Ross Owen Phillips
Fridulv Sagberg
TØI report 1094/2010

Institute of Transport Economics
Norwegian Centre for Transport Research

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Summary:

Rumble strips are seen as systematic interventions that can help prevent lane-departure accidents. There is little evidence, however, for how or even whether rumble strips intervene to prevent specifically fatigue-related road accidents. We therefore asked drivers who actively recalled falling sleeping behind the wheel about their interactions with rumble strips. Our analyses show that real-world driver experience supports claims that rumble strips act by reducing the severity of the consequences of fatigued driving. Most notably we found that significantly fewer sleep-behind-the-wheel incidents resulted in road departure accidents where rumble strips were present.

Sammendrag:

Rumlelinjer anses som tiltak for å forebygge trøtthetsulykker. Selv om det er dokumentert at rumlelinjer reduserer ulykkesrisikoen, er det ikke vist tidligere i hvilken grad dette gjelder trøtthetsrelaterte ulykker. Et utvalg på 2567 forsikringstakere i Gjensidige forsikring ble spurt om de hadde sovnet bak rattet noen gang. 26 % svarte bekreftende på dette. Disse ble så spurt om rumlelinjer hadde betydning for konsekvensene av hendelsen. Vår analyse viser at rumlelinjer påvirker konsekvensene av sovning bak rattet. Blant annet viste det seg at færre tilfeller av sovning endte opp med utforkjøring der rumlelinjer fantes.

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Preface

This report is one outcome of the programme of activities carried out by the ERA-NET TRANSPORT Action Group ENT15: Sleepiness at the wheel. The aim of the programme is to chart the problem of fatigue in driving and evaluate the effectiveness of certain countermeasures.

Rumble strips are seen as systematic interventions that help prevent lane-departure accidents, but there is little evidence to show that they intervene to prevent specifically accidents related to fatigue or sleepiness. To investigate this issue, items on fatigue and rumble strip experiences were included as part of a large-scale survey of accident-involved Norwegian drivers in 2008.

We wish to express our thanks to Gjensidige forsikring for their help with sampling and data collection.

We also wish to thank our ENT15 partners at TNO, VTI, the Karolinska Institute and CNRS for their comments at the outset of the project. In particular we would like to thank TNO for collaboration on the YAWN project, which is included as part of the ENT15 programme.

At TØI, Fridulv Sagberg has been project manager. Agathe Backer-Grøndahl has collected and prepared the data. Ross Owen Phillips has analysed the data, and researched and written the report. Marika Kolbenstvedt has been responsible for quality assurance. Trude Rømming has edited and prepared the report for printing.

Oslo, October 2010
Institute of Transport Economics (TØI)

Lasse Fridstrøm
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Summary:

Woken by rumble strips. Reports from drivers who have fallen asleep at the wheel

Rumble strips are seen by road safety planners as systematic interventions that may help prevent fatigue-related accidents. There is little evidence, however, for how or even whether rumble strips intervene to prevent specifically those accidents related to fatigue in real-world driving. We therefore asked drivers who actively recalled falling sleeping behind the wheel, about their interactions with rumble strips. Our analyses show that real-world driver experience supports claims that rumble strips act by reducing the severity of the consequences of fatigued driving. Most notably we found that significantly fewer sleep-behind-the-wheel incidents resulted in road departure accidents where rumble strips were present.

Self-report data were collected on the fatigue and rumble-strip experiences of 2567 Norwegian drivers. The share of drivers reporting they could recall sleeping or nodding off behind the wheel was 26 per cent. Responses of these "sleeping" drivers were then analysed to draw the following conclusions:

- Rumble strips were present in 28 per cent of cases of sleep behind the wheel.
- Rumble strips woke 64 per cent of those drivers sleeping on roads on which they are present.
- The share of sleep-behind-the-wheel incidents resulting in a road departure is lower if the sleep occurs in the presence (1.9 per cent) rather than absence (4.9 per cent) of rumble strips.
- There is little evidence that being woken by rumble strips "panics" the driver and results in more serious consequences (either driving off the road or into the opposite lane).
- It is likely that being woken by rumble strips increases the chance that the consequence of sleepy driving is less serious in nature i.e. driving outside the edge-line rather than off the road.

As far as we know, however, this is the first time that large-scale reports of real-world driver experiences can be used supplement evidence that rumble strips reduce accident numbers by reducing the severity of consequences specifically of fatigue-related driving.

In considering the findings it should be remembered that they are based on driver recall; and in particular that the saliency of rumble strips in the memory may depend on whether or not the driver drove over them.

We therefore recommend that these findings be used in conjunction with objective studies that to further inform about the mechanism of rumble strip effects, so that rumble strips may be more effectively deployed by road authorities in the future.

