be the obvious restriction of range caused by the very high level of sleepiness at the start (7.4 units) and the ceiling effect due to the scale's end point being 9. One could conceive of using a higher end point, but it is logically difficult to argue that one can perceive sleepiness to exceed the level when one is "fighting sleep (exerting) in an effort to remain awake". Physiological and behavioral indicators can, however, logically be extended considerably further, while a person is fighting a losing battle against an increasing frequency of micro sleep.

There were 48 occasions with KDS levels of >50%, but only 13 out of these resulted in lane departures (27%). This finding is in line with the results of earlier studies (2). Thus high levels of physiological sleepiness do not automatically lead to lane departures. This situation could be due to the presence of a stretch of straight road with less risk of lane departure or to the pattern of physiological sleepiness—10 continuous seconds may give more time to depart from the lane than an on–off pattern does. We could also speculate that there is a need for the presence of theta activity [indicating sleep (15)] or perhaps slow eye movements or very long eye blinks. The relative importance of these indicators has not been established. To establish the latter seems an important future task.

One implication of our findings is that a fatigue warning system should be activated no later than at a KDS of 20%. At this level signs related to a decrease in driving performance and a risk of lane departure is observed. This finding is based on night driving, however, and may not apply to day driving since a KDS of 20% occurred too seldom for a proper analysis.

One limitation of this study is the use of simulator data instead of data from actual driving. Clearly, sleepiness may show a completely different pattern on an actual road even if our simulator was very realistic (36). The advantage with the simulator is the possibility to monitor the driver without any risk of complete onset of sleep and actual lane departure. Since touching the lane boundaries is an early indication of an incident, it could however be possible to run a similar experiment on a test track or on real road without risk. A disadvantage would still be the need for a vehicle equipped with double command and a supervisor present to stop the session if necessary. Philip et al (37) concluded, in a comparative study, that sleepiness can be studied equally well in actual and simulated driving conditions. The effects are the same except that the simulator shows more frequent line crossings and road departures than driving in a real environment.

Table 5. Cox regression for lane departure—odds ratio for lane departure Exp(β), 95% confidence inteval (95% CI), and significant level (P-value). Significant effects are shown in boldface. [Reference value: Karolinska drowsiness score (KDS) = 0 (19 participants; 659 observations; 53 lane departures; 13 participants with lane departures)]

	Odds ratio	95% CI	P-value	Observations (N)	Lane departures (N)
KDS 10%	1.20	0.54–2.67	0.66	140	9
KDS 20%	2.16	0.94–5.00	0.07	64	8
KDS 30%	**2.61**	**1.03–6.59**	**0.04**	51	6
KDS 40%	**6.04**	**2.51–14.53**	**<0.00**	27	7
KDS 50%	1.95	0.72–5.25	0.19	37	5

Another limitation of simulator studies is that, after a lane departure, drivers are aware of the fact that lane departure will involve no crash, unlike actual driving. Even if some of the drivers experienced several lane departures and only the five first were included in the study, it may be that the situation was too unrealistic. An advantage with Cox regression is, however, that it, to some degree, handles different hazard functions for lane departures, depending on whether a departure is the first, second, third, and so forth.

In summary, our study has shown that simulator driving during late night affects behavior, depending on the level of physiological sleepiness (KDS). The risk of lane departures increases when sleepiness increases. The maximum risk for lane departure occurred at a KDS level of 40%. When driving late at night in a sleep-deprived situation, the driver showed sleepiness signs (KDS ≥10%) about 50% of the time. The results seem to suggest that the KDS procedure is a reasonable means with which to estimate physiological sleepiness in different tasks. It might, for example, serve as a proxy in studies searching for methods to monitor alertness.

