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Rumble Strips in Centre of the Lane and the Effect on Sleepy Drivers

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Abstract: The aim of this study was to describe the effects of sleep loss on behavioural and subjective indicators of sleepiness on a road containing a milled rumble strip in the centre of the lane. Particular attention was paid to behavioural and subjective indicators of sleepiness when using the centre lane rumble strip, and to possible erratic driving behaviour when hitting a rumble strip. In total 9 regular shift workers drove during the morning hours after a full night shift and after a full night sleep. The order was balanced. The experiment was conducted in a moving base driving simulator on rural roads with a road width of 6.5 and 9 meters. Out of the 1,636 rumble strip hits that occurred during the study, no indications of erratic driving behaviour associated with the jolt caused by making contact with the centre lane rumble strip could be found. Comparing the alert condition with the sleep deprived condition, both the standard deviation of lateral position (SDLP) and the Karolinska Sleepiness Scale (KSS) increased for sleepy drivers. For the two road widths, the drivers drove closer to the centre line on the 6.5-meter road. The KSS and the SDLP increased with time on task. This simulator study indicates that rumble strips in the centre of the lane may be an alternative to centreline and edgeline rumble strips on narrow roads.

Key words: Milled rumble strips, Centre of the lane, Narrow rural roads, Sleepy drivers, Driving behaviour, Driving simulator study

Introduction

Work hours and sleep habits are important factors when it comes to occupational safety and it is known that night driving increases crash risk several fold (5–6 times)[1–3]. Night shift work is also associated with increased reported sleepiness[4, 5] and especially driving home after a night shift is a critical situation with at least a doubling of the risk of a crash[6, 7]. Sleepiness and fatigue have been estimated to account for 10 to 30 per cent of all crashes[1, 2, 8–11]. Recently, it has also been shown that sleepiness may be a stronger cause to road crashes than alcohol and that the two factors interact in a dramatic way[12]. Finding countermeasures against sleepy driving is therefore of great importance.

There are a number of more or less effective methods that drivers use to avoid acute sleepiness while driving[13, 14]. A few common examples include napping, caffeine consumption, taking a break, opening a window, turning on the radio, singing and talking. Very few have been systematically tested in sleepy drivers except for the first two ones[15]. A systematic public intervention approach is the so called rumble strips. The rumble strips are useful not only to alert sleepy drivers, but also to warn distracted drivers[16, 17]. The introduction of rumble strips at the centreline has been found to reduce crashes by approximately 15%, and the effect of rumble strips on the edgeline is even more positive, with a reduction of 40–50%[18, 19]. The best effect is achieved by installing rumble strips on both edgeline and centreline[17]. Based on physiological indicators

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as well as on driving behaviour, it has been shown that sleepy drivers are alerted as they hit the rumble strip[20]. However, the alerting effect is temporary, and after 3–4 min the driver is back to pre-hit drowsiness levels[20]. There is no evidence for erratic behaviour as a result of the jolt caused by making contact with the strip either in alert[21, 22] or sleepy drivers[20]. A Finnish study with alert drivers[23] showed an effect in terms of a decrease in mean and standard deviation of lateral position due to less space for swerving before hitting the rumble strips.

Adding rumble strips to an existing road both on the centreline and edgeline requires that the road is wide enough to house the rumble strips. This means that rumble strips placed at the centreline and at the edgeline cannot be used on narrow roads. An alternative approach which prevents a vehicle from exiting its lane is to place one rumble strip in the centre of the lane instead. This countermeasure needs less space and only needs to be placed in the centre of the lanes instead of on both the centreline and the edgeline. The results of such approaches are not well researched. One might assume the occurrence of more driving in the middle of the lane compared to conventional placement of rumble strips. A second issue is the effect of sleep loss on reactions to mid-lane rumble strips. Possibly, this position will aid the driver to stay on course and reduce the variability of driving patterns that is normally seen with sleepy driving[20].