The report can be ordered from:
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Sammendrag:

Vekket av rumlelinjer. Rapport fra førere som har sovnet bak rattet

Rumlelinjer anses som tiltak for å forebygge ulykker der bilførere krysser midtlinje eller kantlinje. Selv om det er dokumentert at rumlelinjer reduserer ulykkesrisikoen, er det ikke vist tidligere i hvilken grad dette gjelder trøtthetsrelaterte ulykker. Derfor spurte vi bilførere som aktivt husket at de hadde sovnet bak rattet, om rumlelinjer hadde hatt betydning for konsekvensene av hendelsen. Vår analyse viser at rumlelinjer påvirker konsekvensene av sovning bak rattet. Blant annet viste det seg at færre tilfeller av sovning endte opp med utforkjøring der rumlelinjer fantes.

Spørreskjemadata ble samlet inn fra 2567 norske førere for å fange opp hendelser med trøtthet og rumlelinjer. Andelen førere som husket at de hadde sovnet bak rattet, var 26 prosent. Svarene fra disse "sovende" førere ble analysert, med følgende konklusjoner:

- Rumlelinjer fantes i 28 prosent av tilfellene der føreren sovnet bak rattet.
- Sekstifire prosent av førerne som sovnet på veger der det var rumlelinjer, svarte at de ble vekket av linjene.
- Andelen søvnhendelser som førte til utforkjøringer, var mindre der det var rumlelinjer (1,9 prosent) enn der det ikke var rumlelinjer (4,9 prosent)
- Det var lite som tydet på at det å bli vekket av rumlelinjer er farlig, dvs at det ikke er forbundet med andre farlige hendelser, for eksempel ved at føreren overreagerer (utforkjøring eller kjøring inn i motsatt kjørefelt).
- Det er mer sannsynlig at det å bli vekket av rumlelinjer minsker risikoen for alvorlige hendelser (utforkjøring eller kjøring inn i motsatt kjørefelt) enn omvendt.

Så vidt vi vet er dette første gang man kan vise at rumlelinjer reduserer ulykkestall ved å begrense konsekvensene av kjøring i trøtt tilstand.

Det skal bemerkes at disse funnene baseres på selvrapporterte hendelser. Hvorvidt rumlelinjer er fremtredende i hukommelsen, kan være avhengig av om føreren kjørte over dem eller ikke.

Dermed bør disse funnene ses i sammenheng med data fra mer objektive studier for å gi grundigere kunnskap om hvordan rumlelinjene påvirker bilførerne og risikoen for ulykker. På denne måten kan rumlelinjer bli benyttet mest mulig effektivt av vegmyndigheter framover.

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1 Introduction

1.1 Rumble strips

Although estimates of the influence of fatigue on road crashes vary, it is often stated that about one in ten of all road crashes resulting in personal injury is sleep related (Connor, Whitlock, Norton, & Jackson, 2001; Philip, Vervialle, Le Breton, Taillard, & Horne, 2001; Sagberg, 1999). On motorways and rural roads sleep is implicated in as much as one in five crashes (Horne, 2009).

Rumble strips are seen by road planners as systematic interventions that can improve the safety outcomes of fatigued driving. The last two decades has seen a large increase in their use. The strips, usually placed at the edge (shoulder) or centre of the road, are made by thermoplastic painting or milling into the road surface in order to introduce an interrupted profile in the road. As a vehicle drives over the strips, the profile transmits to the driver sound and vibration via the wheels of the vehicle, supposedly drawing the driver's attention to the fact that they are drifting into the opposite lane (centre strips) or off the road (edge or shoulder strips). By alerting the driver in this way, rumble strips are thought to act as a countermeasure to those drivers who are drifting because they are sleepy.

Several studies have documented a reduction in crash risk after implementation of rumble strips, both at the edge and centre of the road (Elvik, Høye, Vaa, & Sørensen, 2009; Gaarder & Alexander, 1995; Hickey, 1997). A recent review of rumble strip evaluations found support that both edge- and centre-line strips, either alone or in combination, reduce crashes on the side of the road on which they are employed (Hatfield, Murphy, Job, & Du, 2009). Cost-benefit analyses are also available showing that the benefits of rumble strips outweigh their costs, although more evaluation is still needed on which types of rumble strips are most effective.

Several studies imply that rumble-strips are specifically effective at reducing fatigue-related incidents. A Dutch study of profiled edge-lines showed that volunteer drivers reduced both their speed and lateral variation, and increased their mental alertness, when driving on a stripped test road as compared to a non-stripped road (Elvik et al., 2009; Giæver, Sakshaug, Jenssen, & Berge, 1999). Support for the specific effects of rumble strips on driver fatigue can also be found in the form of behavioural measures taken in simulator studies; reduced observations of the number of vehicles coming over into the opposite lane; and decreases in the rates of both head-on collisions and single vehicle road departure accidents (Giæver et al., 1999; Perrillo, 1998).

