Night Driving, Season, and the Risk of Highway Accidents

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Abstract: Official accident and traffic density statistics on Swedish highways were used to compute the relative risk (Odds Ratio - OR) of being injured or killed in a traffic accident at different times of day. After removing accidents due to alcohol 10344 accidents remained for computations, and the period 10:00h—11:00h was used as the reference point. The highest total risk was seen at 0400h (OR=5.7, Confidence interval = 5.6-5.8), with an OR of 11.4 (Ci=10.3-12.5) for fatal accidents at the same point. The same pattern was exhibited by single vehicle, head-on, and "other" (e.g., turning off the road) accidents, whereas overtaking and rear-end accidents did not show clear 24 hour patterns. Retaining alcohol-related accidents approximately doubled the nighttime peak for total accidents. During the winter, the peak of total accidents occurred at 03:00h (OR=3.8, Ci=3.5-4.0), five hours before sunrise, whereas the summer peak occurred at 04:00h (OR=11.6, Ci=11.3-11.9), shortly after the early summer sunrise and with consistently higher nighttime risk than for winter driving. It was concluded that early morning driving is several times more dangerous than driving during the forenoon. Apart from alcohol the effect seems related to sleepiness, but not to darkness.

Key words: Driving, accidents; highway; car; time of day; light; sleepiness; fatigue; circadian; sleep loss

INTRODUCTION

OFFICIAL ROAD SAFETY STATISTICS USUALLY SHOW MUCH LOWER ACCIDENT RATES AT NIGHT COMPARED TO DAYTIME, WHEN PEAK LEVELS ARE REACHED IN THE MORNING AND AFTERNOON.[1] This pattern is very similar to the 24 hour pattern of traffic density, suggesting a rather logical relation, with accidents being dependent on the number of cars on the road. This should encourage night driving for higher safety, and, to some extent, such a trend is already in progress.

On the other hand, there appears to be a higher overall risk at night in terms of accident per mile driven.[2,3,4,5,6,7] It is not clear, however, whether the higher rate is uniform during the night or whether there exists a clear peak or, for that matter, whether there exists a trough of sharply reduced risk during the day.

Much of the increased risk at night has been attributed to darkness or alcohol. An alternative hypothesis involves sleepiness, since sleep-related accidents show a pronounced peak around 03:00—05:00 in the morning.[8,9,10,11] On the other hand, the term "Sleep related" is, a diffuse and largely subjective concept, clearly biased towards single vehicle accidents, especially in the early morning. An alternative approach may be to reverse the logic and look at all types of accidents (head-on, overtaking, etc.), regardless of suspicion of sleepiness, while excluding alcohol and while using seasonal differences in lighting to control for the darkness effect. Even if snow and ice would add to the risk of winter driving, the effect should be evenly distributed across the 24-hours.

The purpose of the present study was to provide a detailed 24h pattern for the risk (alcohol excluded) of being involved in any type of highway accident, resulting in injury or death. It was of particular importance to try to estimate the exact time of the peak, as well as the actual risk of being on the road at different times of day. The concept of risk probably has a higher relevance for the individual contemplating driving at night than the traditional accident rate per mile driven. There is also some evidence that the rate of accidents, based on miles driven, may be a confound since mileage is correlated with experience. Thus, a large number of miles per year may actually be associated with a reduced risk of an accident.[5]

It was also the intention to investigate whether darkness may be involved in the higher accident rate at night. For this purpose we used the accident patterns around the winter and summer solstices, since these two times of year differ greatly in daylight pattern at 58°-61°N, from which latitudes most of the present data were obtained.

METHODS

Data on police reported accidents (involving an injury to the driver) on five major highways (E20, E4, E6, E18 and E66) during five years (1987—1991) were obtained from Statistics Sweden. This yielded 12,535 injuries due to road accidents, but 10344 remained after excluding injuries to passengers and accidents involving alcohol. The latter was based on one item in the accident report form, and checking of this item is normally based on a positive blood sample (›0.05% blood alcohol level), usually subsequent to a positive breathalyzer test. The latter is normally carried out if there is any suspicion of alcohol, based on erratic driving, smell, intoxicated behavior by the driver or passengers, etc. Fatal accidents virtually always involve an autopsy with screening for alcohol and other drugs (amhpetamine, marijuana, sedatives, and similar substances).