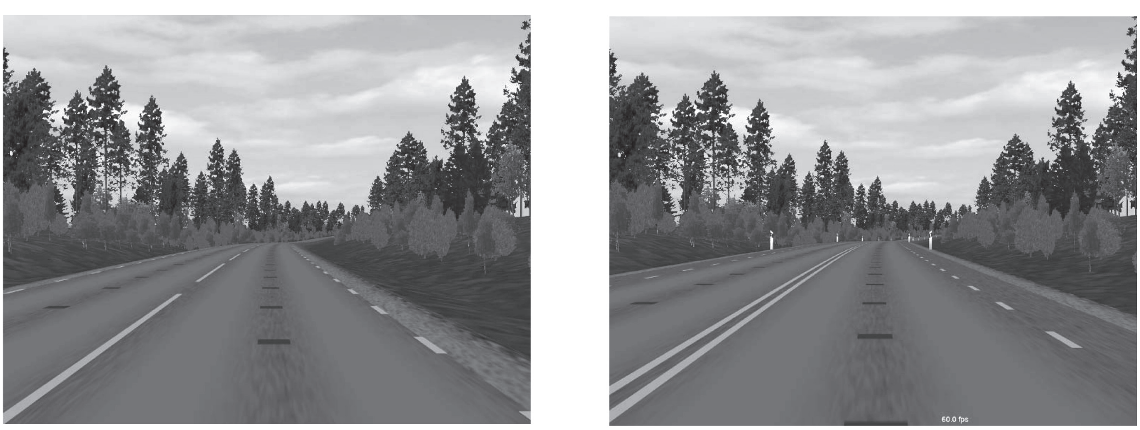
The primary aim of this study was to investigate the effects of sleep loss on driving behaviour and subjective sleepiness ratings when driving on a road with a milled rumble strip in the centre of the lane. A secondary aim was to compare rumble strips in the centre of the lane with the more established rumble strip placement on the centreline and edgeline of the road. The secondary aim was investigated with a cross-study comparison with a previous study on the effect of sleep loss on rumbles strips at the centreline and edgeline. The two studies involved the same individuals and were identical in all other aspects except for the position of the rumble strips.

Method

Design

The design of the study involved two conditions – sleep deprivation and normal sleep. The order of conditions was balanced between participants and within sex. The sleep deprived condition took place in the morning directly after a night of regular night-work and the normal sleep condition took place in the morning after a night with normal sleep. During 40 min of the drive the road width was 9 m (lane width 3.5 m; shoulder 1 m), and during 40 min it was 6.5 m (lane width 3.15 m; shoulder 0 m), see Fig. 1. Both types of roads were two-lane roads (one lane in each direction). Since Swedish rural roads are mainly 6.5 or 9 m wide, both types were studied. The order between road types was balanced between the participants.

For the comparison of rumble strip placement, the results from the centre of the lane placement on the 9 m road of the present study was compared with the 9 m road with rumble strips on both the centreline and the edgeline from a previous study. The two studies were identical except for the placement of the rumble strips[20].



Road width: 6.5 m;
Lane width: 3.15 m
Shoulder: 0 m

Road width: 9 m;
Lane width: 3.5 m
Shoulder: 1 m

Fig. 1. Scenarios used with Målilla rumble strip (length 15 cm; depth 1.0 cm; width 35 cm; distance 105 cm).

Participants

All participants had previously been involved in a simulator study with milled rumble strips[20], and 4 females and 5 males from that earlier, identical, study were recruited for this complementary investigation of rumble strips located in the centre of the lane. In the previous study, 35 participants drove on roads with several types of rumble strips, 9 of which used the same type of rumble strip as was used in the current study. These drivers were prioritized when recruiting participants to the current study in order to facilitate comparisons between the two studies. The participants had a mean age of 42 yr (SD=9.9 yr), they had had their driving license for 20 yr (SD=9.8 yr) and they drove 17,000 km (SD=4,720 km) last year. All were shift workers mainly from the hospital and the police. The criteria for participation included good reported health (questionnaire), absence of sleep disturbances (including restless legs), no glasses needed for driving (to permit camera monitoring of eye movements), a minimum of 15,000 km of driving per year, and no problems with motion sickness (for the simulator).

One participant had been involved in a sleep related crash and 3 had experience of incidents caused by sleepiness. The majority of the participants (6 persons) reported that they normally have enough sleep and a rather high sleep quality. One subject reported a "rather bad" sleep quality, and three subjects reported that they "to some part" do not sleep enough. None of the subjects reported snoring or problems to fall asleep more than occasionally. The BMI in the subjects was on average 26 (SD 6).

The average value on the Epworth sleepiness scale[24] was 8 (SD 3.2; min 2; max 13). The participants received a monetary compensation of approximately €200. The study was approved by the local ethical committee (Regionala etikprövningsnämnden i Linköping (EPN), 2006 dnr 179-06) and all participants gave their informed consent.