Despite this knowledge there is still much to learn about the effect of rumble strips on driver fatigue. While simulator studies generally show that strips can

induce averting action in fatigued drivers (A. Anund, Hjälmdahl, Sehammar, Palmqvist, & Thorslund, 2005; Elvik et al., 2009), they often fail to account for important real world factors such as variation in rumble strip material and dimensions, weather factors and strip wear (Giæver et al., 1999). Further investigation is also required to address questions raised by simulator studies about the ultimate ability of rumble strips to prevent fatigue-related incidents occurring. For instance Anund et al. (2008) find that although sleepy drivers are alerted as they hit rumble strips, they become drowsy again in a matter of minutes (Anna Anund, Kecklund, Vadeby, Hjälmdahl, & Åkerstedt, 2008). This suggests that rumble strips could simply postpone accident risk for fatigued drivers, either until they fall more deeply asleep or until they reach a road where there are no longer rumble strips. Indeed, one study finds that, in line with risk homeostasis theory, rumble strips are associated with *increased* driving while fatigued (Hatfield, Murphy, & Job, 2008). An additional concern is that fatigued drivers suddenly woken or alerted by rumble strips might drive erratically due to a momentary loss of situational awareness, thus increasing the chance of accidents involving other vehicles.

It is better to address such concerns by observing what happens to fatigued drivers in the real world as they encounter rumble strips. This is currently done using reports on accidents resulting from unintentional lane departures, because these are assumed to be indicative of incidents involving fatigue or sleep. However, driver inattention and distraction also play a role in these events, which cannot therefore tell us about the effect of rumble strips solely on *fatigue*-related accidents (Backer-Grøndahl & Sagberg, 2010).

One way to find out more specifically about the effect of rumble strips on fatigue-related accidents would be to carry out naturalistic studies (Backer-Grøndahl, Phillips, Sagberg, Touliou, & Gatscha, 2009). However, such studies require advanced equipment and are expensive to perform, at least on larger scales. A survey of the rumble-strips experiences of large numbers of drivers, on the other hand, would be relatively easy and inexpensive to perform, would inform plans for naturalistic driving studies, *and* supplement existing evidence on the effect of rumble strips on fatigue from test tracks and simulator studies.

Survey data might also inform about the effects of different rumble strip placements. Available studies estimate that edge lines reduce all crash types by up to 50 per cent and centre lines by up to 35 per cent (Giæver et al., 1999; Mahoney, Porter, Donnell, & Pietrucha, 2003; Persaud, Retting, & Lyon, 2003). However, while central lines are better suited to certain road widths, and while we do not know the relative effects for fatigue-related accidents, questions remain concerning the best strip placement specifically for reducing the effects of fatigue.

1.2 Rumble strips in Norway

In Europe rumble strips were originally designed and used to increase the light reflective properties of edge and centre lines to assist the driver in dark, wet

weather. Norway was among those countries that recognised the additional alerting value of the noise and vibration the driver experiences as he or she drives over them.

An effort was made to evaluate the potential of rumble strips to alert distracted or fatigued drivers in Norway as part of a response to an increase in head-on collisions and run-off-road accidents in the 1990s. A decrease in sleep-related accidents of 34 per cent was found over the first year following centre line rumble strip introduction, although the decrease in accidents fell below significance for extended after-periods (Giæver et al., 1999). A corresponding non-significant decrease in sleep-related accidents was found for rumble strip introduction at the edge of the road.

Most of the rumble strips in Norway are placed at the centre or edge of main roads (mostly state roads) and motorways (Figure 1). The profiled strips used in Norway, Sweden and Denmark are of a different thermoplastic than that used in the UK and in some other EU countries.

The Norwegian Road Directorate is currently evaluating strips that combine the light emitting properties of thermoplastic lines with the superior alerting properties of milled or etched road surfaces (personal communication, Bjørn Skaar). This is achieved by painting the lines on top of a milled road surface. Although it is likely that more and more of the strips in Norway will be like this, most rumble strips in Norway in 2008 were still of the old type (Figure 1).