Most of the highways were four-lane type motorways, although a significant portion had only two lanes. The recorded accidents were characterized as: injuries due to single vehicle accidents, to rear-end accidents, to overtaking/change of lane

Accepted for publication March 2001
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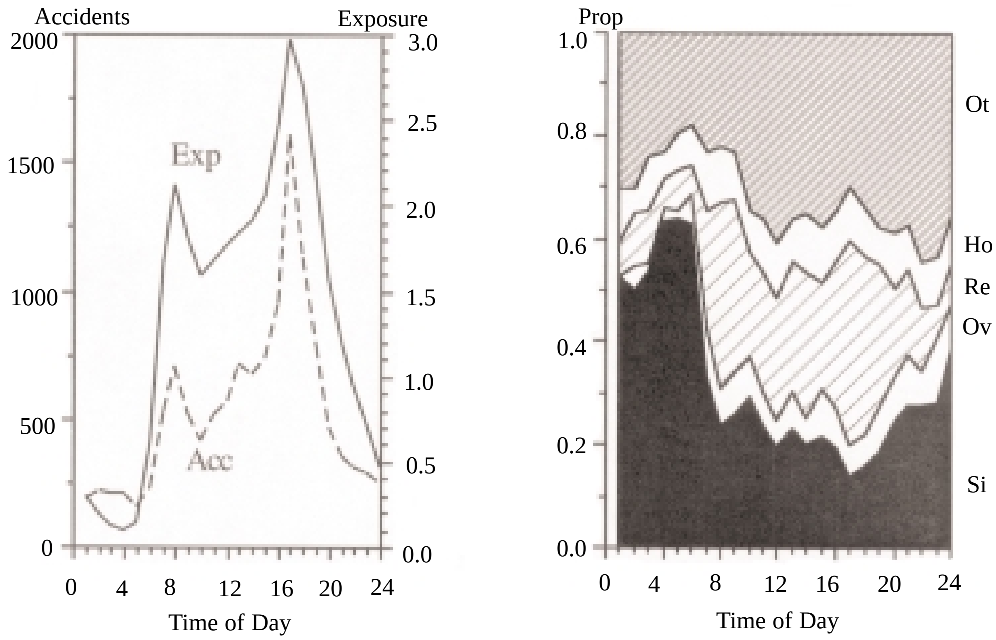

Figure 1—Left: Exposure (traffic density) and accidents involving an injury to the driver, or death, plotted at different times of day in one-hour intervals.
Right: Proportion of different types of accidents occurring at different times of day. Each field represents the proportion of the total of each type at each time of day. Ot=other accidents, Ho=head-on accidents, Re=rear-end accidents, Ov=accidents involving overtaking or change of lane, Single=single vehicle accidents

accidents, to head-on accidents, and those due "other" accidents. The latter largely involved accidents with vehicles turning off the road, meeting another vehicle at intersections or running into animals (mainly moose, deer, and reindeer).

Traffic flow measures (vehicles per hour and day) were obtained from the National Road Administration for each day of the year of 1990 at seven measurement points on four of the highways. E66 was excluded because of measurement problems. The results were multiplied by five to form an estimate of the five years 1987—1991. The traffic flow changed very little across these years and should not have any effect on the subsequent analyses.

All data were first organized in one-hour bins. A risk ratio was then computed as the total number of accidents/number of vehicles/hour (absolute risk per hour). To compute the relative risk, as the odds ratio (OR), at different times of day, the bin between 10:00h and 11:00h was used as reference (labeled "11:00h"). This reference point was preferred to, for example, a mean across the 24 hours or across the daylight hours since it may be easier to communicate the implication of risk if an easily identifiable time of lowest risk is used as the reference. The time between 10:00h and 11:00h was particularly suitable since it represented a relatively stable plateau after the morning rush hour.

For each risk ratio a 95% confidence interval was computed as $OR^{1 \pm \sqrt{1.96/Chi^2}}$.[12] These analyses were carried out for the total number of accidents involving an injury to the driver, as well as for: single vehicle, head-on, overtaking, rear end, and "other" accidents. For most ratios the number of accidents were well above 20, but for night time accidents (02:00h - 06:00h) overtaking and rear end accidents fell to between five and ten, and for overtaking, the level fell below five for this period, which makes the estimates highly unreliable.