Materials

An advanced moving base driving simulator at the Swedish National Road and Transport Research Institute (VTI) was used, see Fig. 2. The car body consisted of the front part of a Volvo 850 with a manual 5 shift gearbox. Noise, infra-sound and vibration levels inside the cabin corresponded to those of a modern car. There were three channels of forward view covering 120° × 30° from the subject's position in the simulator. The driving simulator model has been extensively validated[25–27]. To generate the sensation of driving on real milled rumble strips in the simulator, the sound system was used to produce noise and the moving base induced vibrations into the simulator car cabin while the torque motor induced vibrations in the simulator steering wheel[28].

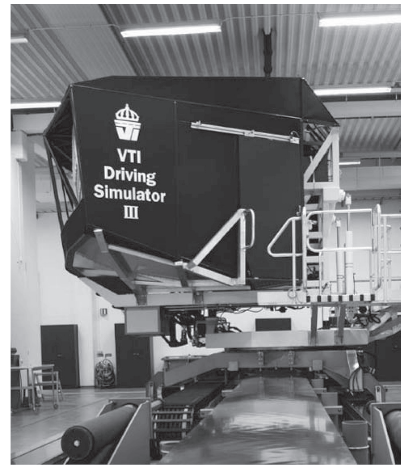


Fig. 2. VTI's driving simulator III.

The scenario consisted of a rural road with a speed limit of 90 km/h. The rumble strip was of the so called "Målilla" type (length 15 cm; depth 1.0 cm; width 35 cm; distance 105 cm; increase in dB(A) 7 dB(A)). The driving condition was daylight, clear view and full friction. The road had a smooth curvature. There was oncoming traffic, but no vehicles in front. The only difference in the scenario between the new data set and the previously collected data set was the rumble strip placement (centre of the lane as compared to centreline and edgeline).

The driving behaviour data obtained from the simulator were lateral position, standard deviation of lateral position (SDLP) and speed. Lateral position was defined as the perpendicular distance from the centre of the road to the centre of the car and the unit was in meters. Also the number of rumble strip hits was recorded. Driving behaviour was recorded at a frequency of 25 Hz.

The drivers rated their sleepiness on the Karolinska Sleepiness Scale (KSS)[29]. The KSS ranges from 1–9 where 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[30].

Procedure

The participants were instructed not to drink alcohol for 72 h before the test day, not to drink coffee/tee or eat three hours before arrival at the laboratory, and not to take naps during the preceding night shift. They also filled out background questionnaires, sleep and wake diaries (three days before arriving at both conditions) and informed consent. They were also instructed to learn and practice to use KSS[29]. In order to keep control of the participants' preparations they were instructed to send a text message (SMS) to the laboratory at two, three and four am.

The study procedure was the same for both conditions. The participants started with 10 min of training to get used to the simulator and to practise to use the KSS. The subsequent driving session was 80 min. During the drive the subjects reported KSS every fifth minute, corresponding to their experienced sleepiness level during the last five minutes. They were reminded by a written message "Sleepy?" presented on the screen of the driving simulator. After the driving session the participants were debriefed and sent home. During the sleep deprived condition the participants were brought to the simulator and back by taxi.

Statistical analyses

For the question on the effect of sleep loss when driving on road with a rumble strip in the centre of the lane, the statistical analysis involved repeated measures ANOVA (2*2*8). The independent factors were condition (sleep deprived – alert), road width (6.5–9 m) and time on task (8 levels: min 5–40 in 5-min intervals) and the dependent factors were KSS, lateral position, SDLP and speed. The independent factor time on task was included since it has a strong effect on many sleepiness indicators, especially for subjective sleepiness ratings and lateral variability[31].

The number of rumble strip hits was statistically analysed with repeated measures ANOVA (2*2). The independent factors were side of hit (left – right) and condition (sleep deprived – alert). The reason for the more aggregated level of this analysis is that there were no rumble strip hits in some of the time intervals. The partial correlation between rumble strip hits and SDLP was also calculated to check for relations between lane departures and an established objective indicator of sleepiness at wheel.

For the second question, when comparing rumble strip placement in the centre of the lane with the more established centreline and edgeline placement, a repeated measure ANOVA (2*8) with the independent factors placement of rumble strip (centre of the lane – centreline and edgeline) and time on task were used. Since the previous study only contained data from the 9 m road and from sleep deprived drivers, the factors condition and road width could not be included in the analysis. The dependent factors were KSS, lateral position, SDLP and speed.