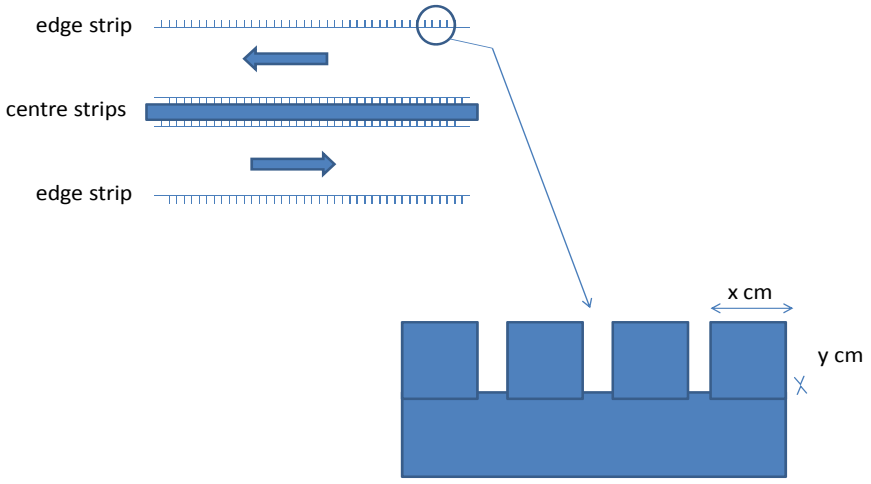

Figure 1. Typical rumble strips in Norway. The lengths x and y vary, but are typically either 6 or 10. "Longflex" strips are shown, but the lines can also be dippled or plain. Another common variant is an interrupted or 'dashed' rumble strip.

It was not possible to obtain estimates of the length of roads covered by rumble strips in Norway.

1.3 Aim of this study

The purpose of the present study is to begin assess the potential of rumble strips to reduce sleep-related crashes by collecting questionnaire data from drivers who have fallen asleep while driving in Norway. To give context to specific responses on rumble strip experiences, we also collected data on the number of accidents caused by fatigue and the incidence of sleep behind the wheel.

We aimed to answer the following questions.

Firstly, to confirm that fatigue while driving is a problem,

- How common is actual sleeping while driving and is it a direct cause of accidents?

Then, what role do rumble strips play in tackling fatigue while driving?

- Do rumble strips wake sleeping drivers?
- Do those drivers not woken by rumble strips report more serious incidents?
- Does the presence of rumble strips reduce the type of incidents resulting from sleep behind the wheel?

2 Method

The answers used in this report were given in response to a set of questions included as part of a larger driver survey conducted by TØI during April and May of 2008. The study was carried out in collaboration with the major Scandinavian injury insurance company, Gjensidige.

2.1 Survey

2.1.1 Procedure

Invitations to participate in the survey were sent via post to Norwegian drivers insured by Gjensidige who reported involvement in a road accident resulting in damage to persons or property during the preceding twelve months. Guidelines specified that the survey was to be answered by the driver of the car involved in the accident, and that the survey could be undertaken either on the internet or, if the participant preferred, on paper. Respondents were told that if they agreed to complete the survey they would be entered into a prize draw. The anonymity of their responses was guaranteed[1].

2.1.2 Design

The survey took between 15 and 25 minutes to complete. In addition to questions about sleepiness behind the wheel and rumble strips, the survey contained questions about the nature of the last reported accident; medicine use and health complaints; the use of mobile phone while driving; use of other electronic or automatic equipment while driving; and the general background of the driver. Findings on other questions are reported elsewhere (Backer-Grøndahl & Sagberg, 2010).

2.1.3 Sampling

A sample of participants was drawn up by Gjensidige from their register of damages claimed by drivers of privately owned vehicles (private cars, vans or goods vehicles with total weight under 3.5 tonnes) involved in an accident over the preceding 12 months. The vehicles included were those involved in accidents

[1] The prize was a travel voucher worth about 1200 Euros. To ensure anonymity, a third party (Talk2me) coupled the name and addresses (provided by Gjensidige) to the internet survey (provided by TØI). The invitations were dispatched by the third party.

defined by Gjensidige as being 'damaged in traffic', which means (a) that they were involved in collisions while out in open traffic, in which other vehicles may or may not have been involved; and (b) that the result was damage to property and/or persons. The sample included both those drivers at-fault and not-at-fault for the accident.

2.1.4 Response rate

Viable invitations to participate in the survey were sent to 33,103 people, and 6111 viable responses received. The response rate was thus 18 per cent. Of those that responded, most used the internet. Only 456 (7.5 per cent of the total that responded) used the paper survey.

2.1.5 Sample description

Of those that responded, 61 per cent were male and 39 per cent female. The mean age was 46.8 years (standard deviation 16.7 years). On average, the respondents drove 16,700 km in the year leading up to the survey (standard deviation 14,400 miles).

2.2 Analysis of survey responses according to responsibility

One problem when surveying accident-involved drivers is that it is difficult to know whether incidents in which they are involved are representative of those occurring in the normal driving population, most of which is not involved in accidents. In this study we therefore make the assumption that the not-at-fault drivers in our sample represent the normal driving population, and select exclusively for this population when analyzing rumble strip experiences and incidents of fatigue or sleep behind the wheel.

The responses of the at-fault drivers were used to set the findings on rumble strips in context of the sort of accidents occurring at the time of the findings. In other words, the responses of at-fault drivers are used to find out how often fatigue is a direct cause of accidents. Because we describe responses from two sub-samples of drivers i.e. at-fault and not-at-fault drivers, it is important to consider differences between them.