In addition, the risk at different times of day was computed for the month of the summer and winter solstice plus the preceding month, that is, for May + June and November + December (based on the exposure values for these two periods). Two months were needed to obtain a sufficient number of cases. In order to explicitly compare driving during the short summer nights with long winter nights, the odds ratio for summer driving was computed for each time of day, using the winter period as the "unexposed" condition. Finally, a time of day analysis was carried out also for weekday and weekend driving separately, followed by a computation of weekend risk, using weekday as the unexposed condition. Weekend was defined as the time between 00:00h on Saturday to 24:00h on Sunday.

RESULTS

Figure 1 shows a bimodal distribution of exposure and accidents with clear morning and afternoon peaks for both types of measures. The two patterns are very similar. After removal of all injuries to passengers and all accidents which involved alcohol, 10344 accidents resulting in injury or death remained, of which 6.1 % (629) were fatal. Out of the 10,344 accidents, the 2,604 single vehicle ones accounted for 25.2%, the 2,622 rear end accidents for 25.3%, the 1285 head-on accidents for 9.5%, the 987 overtaking accidents for 7.0%, and the 3,406 "other" accidents for 32.9%. Figure 1 also shows that single vehicle accidents dominated the night hours. In addition, 683 accidents involved suspicion of alcohol, accounting for 6.19% of the total (10344 + 683). All computations of risk below are based on the 10344 accidents not involving alcohol.

Figure 2 shows that, compared with driving between 10:00 and 11:00 am, the relative risk of having an injury was five-fold at 04:00 in the morning and well above unity from 23:00h to 06:00h. Incidentally, the corresponding absolute risk per driver on the road around 04:00 (i.e., at 03:00—04:00h) was approximately 0.026% and the daytime values oscillated around

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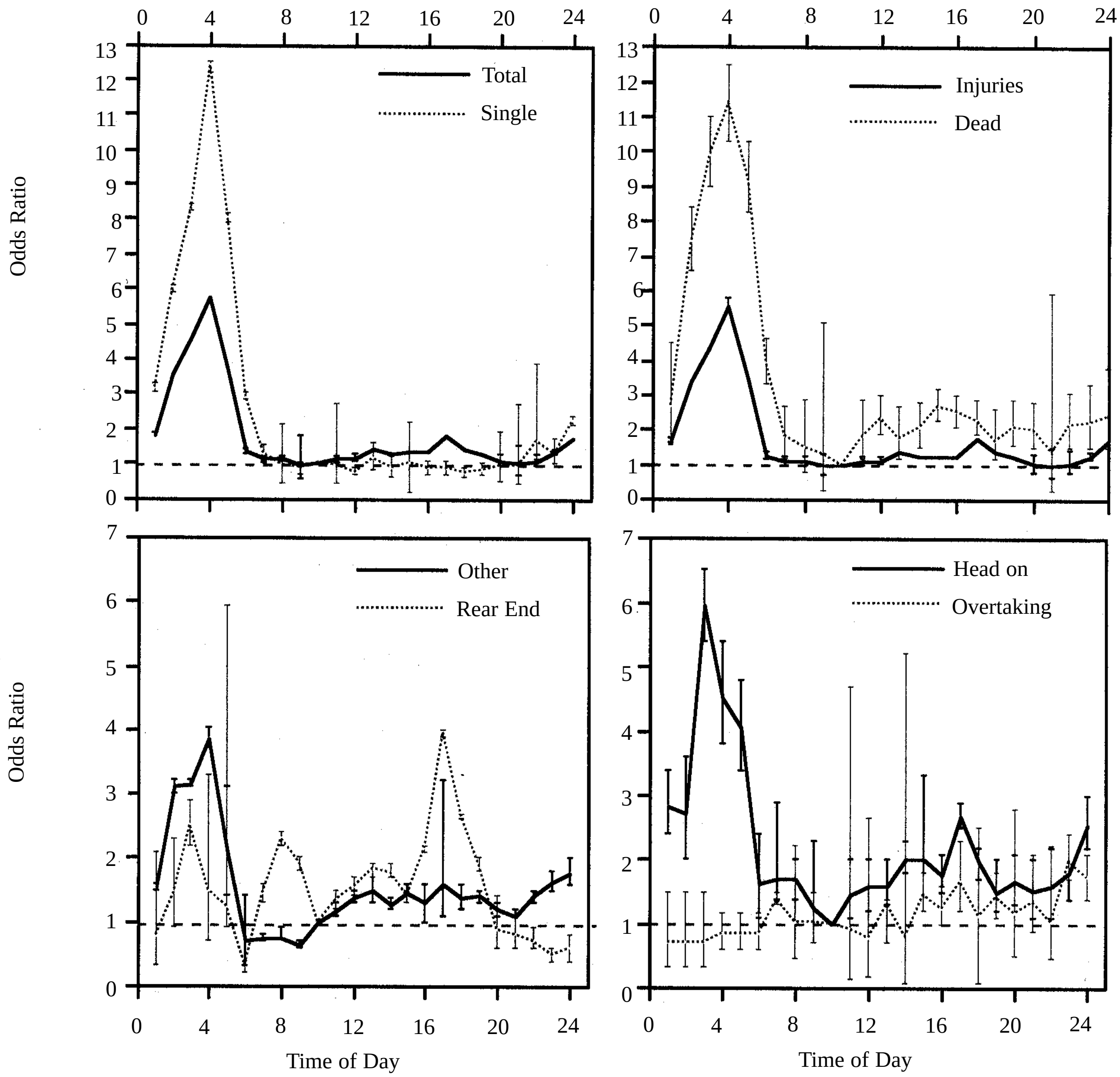