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References

1. Kecklund G, Åkerstedt T. Sleepiness in long distance truck driving: an ambulatory EEG study of night driving. Ergonomics. 1993;36(9):1007 17.
2. Mitler MM, Miller JC, Lipsitz JJ, Walsh JK, Wylie CD. The sleep of long-haul truck drivers. N Engl J Med. 1997;337:755–61.
3. Åkerstedt T. Consensus statement: fatigue and accidents in transport operations. J Sleep Res. 2000;9(4):395.
4. National Transportation Safety Board (NTSB). Evaluation of US Department of Transportation: efforts in the 1990s to address operation fatigue. Washington (DC): National Transportation Safety Board; 1999. Safety Report NTSB/SR-99/01.
5. Dinges DF, Mallis MM. Managing fatigue by drowsiness detection: can technological promises be realized. In: Hartley L, editor. Managing fatigue in transportation, Oxford (United Kingdom): Elsevier Science; 1998.
6. Brookhuis K, de Waard D. The use of psychophysiology to assess driver status. Ergonomics. 1993;36:1099–110.
7. Jewett ME, Dijk D-J, Kronauer RE, Dinges DF. Dose-response relationship between sleep duration and human psychomotor vigilance and subjective alertness. Sleep. 1999;22:171–9.
8. Åkerstedt T, Folkard S. The three-process model of alertness and its extension to performance, sleep latency, and sleep length. Chronobiol Int. 1997;14(2):115 23.
9. Horne JA, Reyner LA. Vehicle accidents related to sleep: a review. Occup Environ Med. 1999;56(5):289–94.
10. Horn J, Baulk S. Awareness of sleepiness when driving. Psychophysiology. 2004;41:161–5.
11. Otmani S, Joceline R, Alain M. Sleepiness in professional drivers: effect of age and time of day. Accid Anal Prev. 2005;37(5):930–7.
12. Wierwille WW, Ellsworth LA. Evaluation of driver drowsiness by trained raters. Accid Anal Prev. 1994;26:571–81.
13. O'Hanlon J, Kelly G. A psycho-physiological evaluation of devices for preventing lane drift and run-off-road accidents. Goleta (CA): Human Factors Research Inc; 1974. Technical Report 1736-F
14. Otmani S, Pebayle T, Roge J, Muzet A. Effect of driving duration and partial sleep deprivation on subsequent alertness and performance of car drivers. Physiol Behav. 2005;84:715–24.
15. Rechtschaffen A, Kales A. A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects. Bethesda (MD): US Department of Health, Education and Welfare, Public Health Service; 1968.
16. Carskadon MA, Dement WC, Mitler MM, Roth R, Westbrook P, Keenan S. Guidelines for the multiple sleep latency test (MSLT): a standard measure of sleepiness. . Sleep. 1986;9(4):519–24.
17. Mitler M, Gujavarty K, Broman C. Maintenance of Wakefulness Test: a polysomnographic technique for evaluating treatment efficacy in patients with excessive somnolence. Electroencephalogr Clin Neurophysiol. 1982;53:658–61.
18. Valley V, Broughton R. The physiological (EEG) nature of drowsiness and its relation to performance deficits in narcoleptics. Electroencephalogr Clin Neurophysiol. 1983;55:243–51.
19. Sallinen M, Härmä MI, Akila R, Holm A, Luukonen R, Mikola H, et al. The effects of sleep debt and monotonous work on sleepiness and performance during a 12-h dayshift. J Sleep Res. 2004;13:285 94.
20. Santamaria J, Chiappa KH. The EEG of drowsiness in normal adults. J Clin Neurophysiol. 1987;4:327–82.
21. Gillberg M, Kecklund G, Åkerstedt T. Sleepiness and performance of professional drivers in a truck simulator comparisons between day and night driving. J Sleep Res. 1996;5:12 5.
22. Lowden A, Holmbäck U, Åkerstedt T, Forslund J, Lennernäs M, Forslund A. Performance and sleepiness during a 24 h awake in constant conditions are affected by diet. Biol Psychol. 2004;65:251 63.
23. Horne JA, Reyner LA. Driver sleepiness. J Sleep Res. 1995;4 suppl 2:23–9.
24. Langlois PH, Smolensky MH, Hsi BP, Weir FW. Temporal patterns of reported single-vehicle car and truck accidents in Texas, USA during 1980–1983. Chronobiol Int. 1985;2(2):131–46.
25. Lavie P, Wollman M, Pollack I. Frequency of sleep related traffic accidents and hour of the day. Sleep Res. 1987;16:275.
26. Åkerstedt T, Kecklund G. Age, gender and early morning highway accidents. J Sleep Res. 2001;10:105 10.
27. Campagne A, Pebayle T, Muzet A. Correlation between driving errors and vigilance level: influence of the driver's age. Physiol Behav. 2004;80:515–24.
28. Åkerstedt T, Gillberg M. Subjective and objective sleepiness in the active individual. Int J Neurosci. 1990;52:29 37.
29. Reyner LA, Horne JA. Falling asleep whilst driving: are drivers aware of prior sleepiness? Int J Legal Med. 1998;111:120–3.
30. Jerand A. Improvement, validation and multivariate analysis of a Real Time Vehicle Model. Stockholm: Royal Institute of Technology (KTH); 1997.
31. Aurell J, Andersson J, Fröjd N, Jerand A, Nordmark S. Correlation between objective handling characteristics and subjective perception of handling qualities of heavy vehicles. Gothenburg (Sweden): Volvo Truck Corporation; 1999. Volvo internal report (classified).
32. Aurell J, Nordmark S, Fröjd N. Correlation between objective handling characteristics and subjective perception of handling qualities of heavy vehicles. In: Proceedings of the 5th International Symposium of Advanced Vehicle Central (AVEC); August 22–24, 2000; Ann Arbor (MI), USA; 2000. Ann Arbor (MI): AVEC; 2000.
33. Horne JA, Baulk SD. Awareness of sleepiness when driving. Psychophysiology. 2004;41:161–5.
34. Åkerstedt T, Peters B, Anund A, Kecklund G. Impaired alertness and performance driving home from night shift: a driving simulator study. J Sleep Res. 2005;14:17 20.
35. Carskadon MA, Harvey K, Dement WC. Sleep loss in young adolescents. Sleep. 1981;4:299–312.
36. Törnros J. Driving behaviour in a real and simulated road tunnel a validation study. Accid Anal Prev. 1998;4:497 503.
37. Philip P, Sagaspe P, Taillard J, Valtat C, Moore N, Åkerstedt T, et al. Fatigue, sleepiness, and performance in simulated versus real driving conditions. Sleep. 2005;28(12):1511–6.

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