Of 5948 who responded to the question '*Who according to the insurance company had responsibility for the accident?*', 53.6 per cent answered that they themselves were at-fault, 43.9 per cent that another party was to blame, and 2.4 per cent that responsibility was shared. A greater proportion of younger (59 per cent) and older drivers (61 per cent) said they were at-fault than those drivers who were between 25 and 49 years old (51 per cent). These differences were significant ($\chi^2 = 57{,}4$; $p < .001$). There were no significant differences between the two groups according to gender.

2.3 Exclusion of unreliable responses

Forty-six of the not-at-fault driver responses were considered unreliable and were eliminated before the analyses in the Results section. These people either said (i) that they had been woken by rumble strips *and* that there had not been rumble strips on the stretch of road where they slept; or (ii) that they had been woken by rumble strips *and* that they could not remember whether there had been rumble strips where they slept. Exclusion of unreliable responses reduced the number of valid responses from not-at-fault drivers from 2613 to 2567.

3 Results

If practitioners from other EU countries are to learn from and apply findings about driver rumble strip experiences reported here, it will be important for them to account for the relative level of driver fatigue and the incidence of sleep-related accidents in Norway. We therefore begin by charting the problem of on-road fatigue according to our sample of Norwegian drivers.

3.1 Incidence of sleeping while driving

To get an idea about the incidence of sleeping behind the wheel in the population of interest, we asked reliable not-at-fault drivers "*Have you at any time experienced falling asleep or nodding off for a moment while driving?"*. Out of 2443 reliable not-at-fault drivers responding to the question, 26 per cent (n = 636) reported that they had at some time slept or nodded off behind the wheel[2].

3.2 Fatigue and sleep behind the wheel as a direct cause of accidents

To find out about the incidence of fatigue or sleep behind the wheel as a direct cause of road accidents, we asked the at-fault drivers "*Did fatigue or sleep behind the wheel contribute to the accident referred to in the letter from the insurance company?*". Of those 3193 drivers at-fault for the accident, 0.6 per cent reported that the accident happened because they had fallen asleep behind the wheel. A further 1.6 per cent reported that even though they had not slept, the accident had happened because they had been tired. Thus the total share reporting that fatigue contributed directly to the accident was 2.2 per cent.

We now turn to driver responses to questions specifically about rumble strips.

[2]29 per cent of at-fault drivers said the same.

3.3 Presence of rumble strips where drivers sleep

Those not-at-fault drivers reporting that they had some time slept while driving were asked "*Were there rumble strips (profiled edge or centre lines) on the stretch of road where you slept?*".

Excluding those drivers who said that they could not remember, less than a third (28 per cent) of those drivers falling asleep behind the wheel reported that rumble strips were present.

Of these drivers, 46 per cent report that there were both centre- and edge-strips present, while 45 per cent report that there were only edge-strips present. Only 10 per cent reported sleeping where there were exclusively centre-lines.

The data, including that from those drivers who could not recall, are given in Table 1.

Table 1. Presence of rumble lines according to not-at-fault drivers who remember falling asleep while driving. Column percentages are shown.

Rumble strips where you slept?	(n = 636)
Edge-lines	9.7
Centre-lines	1.9
Edge- and centre-lines	9.9
No	54.2
Can't remember	23.7
Missing	0.5
Total	100.0

Source: TØI report 1094/2010

3.4 Do rumble strips wake sleeping drivers?

Those drivers recalling the presence of rumble strips were then selected and their responses to the question "*Were you woken when you drove on the rumble strips?*" were analysed. Sixty-four per cent of drivers recalling that they fell asleep where rumble strips were present also reported being woken by them.

Interestingly, of these drivers, a greater share report being woken where only edge lines were present (71 per cent) than those sleeping where both edge and centre lines were present (57 per cent).

Although a large share report being woken where only centre lines were present, the numbers are too low to be reliable (Table 2).

Table 2. Whether not-at-fault drivers experiencing sleep at the wheel were woken by rumble strips according to rumble strip type. In this case ROW percentages are shown.

Rumble strips where you slept?	Were you woken by rumble strips?	
	No	Yes
Edge lines (n = 62)	29.0	71.0
Centre lines (n = 11)	18.2	81.8
Edge and centre lines (n = 63)	42.9	57.1
No (n = 343)	100.0	--
Can't remember (n = 140)	100.0	--
Missing (n = 17)	--	--

Source: TØI report 1094/2010

3.5 Do rumble strips change the consequences of sleepy driving?

3.5.1 Not-at-fault drivers

To learn about the safety effects of rumble strips on fatigue in real world driving, it would be interesting to know whether drivers who recall falling asleep report more or less serious consequences of falling asleep depending on (a) whether the road they fell asleep on had rumble strips; and (b) whether they were woken by rumble strips when rumble strips were present.

To address this we divided the responses of sleeping drivers depending on:

(a) whether they reported the presence or absence of rumble strips; and

(b) whether they were woken by rumble strips when they were present.