Figure 2—Odds ratio (95% Confidence interval) for being involved in a highway accident at different times of day, resulting in injury or death. The reference time is 10:00h—11:00h, with OR=1 (dashed, horizontal line). The different types of accidents (including total) all involve injury or death as outcomes. In the upper right panel total accidents have been separated in the categories "injuries" and "dead."

0.0006% per hour.

Fatal accidents showed approximately the same relative risk pattern as the total number of accidents, but the increase in risk was eleven-fold around 04:00h and there was a high relative risk throughout the night. The percentage of fatal accidents (of the total number) at different times of day varied between 3.4 and 10.4%, with the highest value around 06:00h.

With regard to type of accident, the relative risk of having a single vehicle accident at 04:00h was increased twelve-fold and stayed high all the time between 24:00h and 06:00h. The rest of the day it did not deviate from unity. The number of accidents varied between 63 and 183, with the lowest figures for the night hours.

Also the risk of head-on accidents was increased during the night hours (with a six-fold value around 03:00h), but remained at high levels during most of the day. The number of accidents varied between 9 and 168, with low values of 9—20 during the early morning hours.

The relative risk of other accidents (turning, collision with an animal) was also clearly increased during the night (four-fold at 04:00h), decreased during the forenoon, increased slightly during the afternoon, and started to rise after 21:00h. The number of accidents varied between 7 and 100 per hour, with the lowest levels during the early morning.

Accidents related to overtaking did not show any clear time of day pattern and had odds ratios close to unity. In addition, the number of accidents between 01:00 and 06:00h was less than five, which makes the estimates highly unreliable.

Rear end accidents showed a nighttime increase in relative risk, but also clear morning and afternoon-evening peaks, reaching a four-fold risk level around 17:00h. The number of accidents varied between 9 and 904 per hour, with the lowest levels in the early morning.

The relative risk of the alcohol-related accidents is not presented since the extremely low daytime levels make the nighttime risk almost astronomical at 04:00h. The Odds Ratio reached