All analyses were carried out with SPSS 15.0 and all tests used a significance level of α=0.05. A factor for participant was used as random in all analyses. The data were assumed to be normally distributed and this was checked for before the analysis started. The results were corrected for sphericity using the Huyhn-Feldt method. The time evolution of the car's position on the road after a rumble strip hit was evaluated using MATLAB 7.2.

Results

Milled rumble strip in the centre of the lane

There was a significant effect of sleep deprivation for SDLP (Alert: 0.12 m – Sleepy: 0.16 m) and KSS (Alert: 5.35 – Sleepy: 8.11). SDLP and KSS also increased over time (see Table 1 and Fig. 3). There was a significant effect of road width on lateral position (9 m: –1.54 – 6.5 m: –1.70) where the distance to the road centre decreased on the narrower road. There were no significant first level interactions except for condition*time for SDLP. The latter showed an increase in SDLP with time driven after sleep deprivation, compared to the full sleep condition. There were also significant interactions on the second level for condition*road width*time for KSS and SDLP, with increased levels during the sleep deprived condition on small roads and with increased time on task.

Table 2 summarizes the amount of rumble strip hits. There were less rumble strip hits in the alert condition as compared to the sleep deprived condition ($F_{(df\ 1,8)}$=16.38; p=0.004). However, the variation between individuals was large, with a total amount of rumble strip hits ranging from 0–67 in the alert condition and from 3–206 during the sleep deprived condi-

Table 1. Results from repeated measures ANOVAs. F-value and *p*-value

	Condition (df: 1, 7)	Road width (df: 1, 7)	Time (df: 7, 49)	Condition* *road width (df: 1, 7)	Condition *Time (df: 7, 49)	Road width *Time (df: 7, 49)	Condition* Road width *Time (df: 7, 49)
KSS	**283.09 (0.00)**	0.53 (0.49)	**74.87 (0.00)**	1.72 (0.23)	1.36 (0.28)	0.48 (0.62)	**6.25 (0.00)**
Lateral position (m)	3.30 (0.11)	**172.98 (0.00)**	1.11 (0.37)	0.05 (0.83)	1.80 (0.11)	0.99 (0.45)	0.63 (0.69)
SDLP (m)	**8.44 (0.02)**	0.55 (0.48)	**7.59 (0.00)**	0.02 (0.89)	**6.16 (0.00)**	0.93 (0.46)	**3.58 (0.03)**
Speed (km/h)	3.56 (0.10)	2.39 (0.17)	0.40 (0.69)	0.04 (0.86)	0.73 (0.57)	1.75 (0.19)	0.47 (0.76)