We then looked for any differences in group responses to the question "*What was the consequence of you being tired or asleep behind the wheel?*" (Table 3).

We found that a greater share of those drivers sleeping where rumble strips were absent reported driving off the road (12 out of 343 drivers; 3.5 per cent) than those sleeping where rumble strips were present (one out of 137 drivers; 0.7 per cent). The numbers do not give sufficient power for statistical conclusions, but this potential difference is important because it implies that fatigue-related road departure incidents are less likely where there are rumble strips. This difference is therefore analysed further by including at-fault drivers in the analysis in Section 3.5.2.

There was little difference in the share of drivers driving into the opposite lane according to whether rumble strips were present or absent (Table 3).

Table 3. Whether not-at-fault drivers, having slept behind the wheel, report presence of rumble strips according to consequences. Column percentages are shown.

What was the consequence of you sleeping behind the wheel?	Were rumble strips present where you slept?		
	No	Yes	Can't remember
	(n = 343)	(n = 137)	(n = 150)
Drove into the opposite driving lane	8.7	8.0	2.0
Drove outside right edge-line	15.7	28.5	4.0
Drove outside left edge-line	2.3	5.1	0.7
Drove off the road	3.5	0.7	2.7
No consequence	67.5	55.5	69.6
Other	2.3	2.2	2.5
Total	100.0	100.0	100.0

Source: TØI report 1094/2010

Differences in road departure incidents according to whether drivers were woken by rumble strips where they were present are given in Table 4. Note that the analysis is exclusively of responses of drivers recalling the presence of rumble strips.

Table 4. Whether not-at-fault drivers, having slept behind the wheel, report being woken by rumble strips according to consequences. Column percentages are shown. Note - responses are limited to those reporting rumble strips where they slept (n = 137).

What was the consequence of you sleeping behind the wheel?	Were you woken by the rumble strips?	
	No	**Yes**
	(n = 48)	(n = 89)
Drove into the opposite driving lane	6.4	9.0
Drove outside right edge-line	17.0	34.8
Drove outside left edge-line	.0	6.7
Drove off the road	.0	1.1
No consequence	72.3	47.2
Other	4.3	1.1
Total	100.0	100.0

Source: TØI report 1094/2010

A significantly greater share of those drivers who were *not* woken by rumble strips report that there were *no* consequences of nodding off (72 versus 47 per cent; $z = 2.63$; $p < .05$[3]).

Significantly more of those drivers driving over right edge-lines also report being woken by them ($z = 2.03$; $p<.05$).

[3] http://www.dimensionresearch.com/resources/calculators/ztest.html

3.5.2 All drivers

At-fault drivers in our sample were more likely to report having slept at the wheel while driving than the not-at-fault drivers (29 vs- 26 per cent, respectively; z-test $p < .05$). For this reason, and because of demographic differences, we must be careful not to treat at-fault drivers as representative of the normal driving population.

However, for the purposes of analysing whether there are fewer road departure incidents according to reports of rumble strip presence, it is interesting to analyse the response of all drivers independent of their blame for the accident. While the results would not reflect how rumble strips work with normal sleeping drivers, they would reflect whether rumble strips function for those who on the whole may drive more dangerously. Importantly, such an analysis would also give us sufficient numbers to enable statistical conclusions to be drawn.

In this analysis we again found that a greater share of those drivers sleeping where rumble strips were absent reported driving off the road (41 out of 839 drivers; 4.9 per cent) compared with those drivers sleeping where rumble strips were present (6 out of 323 drivers; 1.9 per cent). This time the difference is significant ($z = 2.20$; $p<.05$) and gives further support that reports of road departure incidents are less likely where the sleeping driver recalls the presence of rumble strips.

Again there was little difference in the share of drivers driving into the opposite lane according to whether rumble strips were present or absent (Table 5).

Differences in road departure incidents according to whether drivers were woken by rumble strips are given in Table 6.

Table 5. Whether all drivers, having slept behind the wheel, report presence of rumble strips according to consequences. Column percentages are shown.

What was the consequence of you sleeping behind the wheel?	**Were rumble strips present where you slept?**		
	No	Yes	Can't remember
	(n = 839)	(n = 323)	(n = 371)
Drove into the opposite driving lane	8.5	8.4	3.0
Drove outside right edge-line	16.6	34.7	7.5
Drove outside left edge-line	1.9	5.9	.8
Drove off the road	4.9	1.9	3.0
Collided with other vehicle	.4	.6	0
No consequence	65.8	47.7	83.3
Other	2.0	.9	2.4
Total	100.0	100.0	100.0

Source: TØI report 1094/2010

Differences in road departure incidents according to whether drivers were woken by rumble strips are given in Table 6.

Table 6. Whether all drivers, having slept behind the wheel, report being woken by rumble strips according to consequences. Column percentages are shown. Note - responses are limited to those reporting rumble strips where they slept (n = 320 + 3 missing responses).

