BRSI

Sleepy at the wheel.

Analysis of the extent and characteristics of sleepiness among Belgian car drivers

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Sleepy at the wheel. Analysis of the extent and characteristics of sleepiness among Belgian car drivers

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TABLE OF CONTENTS

SUMMARY

Introduction

Motor vehicle crashes that are due to driver sleepiness are often particularly severe. They usually occur on monotonous high-speed roads and typically involve a drifting vehicle that hits an obstacle at full speed. According to different international estimates, about 20% of all severe road crashes may be attributed to sleepiness at the wheel. This share is in fact similar to that of driving under the influence of alcohol (25% according to the 2009 European SafetyNet project).

Measuring the prevalence of drowsy driving and its role in crash causation is, however, not self-evident. The main reason is that reliable measurement protocols are not available. It is highly challenging to estimate sleepiness purely on the basis of physical characteristics (certainly after a crash occurred) and when drivers that caused a crash can be interviewed, there is a general bias not to report sleepiness – either by unawareness or by unwillingness. As a result, crash reports are usually not accurate with respect to driver sleepiness and few data exist on the overall prevalence of sleepiness at the wheel.

In the vast majority of international studies, the estimation of this overall prevalence is limited to the occurrence of sleepiness at the wheel across a relatively broad time interval. For instance, in Belgium, the 2012 BRSI attitudes survey asked respondents: "How frequently have you felt tired and sleepy while driving in the past year?"(Meesmann and Boets, 2014). It appeared that in 58% of the cases this occurred at least once. Although such a percentage is informative, it collapses driver sleepiness across all single trips that a driver has made during the last year. Hence, it does not deal with the critical question of how much driving involves sleepy drivers at a given point in time.

The goal of the present study is twofold. The first aim is to obtain a trip-based estimate of the prevalence of sleepiness at the wheel among Belgian car drivers. Sleepiness is measured with respect to an actual driving episode (a trip from A to B) instead of a certain time interval (e.g., during the last 12 months). A trip-based prevalence estimation can be compared with what is done in road-side studies on driving under the influence of alcohol where drivers are stopped to measure their blood-alcohol concentration (e.g., Riguelle, 2014). The current study introduces a new methodology: via an online questionnaire drivers were asked to reflect on a single journey they made during the last 24 hours and to indicate the level of sleepiness they experienced while driving on the Karolinska Sleepiness Scale (KSS). This new methodology reduces the risk of response bias (not admitting sleepiness at the wheel) because it avoids direct contact between respondents and researchers (as in a road-side set-up, for instance). At the same time it is feasible to reach a large sample of drivers that is representative of the Belgian car drivers population.

The second goal of the present study is to understand the prevalence of sleepiness at the wheel among Belgian car drivers through a wide range of contextual variables. Apart from acute sleepiness during the journey, drivers were also asked about trajectory features, sleep habits, driving behaviour and several socio-demographic variables. Chronic sleepiness was assessed via the commonly used Epworth Sleepiness Scale (ESS; Johns, 1991).

Method

BRSI organized a web-based survey between June 15th and July 15th 2014. Over 2,500 respondents, drawn from a panel of 130,000 individuals completed the survey. At the start of the survey, participants indicated whether they drove a car within the last 24 hours. Immediately afterwards, they were asked to bring one of the journeys to mind and answer questions about that journey as accurately as possible. The journey of interest was determined randomly.

The survey was structured according to six topics (see Appendix 2 for the full survey):