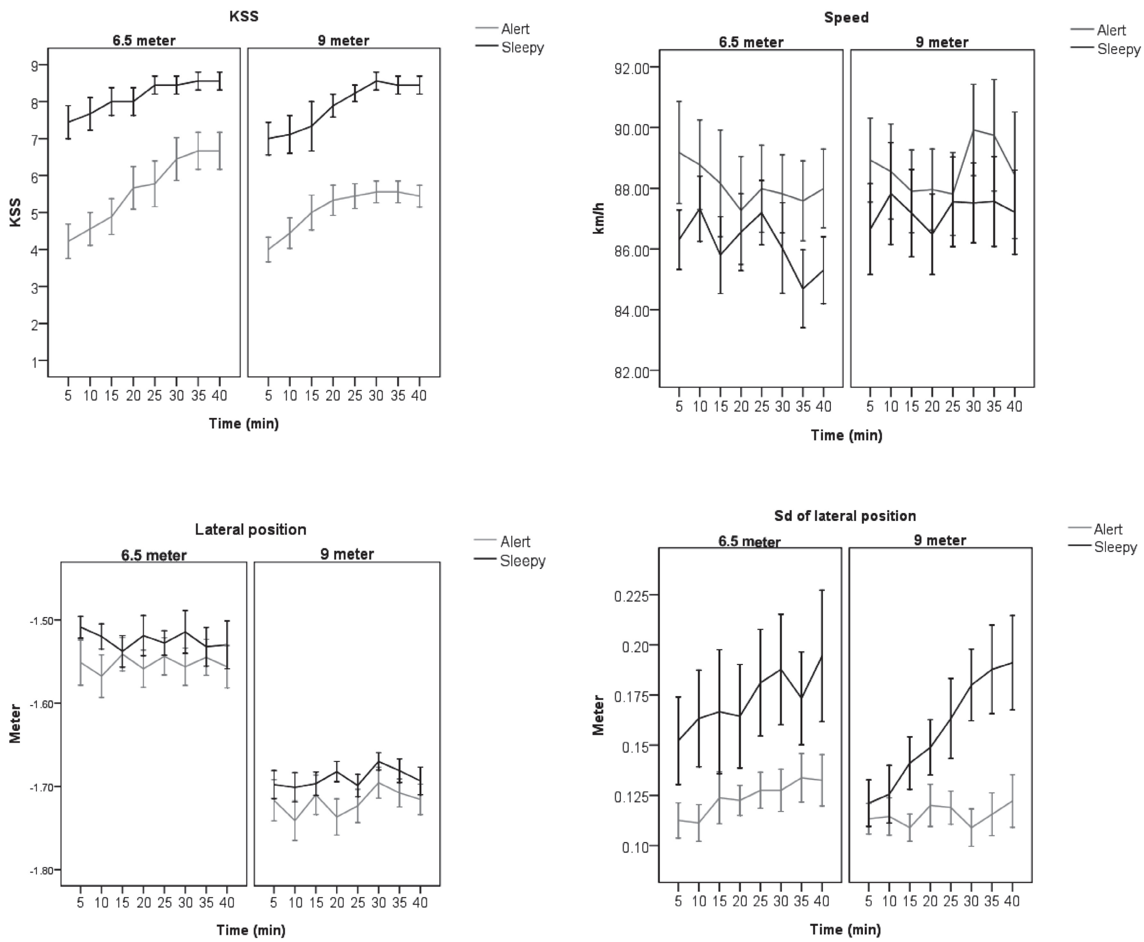


Fig. 3. Mean ± SE for KSS, Speed, Lateral position and standard deviation of lateral position (middle of the car in relation to the right edge line) on road wide 6.5 m and 9 m with rumble strips in centre of lane.

Table 2. Number of rumble strip hits for the left wheel, the right wheel and the total number of hits for all participants. The average and SD values showing individual differences are given in parentheses

	Alert		Sleep deprived	
	6.5 meter	9 meter	6.5 meter	9 meter
Hits with left wheel	55 (6 ± 8)	45 (5 ± 8)	188 (21 ± 23)	191 (21 ± 20)
Hits with right wheel	132 (15 ± 21)	108 (12 ± 16)	525 (58 ± 54)	392 (44 ± 33)
Total amount of hits	187 (21 ± 24)	153 (17 ± 19)	713 (79 ± 73)	583 (64 ± 50)

tion. There were more hits with the right wheel compared to the left wheel ($F_{(df\ 1,8)}$=6.611; p=0.033). There was also an interaction between condition and hits with left or right wheel ($F_{(df\ 1,8)}$=11.82; p=0.009), with more hits with the right wheel in the sleep deprived condition. Finally, there were also significant 2-level interaction for both KSS and variability of lateral position. Figure 4 shows the time evolution of the car's mean and standard deviation of position on the road after a rumble strip hit. The actual rumble strip hit occurs at time zero in the figure and the driving behaviour is then visualized for five seconds. The alert drivers (dark gray) adjust their course swiftly while the drowsy drivers (light gray) react more slowly and with larger variability. Out of the 1,636 rumble strip hits that occurred during this study, none of them indicated erratic driving behaviour (changes away from the current lane).

There was a significant correlation (partial correlation controlling for road width) between SDLP and rumble strip hits both to the right (Persons r=0.68) and to the left (Persons r=0.64).