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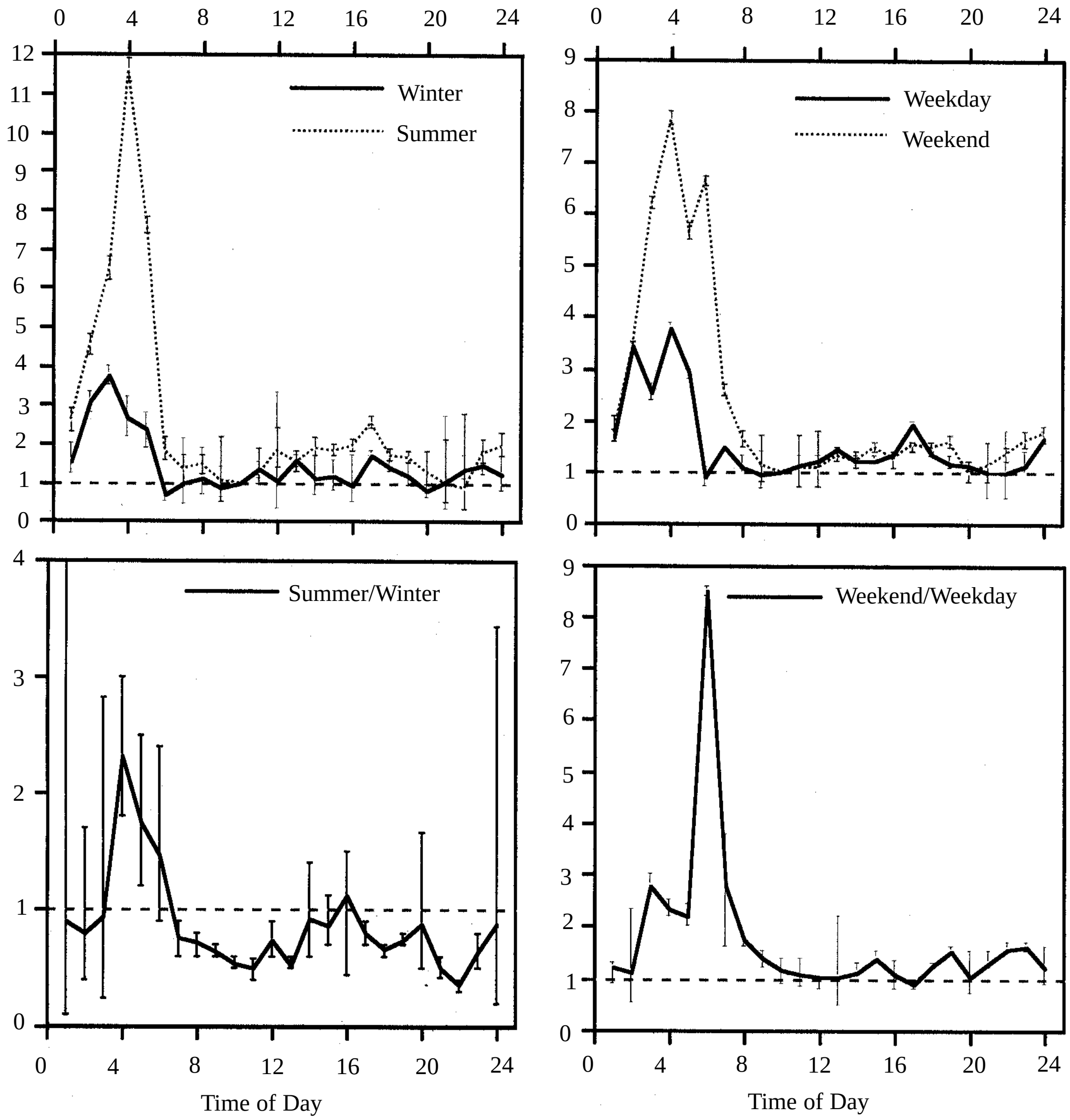

Figure 3—Upper panels: Odds ratio (95% Confidence interval) for being involved in a highway accident at different times of day, resulting in injury or death. The values are given for winter (November + December), summer (May + June), weekdays and weekends. The reference time is 10:00h—11:00h (OR=1; dashed, horizontal line).
Lower panels: Odds ratio (95% confidence interval) for being involved in a highway accident at different times of day, resulting in injury or death. Left panel: for the summer, using winter values as reference (OR=1). Right panel: for weekends, using weekdays as reference (OR=1)

136, for example. The percent of total accidents (based on 10,344 + 683) with alcohol involved was above 20% between 01:00h and 06:00h, varied around 2—3% during most of the day, and started to increase above 5% after 20:00h.

The number of alcohol-related fatal accidents was 73, which is too small a number for a proper risk analysis with respect to time of day, but the percentage of the total number of fatal accidents (629 without alcohol plus 73 with alcohol = 702) was 10.4%. The percentage of fatal accidents (of 702) was 42.3% from midnight to 03:00h, 25% from 03:00h to 06:00h, 7.5% from 06:00h to 09:00h, below 5% up to 18:00h, 15.5% between 18:00h and 21:00h, and 23.6% between 21:00h and 24:00h.