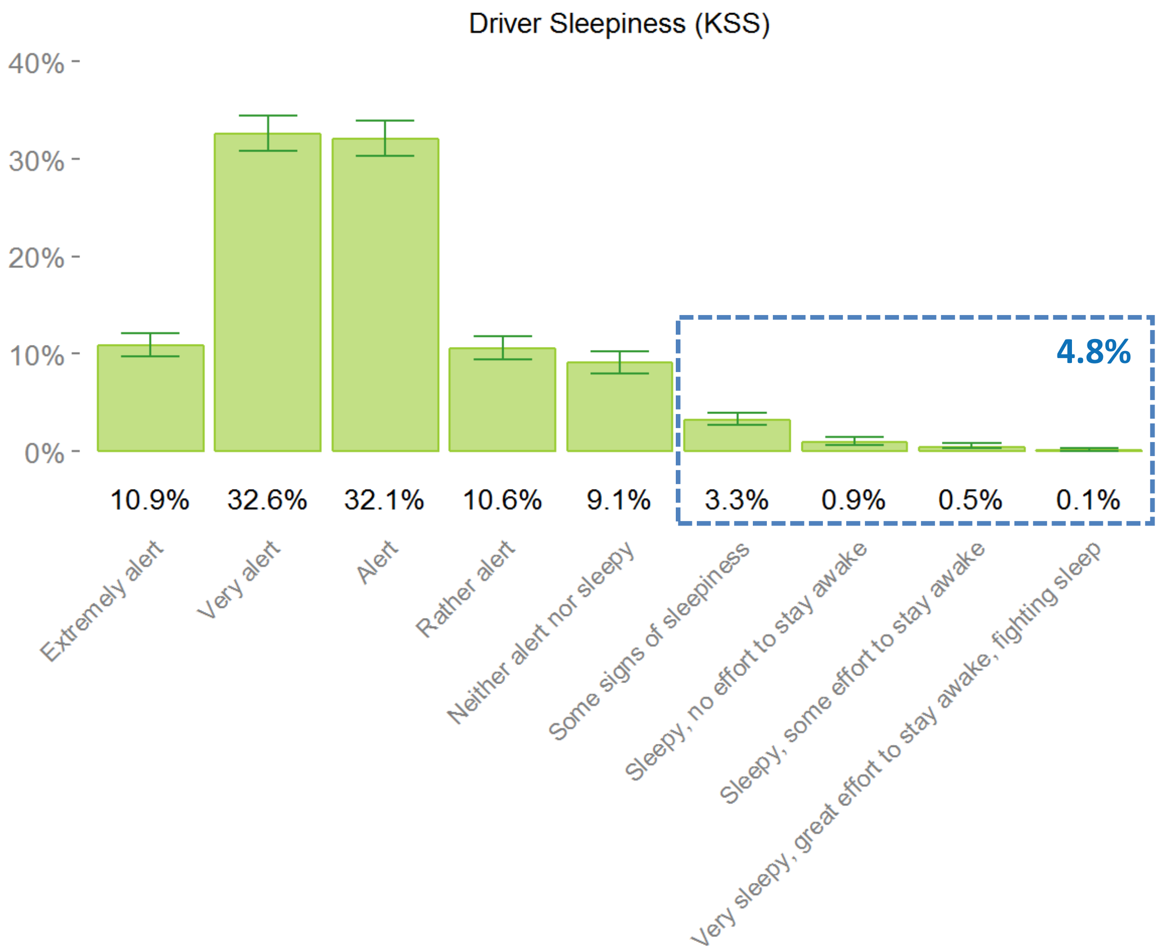
- Physical characteristics of the trajectory
- Sleepiness during the journey
- Last sleep episode before the journey
- Driving behaviour
- Fatigue
- Socio-demographics

The main dependent variable was sleepiness during the journey as measured on the Karolinska Sleepiness Scale.

Results

The results show that overall, 4.8% of the journeys by car drivers in Belgium involve a driver that is showing signs of sleepiness. Figure A shows the obtained distribution with respect to the separate levels of the Karolinska Sleepiness Scale.

Figure A. Prevalence of driver sleepiness as measured with the Karolinska Sleepiness Scale (KSS). Error bars represent the 95% confidence intervals obtained from a fitted proportional odds model.



The analysis of contextual variables shows that various circumstances result in a prevalence that is considerably higher than the overall estimate of 4.8%. A regression analysis reveals unique effects of the following contextual variables on the prevalence of driver sleepiness (in decreasing order of effect sizes; prevalence estimates appear between brackets):