Comparison between rumble strip placements

There were no significant main effects between rum-

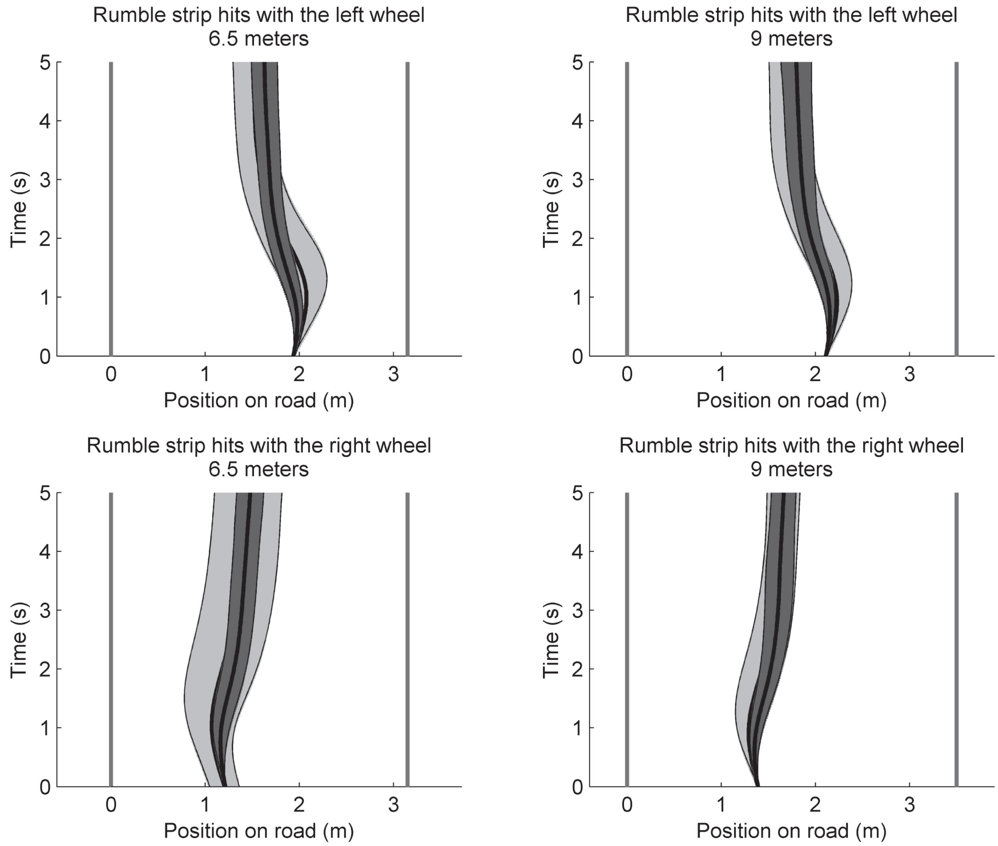


Fig. 4. The time evolution of the car's mean and SD position on the road after a rumble strip hit. Alert drivers are colour coded as dark gray while sleep deprived drivers are coded as light gray. The vertical lines indicate the road centre and the road shoulder, respectively.

Table 3. Results from repeated measures ANOVAs. F-value and (*p*-value) comparing the results for rumble strip placement (shoulder/road centre rumble strips vs. lane centre strips), taking into account time on task effects

	Centreline and edgeline mean (SD)	Centre of Lane, mean (SD)	Strip placement (df; 1, 4)	Time (df; 7, 28)	Strip placement* Time (df; 7, 28)
KSS	7.97 (0.85)	8.20 (1.15)	0.71 (0.45)	**43.89 (0.00)**	1.18 (0.32)
Lateral position (m)	−1.68 (0.20)	−1.63 (0.04)	0.35 (0.59)	0.69 (0.51)	1.13 (0.38)
SDLP (m)	0.20 (0.07)	0.16 (0.04)	2.17 (0.21)	**6.91 (0.02)**	1.30 (0.32)
Speed (km/h)	90.47 (5.22)	88.13 (2.96)	1.70 (0.26)	1.80 (0.22)	**2.53 (0.04)**

ble strips in the centre of the lane versus centreline and edgeline, see Table 3. For speed there was a significant first level interaction between the two types of rumble strips placement and time on task, meaning that participants were more sensitive to time on task on roads with rumble strips in centre of the lane. There were effects of time on task for KSS and SDLP, see Fig. 5.

Discussion

The study showed that sleep deprivation increased SDLP and KSS. The KSS and the SDLP also increased with time on task, and on the narrow road the drivers drove closer to the centre line. Increased sleepiness and SDLP after sleep loss without[32, 33] and with the centre of the lane rumble strip is in agreement with studies on centreline and edgeline placement[20]. So is the effect of time on task[33–35] and the increase in KSS during sleep deprivation[34, 36, 37].