Figure 3 shows that the (total) accident risk during the summer (May + June) had a very high peak at 04:00h, whereas that of winter driving (November + December) occurred at 03:00h and was considerably lower. The summer risk was about twice as high as the winter risk at 04:00—06:00h in the morning, whereas the daytime and evening risks were clearly reduced in the summer. During the beginning of December the times of sunrise and sunset are 08:19h and 14:54h respectively, and during the beginning of June the times are 0347h and 2145h. The number of accidents per hour ranged between 27 to 228 and 13 to 255 for summer and winter, respectively, with the lowest values around 03:00h—05:00h.

Figure 3 also shows that the night-time peak in relative risk was present in both weekend and weekday driving, although the former extended long into the morning hours. In fact, it exceeded that of weekday driving during the whole night, up to 08:00h or 09:00h in the morning, with a very clear peak at 06:00h. Weekend driving accounted for 31.5% of all injuries and deaths with a peak of 72% at 03:00h and a bottom around 07:00h to 09:00h, with 13%-15%. The number of accidents per hour varied

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between 37 and 992 with the lowest value around 0300h.

DISCUSSION

The rate of accidents (involving injuries or death) on main highways showed a clear time-of-day pattern with peaks in the morning and late afternoon, and the same pattern was seen for traffic density. However, the actual risk of injury (controlling for exposure) instead showed a sharp peak around 04:00h, approximately five times the forenoon levels. Obviously, then, the nighttime accidents did not fall from daytime values to the same extent as did traffic flow.

When fatal accidents only were considered, the peak reached 11 times forenoon levels. The pattern was similar for head-on collisions and "other" accidents, while it was even more pronounced for single vehicle accidents. Accident risk involving overtaking did not show any clear pattern, whereas rear-end accidents showed a tendency towards an increase in the afternoon.

The increased nighttime risk clearly agrees with previous work.[2,3,4,5,6,7] The exact position of the peak had very narrow confidence intervals and even if there is a lack of similar studies to compare with, the position of the peak time clearly tallies with previous data on the rate of fatigue-related accidents.[8,9,10] The same early morning peak is also seen when professional drivers are questioned about when fatigue-related accidents/incidents tend to occur,[11,13] and also appear in in-depth investigations of accidents.[14] Also single vehicle accidents, used as proxy for sleep-related accidents, show a clear early morning peak,[15,16] as do sleep intrusions into electroencephalographic (EEG) recordings of truck drivers,[17,18] and train drivers.[19]

Sleepiness as a cause of the increased nighttime risk is also supported by laboratory studies showing pronounced sleepiness (including sleep intrusions into the EEG) towards the end of a night awake.[20] The main causative factors here seem to be the combination of being active at the time of the circadian trough and having spent a long time awake.[21] This may be exacerbated by drivers having slept too little,[22] and possibly also to accumulated sleep loss.[23] Still, it should be emphasized that the present data do not contain sufficient information for drawing conclusions about the extent of fatigue involvement in night-time accidents. In addition, one shouldn't disregard other causes of sleepiness at the wheel, such as sleep apnea and other sleep disturbances,[24] which could exacerbate the other fatigue-inducing aspects of night driving.

Another factor, partly related to sleepiness, may be monotony, since the reduced traffic density at night might be likely to induce such a state. The present study shows that the morning drop in overall in risk occurs simultaneously with the increase in traffic. On the other hand, the risk during the weekend drops from a high level at 06:00h to much lower levels at 07:00h and 08:00, despite the fact that traffic density remains low or has risen only marginally. Thus, monotony may not be a strong influence.

Even if traffic density is not the same as mileage, one should also consider the observation that the rate of accidents, based on miles driven, may be subject to confounding since mileage is correlated with experience. Thus, a large number of miles per year may actually be associated with a reduced risk of an accident.[5]

The weekend risk was also considerably higher than the weekday risk, as has been demonstrated in most of the studies cited above. However, in the present data we also found that the temporal pattern differed—the time at high risk was extended into the late morning. The reason for this is not clear but it is likely that the factors behind sleepiness (extended time awake, short prior sleep, etc) may be more pronounced in connection with weekend driving. Possibly also the duration of driving may be extended in order to reach distant goals outside normal weekday reach. In addition, drugs and perhaps after effects of alcohol consumption may be involved. In any case, the weekend effect needs to be especially considered since a significant proportion of total road accident injuries and deaths occur then.