What was the consequence of you sleeping behind the wheel?	**Were you woken by the rumble strips?**	
	No	Yes
	(n = 108)	(n = 212)
Drove into the opposite driving lane	9.3	8.0
Drove outside right edge-line	13.9	45.8
Drove outside left edge-line	3.7	6.6
Drove off the road	2.8	.9
Collided with other vehicle	.0	.9
No consequence	68.5	37.3
Other	1.9	.5
Total	100.0	100.0

Source: TØI report 1094/2010

Again, a significantly greater share of those drivers who were *not* woken by rumble strips report that there were *no* consequences of nodding off (69 versus 37 per cent; $z = 2.63$; $p < .05$), and there are *clear associations between driving over edge lines and being woken*, which are significant in the case of right edge-lines ($z = 5.5$; $p < .05$).

4 Discussion

To set responses on the rumble strip experiences of fatigued drivers in context we measured the incidence of fatigue in our sample. We found that 26 per cent of drivers could recall that they had fallen asleep at some time while driving. This figure is typical of other Norwegian driver surveys (Nordbakke & Sagberg, 2007; Sagberg, 1999; Sagberg & Bjørnskau, 2004), giving us some confidence that the survey responses are representative of Norway.

Our finding that 2.2 per cent of accidents were caused by fatigue, is somewhat lower than estimates typically reported for other countries. In the UK, for instance, fatigue is typically estimated to be contribute to between 10 and 30 per cent of road accidents (Horne & Reyner, 1999). There are several explanations for this. First, studies estimating the prevalence of fatigue as a causative factor in accidents typically consider more serious accidents, whereas we consider all types of accident. Fatigue is known to play a larger role in more serious accidents, and this may explain the lower incidence of fatigue found when less serious accidents are also considered. The difference may also be due to varying operational definitions of sleep and fatigue, the difficulties of identifying fatigue as a contributory factor, and the widely differing methods used to identify sleep-related incidents.

The main methodological criticism to be leveled at our survey is that it is only as accurate as the recollections made by the drivers in our sample. Recognising this, we maintain that it is important to consider the actual experiences of sleepy drivers with rumble strips when building knowledge about how rumble strips work and might be improved. Regarding the inaccuracies of recall, we make three points. First, driver recall is likely to be clear in many incidences of sleep behind the wheel, which drivers often experience as disturbing and which therefore remain salient in the memory. Second, drivers were given a clear option in our survey to say that they could not remember so that we could discount the responses of those drivers who did not have active recollection of an incident. Third, we consider that the data collected here should only be considered alongside relevant data from simulator studies, in-depth accident analysis, naturalistic driving studies and other methods.

In considering whether the sample used here is representative of the population of interest, it is important to remember that the response rate was quite low[4] (18 %).

[4] The low response rate is perhaps due the fact that we surveyed accident-involved drivers via the drivers' insurance company, after the drivers had already had to fill out an accident report to the insurance company.

While this may be particularly important to consider when generalizing sample findings on the incidence of fatigue as a cause of accidents, it is difficult to see how the responses could be biased in relation to investigating the role of rumble strips in fatigue-related incidents.

We now turn to the findings on rumble strips.

Of those drivers who could actively recall, 28 per cent said that there were rumble strips on the road where they slept. This means that rumble strips were absent in 72 per cent of cases in which drivers nodded off behind the wheel, which would in turn suggest an absence of rumble strips in places where they are needed. More data are required, however, before solid conclusions can be drawn, because we do not know whether the type of roads on which drivers fell asleep are those that are suitable for rumble strip use.

Sixty-four per cent of those drivers actively recalling the presence of rumble strips where they slept reported that they were woken by rumble strips. This may suggest that rumble strips are quite effective at waking or alerting fatigued drivers who fall asleep. However, it could rather be the case that drivers who are woken by rumble strips are more likely to remember that they were present, because interaction with rumble strips means that their presence on the road acquires greater salience for the driver. Those drivers who fell asleep but were not woken by rumble strips may have been more likely to report that they could not remember whether there were rumble strips. Support for this is found in Tables 3 and 5, which show that most of those drivers who could not recall whether rumble strips were present or not also reported that there was no consequence of their sleepy driving i.e. that they did not drive towards the edge of the road. This means we must be careful in interpreting in isolation the proportion of sleeping drivers who are woken by rumble strips where they are present.

More drivers reported being woken on roads where only edge-lines were present than on roads where both edge- and centre-lines were present. This may simply reflect that roads with edge and centre lines are wider, and drivers are therefore less likely to come into contact with rumble strips on these roads after nodding off.