The movement towards the centre line on the narrow road was however unexpected. There are no prior studies to compare with, and the reason for the behaviour

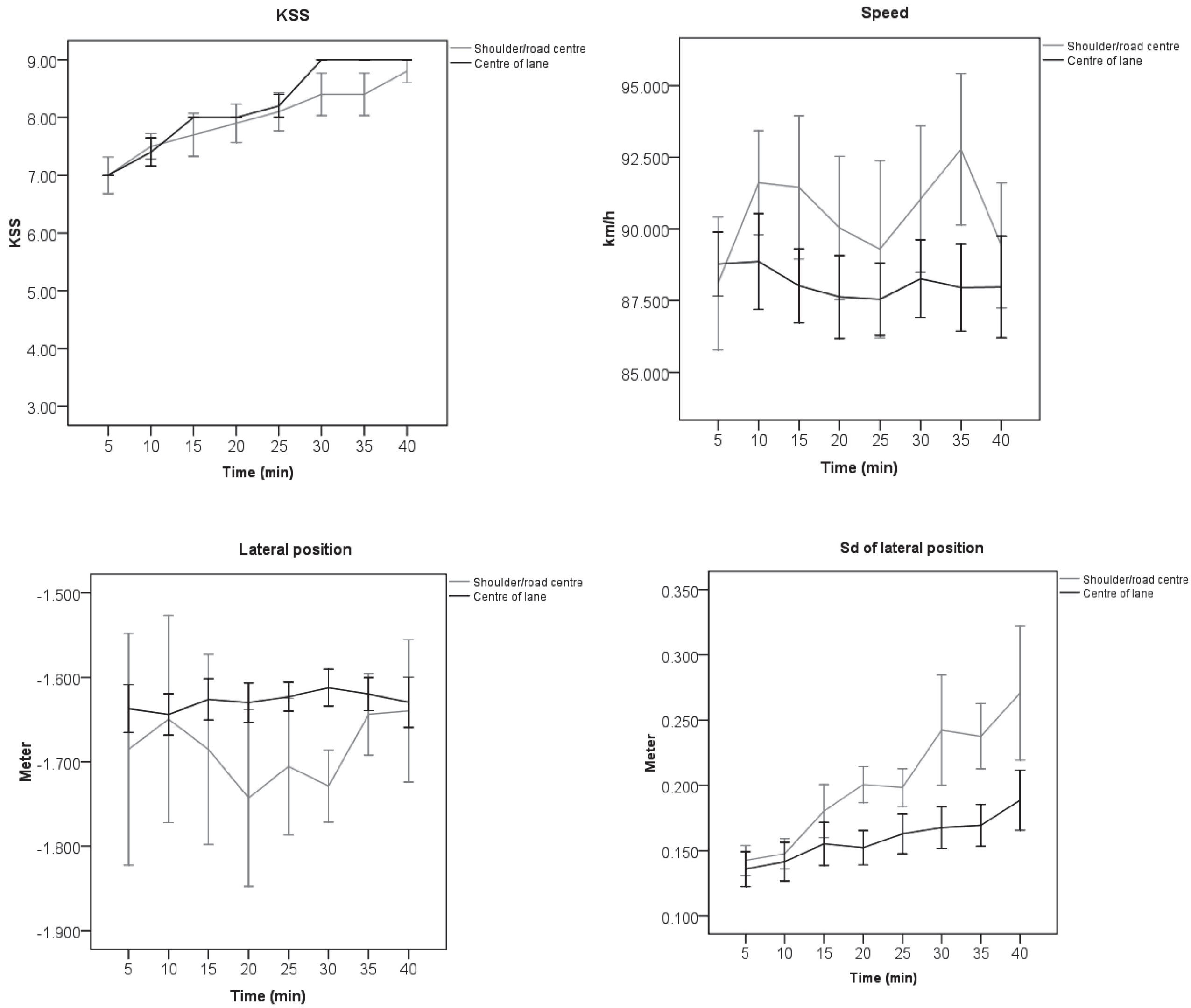


Fig. 5. Mean ± SE for KSS, Speed, standard deviation of lateral position (middle of the car in relation to the centreline) on 9 m road with the rumble strip in the centre of the lane compared to at the centreline and edgeline.

is not clear. Possibly, the lack of road shoulder on the narrow road, in contrast to the one meter shoulder of the wider road, makes the driver feel safer closer to the centre line. This road design is consistent throughout Sweden and thus, the present study compared these two particular types of roads, not the road width per se. Otherwise, the lack of effect of road width suggests that it does not affect sleepiness or lateral variability after sleep loss. However, note that there is a small but significant 2-level interaction showing that road width may influence both SDLP and KSS.