The present study focused on accidents in which alcohol intoxication was controlled for. But it should be emphasized that the time of day pattern of accident frequency is strongly influenced by alcohol, particularly during the early night hours—it accounts for up to 20% of the accidents at night. And there is some risk that the elimination of alcohol-related accidents may not have been completely successful since investigators in injury cases may have failed to perceive signs of alcohol involvement. On the other hand, alcohol-related fatal accidents should have been completely eliminated based on the compulsory autopsies. Consequently, since the risk pattern of fatal accidents is very close to that of all accidents with injury or death, it seems reasonable to conclude that the latter pattern reflects accidents not involving alcohol. Other drugs could be involved in nighttime accidents, but there are no reliable data available. It should be emphasized that also the 73 fatal accidents that did involve alcohol tended to occur during the night hours. However, they clearly did not account for a majority of the nighttime fatalities.

Suicidal behavior is another possible cause of nighttime accidents. The number of such accidents is rather small,[25] however, and seems to involve mainly head-on accidents, which accounted for less than 10% of the total number in the present study.

Driving in darkness was hypothesized as one potential cause of nighttime accidents, because of poor visibility and perhaps reduced stimulation. At the latitude of Stockholm (around 59°N), the sun was below the horizon between 14:54h and 08:19h during the beginning of December, and the accident peak occurred around 03:00h, five hours before sunrise. However, the early morning peak was twice as high during early June, when the sun was below the horizon between 21:45h and 03:47h, and the peak, thus, occurred after sunrise, at 04:00h. This does not support a notion that darkness would be a major cause of the increased accident risk at night. Interestingly, in the summer the daytime risk was clearly below that of winter driving, presumably because of the effects of ice and snow during the winter. Thus, it seems likely that the increased late night risk during the summer involves an underestimation of the risk if snow and ice could be controlled for.

It can also be speculated that driving behavior might be different at night. For example, the duration of the drive, might be longer, perhaps caused by a desire to reach ones destination at any cost. It is also conceivable that less traffic may tempt the driver to increase speed. A third possibility may be that night driving could attract more incompetent or careless drivers. None of these possibilities have any empirical support, however.

Interestingly, accidents due to overtaking seem to have no nocturnal orientation. One may assume that reduced alertness is virtually absent in drivers overtaking another vehicle. Thus, a nocturnal peak may be less expected, particularly if one also considers the fact that the need for overtaking might be less with

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fewer vehicles on the road. Rear end accidents could arise in situations of reduced alertness, but it seems more likely that such accidents would occur in dense (daytime) traffic, as suggested by the morning and afternoon peaks in risk.

In the present paper we have identified the peak risk hours during the 24-hour span, but one need also to consider the trough hours—mainly during the forenoon hours around 10:00h to 11:00h. We have no obvious explanation for this timing but it seems reasonably to assume that an optimal traffic density, the rising metabolism/alertness, the lower probability of having disturbed night sleep or an extended time awake[26] all may contribute. At present we may only speculate, but this time of day, with low accident risk, is worthy of study in its own right.

Another interpretation of the somewhat elevated risk after the forenoon is the influence of a circasemidian (12 hour) rhythm in alertness. A moderate afternoon peak in sleepiness has been demonstrated in a number of laboratory studies[27] there is a clear afternoon increase in sleep-related road accidents.[8,10,28]

It should be emphasized that the present data may only be generalized to highway driving, which accounts for 55% of the total amount of accidents and 66% of the fatal ones, according to the official statistics.[29] Thus, the excess nighttime risk still accounts for a moderate proportion of the total number of accidents. However, with increasing night driving this proportion is likely to increase.

In summary, the results demonstrate that the risk (excluding alcohol) of being injured in a highway accident is increased fivefold in the early morning, probably because of sleepiness induced by the circadian system. This should have implications for traffic policy as well as for individual decisions to drive at night. Clearly, there is a need for detailed field studies of the prevalence of fatigue/sleepiness on the highways.

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