As we have said, drivers were given the opportunity in our survey to say that they could not remember whether rumble strips were absent or present, and it is therefore reasonable to assume that reports that rumble strips were *present* or *absent* are due to *active* recall by respondents. Our finding that *fewer drivers report driving off the road where they recall that rumble strips were present* than report doing so where they recall that rumble strips were absent (see Tables 3 and 5) is therefore interesting, and gives support to claims that rumble strips are effective at reducing the number of road departure accidents involving sleepy drivers.

There was no difference, however, in the share of drivers driving into the opposite lane according to their recall of the presence of rumble strips. First, it is important to consider that fewer of the recalled rumble strips were in the centre of the road than at the edge, and so even where drivers reported rumble strips were present

they may not have been located to prevent drivers driving into the opposite lane. A further explanation for the lack of difference in those drivers driving into the opposite lane according to rumble strip presence is that those drivers who are so fatigued that they drift over to the left might not be woken by rumble strips. An additional, and worrying explanation, is linked to a finding by Hatfield et al. (2008) that rumble strip presence may increase driver tendency to drive while fatigued, through the mechanism of risk homeostasis. Thus the presence of edge-line rumble strips may actually *increase* the likelihood of drift into the opposite lane where no centre strips are present to alert the driver.

We are cautious about interpreting the lower share of drivers reporting that they drove over edge-lines where they recall that rumble strips were absent because we do not know (a) whether all roads had painted lines on; and (b) whether drivers would recall driving over a smooth painted line.

It is more interesting to consider responses of those who recall that rumble strips were present, according to whether or not they were woken by them. But in doing so we must address the apparent anomaly that a greater share of those *not woken* by rumble strips report that there were *no consequences* of sleepy driving in terms of incidents. There are two possible explanations for this:

- Most sleeping drivers not woken by rumble strips are relatively less fatigued and wake "spontaneously" before drifting and driving over the rumble strips (or perhaps by driving *on* but not *over* the strips).
- Interaction with rumble strips panics the waking driver with the result that hazardous consequences are more likely than a driver who wakes "naturally".

Analysis of Tables 4 and 6 gives no evidence that drivers who are woken by rumble strips are more likely to have *serious* consequences (drive off the road or into the opposite lane) because they are "panicked" as a result of driving over the strip. If anything the evidence is in the opposite direction. We therefore find no evidence that being woken by rumble strips is less safe. In other words, even if the driver were to drive erratically as a result of being woken by a strip, our findings suggest that the consequences are minor. These findings somewhat accord with those of Hatfield et al. (2008), in which only one per cent of Australian drivers reported overcorrecting as a result of driving over rumble strips.

If we assume that the first of the above two explanations is more likely then it is reasonable, for the purposes of interpreting the effects of being woken by rumble strips on sleepy driving outcomes, to discount those who woke up naturally and therefore reported no consequences. In doing so it becomes evident that *being woken by rumble strips increases the chance that the consequence of sleepy driving is less serious in nature* (i.e. driving outside the edge-line rather than off the road).

4.1 Future work

Future surveys attempting to capture rumble strip experiences would be usefully supplemented with questions addressing issues such as the type of road on which the sleeping incident happened (partly in order to inform about any extra need for rumble strips), or the nature of the sleeping incident (e.g. momentary nodding off or more serious sleep). It would also be useful to account for driver exposure to rumble strips from annual mileage and knowledge about the length of roads covered by rumble strips.

A survey carried out in several different countries would inform on any national differences in driver experiences, which could then be linked to objective data on the incidence of sleep-related accidents.

As noted, no complete account of rumble strip effect on sleepy driving outcomes should rely exclusively on driver surveys. A promising and increasingly used method to supplement large scale survey data is naturalistic driver observation, which is probably the most reliable way to learn about real life incidences of sleepy driver interaction with rumble strips.

4.2 Conclusions

According to Norwegian drivers recalling incidents of falling asleep while driving:

- Rumble strips are present in 28 per cent of cases of sleep behind the wheel.
- Rumble strips wake 64 per cent of those drivers sleeping on roads on which they are present (although caution is advised because drivers woken by rumble strips may be more likely to recall them).
- More drivers are woken by rumble strips on roads where only edge-lines are present than on roads where both edge- and centre-lines are present, possibly reflecting that roads with edge- and centre-lines are wider, and drivers are therefore less likely to come into contact with rumble strips on these roads after nodding off.
- There are fewer road departure incidents where drivers sleep in the presence of rumble strips than when they sleep in the absence of rumble strips.
- There is therefore no evidence that being woken by rumble strips “panics” the driver and results in more serious consequences (either driving off the road or into the opposite lane).
- It is rather likely that being woken by rumble strips increases the chance that the consequence of sleepy driving is less serious in nature i.e. driving outside the edge-line rather than off the road.

Thus, for the first time, support based on real-world driver experiences is given to claims that rumble strips reduce accident numbers by reducing the severity of consequences of fatigue-related driving.

These data should be used in conjunction with further surveys and objective study to inform about the mechanism of rumble strip effects.

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