There were less rumble strip hits in the alert condition compared to the sleepy condition. However, the individual differences in number of hits were large. Despite the large number of hits, there was not a single instance that indicated erratic driving behaviour associated with the jolt caused by making contact with the rumble strip. This result, associated with a rumble strip located in the centre of the lane, agrees with existing literature on centreline and edgeline rumble strips where it has also been found that there is minimal risk of erratic behaviour amongst sleepy drivers[20)].

Comparing the two types of placements (centre of the lane vs. centreline and edgeline), reduced speed was seen when the rumble strip was located in the centre of the lane. A positive effect here is that reduced speed will promote safety by providing the driver with more time in critical situations as well as reducing the kinetic energy in case of a crash. In Fig. 5, it can also be seen that SDLP is reduced when the rumble strip is placed in the centre of the lane. More stable driving will indirectly lessen the risk of lane departures. However, this also entails negative aspects related to maintenance and the risk for damage of the road surface caused by more vehicles driving in the same track. Note that these results may be an effect of the drivers being exposed to a novel type of rumble strip and also that the change in SDLP is mainly an effect of time on task.

The results indicate big differences between individuals, especially when it comes to the number of rumble strips hits. Driver sleepiness is an area where large individual differences are common[34], and a major problem here is that the difference between one driver who is alert as compared to sleepy may be less than the difference found between two sleepy drivers. This holds true not only for prediction of driver sleepiness or changes in driving behaviour caused by sleepiness, but also for driver reactions caused by countermeasures like rumble strips. However, the use of few participants has in earlier studies been proven to be enough for relative comparisons in driving simulator studies with shift workers[27, 34, 37, 38], but still there is a need for further systematic investigations. It may be that the effects in this study are pronounced compared to normal driving under sleepiness since it is based on shift workers performance going back home from night shifts. That this is a critical situation with high risk of falling asleep, resulting in lane departures, has been proven before[37].

There are a number of limitations in the present study. One concern is the use of indirect measures of sleepiness such as the standard deviation of the lateral position. This measure is quite common, however, and well validated[32, 33]. This study also used subjective ratings of sleepiness, another well established and validated measure, but still subjective[34, 37, 38]. Objective measures that are commonly used include an increased duration of eye blinks[39], presence of slow rolling eye movements[29] and alpha band (8–12 Hz) and theta band (4–8 Hz) activity in the electroencephalogram (EEG)[9, 40]. EEG or EOG measures would have been useful in this study as well. However, it has been shown that changes in KSS are closely related to crash risk in driving simulators[30, 34, 38]. Also, in the comparison of rumble strips in the centre of the lane as compared to the centreline and edgeline, there was a sequence effect. It is not clear what this means for the interpretation since one might conceive of a learning effect and a boredom effect, which may have had opposite effects on performance and sleepiness.

It could also be discussed if the feedback provided when hitting a rumble strip is good or bad. Sleepy drivers are alerted when they are straying from their lane, but it does not stop them from being sleepy[20]. Rumble strips are very effective in preventing run-off-road accidents and they have an extremely high benefit-cost ratio, but since the driver does not become less sleepy, a conceivable crash might just be migrated further downstream of the road. Long term effects of rumble strips needs further research, but it is possible that road design parameters that lead to an increase in rumble strip hits, such as narrow roads or the placement of rumble strips, will influence driver sleepiness and performance.

In the comparison between rumble strip placement in the centre of the lane vs. centreline and edgeline, some recordings in the previously acquired dataset were based on the Pennsylvania rumble strip instead of the Målilla strip. The implications on this study are however small since previous results show no differences between the alertness effects due to rumble strip type[20]. Evaluation studies and analyses of crash statistics usually compare results with and without strips, disregarding differences between types[18, 19]. When evaluating the short term effect on sleepy drivers, no differences have been found between different rumble strip designs[20] while the long term effect is still unknown. However, there are indications that a deeper and wider rumble strip will increase the time until the next rumble strip hit[28].

In conclusion, rumble strips placed in the centre of the lane demonstrate the same positive effects on sleepy driving as conventional rumble strip placements. The drivers showed no erratic driving behaviour associated with the jolt caused by making contact with the rumble strip, however, sleep deprived drivers made larger corrective manoeuvres as compared to alert drivers. This simulator study indicates that rumble strips in the centre of the lane may be an alternative to centreline and edgeline rumble strips on narrow roads. The next step in the evaluation of rumble strips in the centre of the lane is to perform tests on real roads with a larger study population.

Acknowledgements

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