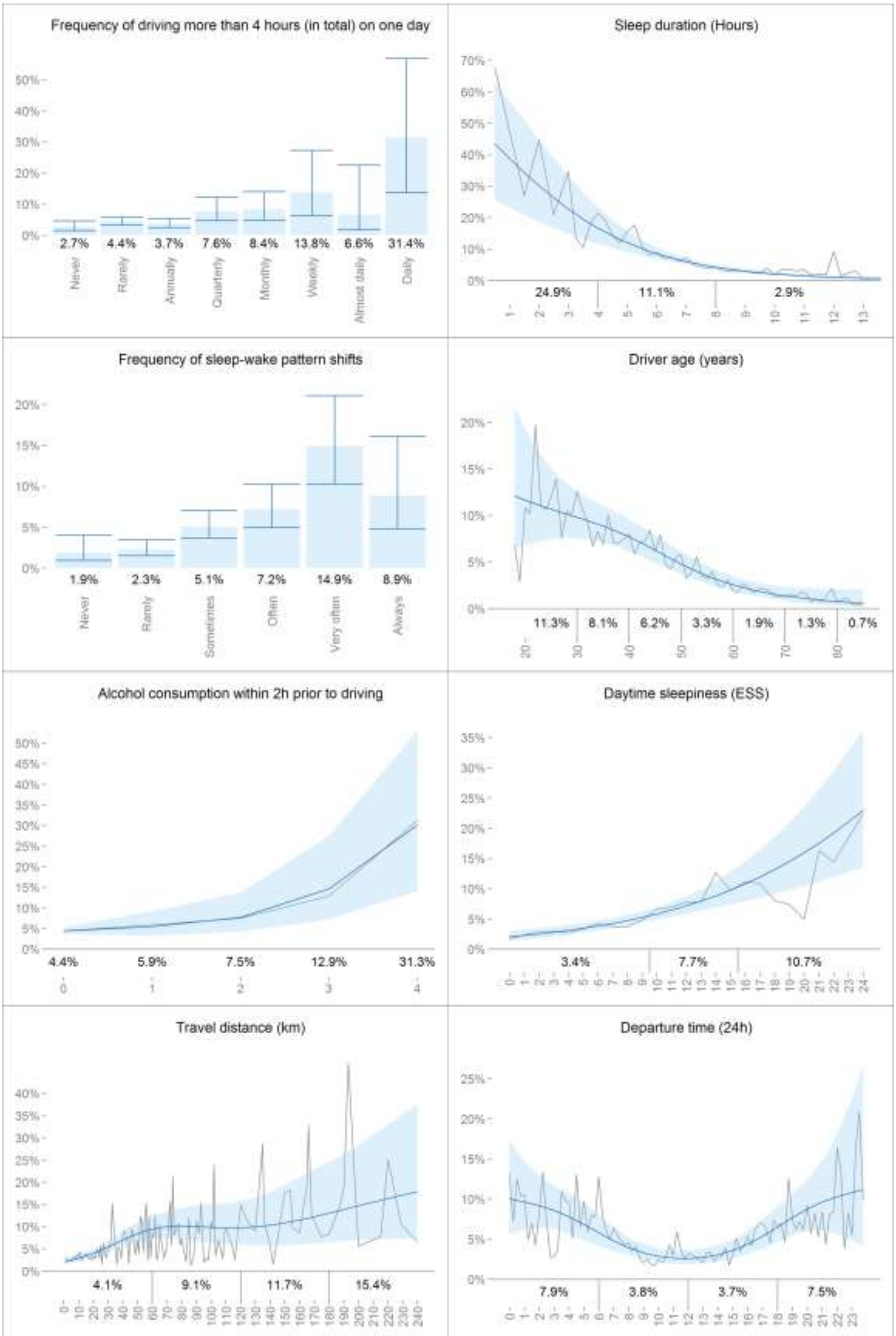
1. Spending more than 4 hours a day at the wheel (31%)
2. Having caught less than 8 hours of sleep (4-8 hours: 11% on average; 0-4 hours: 25% on average)
3. Having an irregular sleep-wake pattern with frequent shifts of more than 2 hours (15%)
4. Being an adolescent/young adult (18-30 years: 11% on average)
5. Having consumed 2 or more standard units of alcohol prior to driving (2-4 units: 11% on average)
6. Having caused a crash or a near-crash during the past 12 months (11%)
7. Experiencing excessive daytime sleepiness (9<ESS≤15: 8% on average; ESS>15: 11% on average)
8. Long distance driving (>60 km: 11% on average)
9. Driving in the evening or at night (6-12pm: 8% on average; 12pm-6am: 8% on average)

Figure B illustrates the continuous nature of these effects (with the exception of the binary crash history variable). Individual effects together with the 95% confidence bands are shown in blue. Irregular grey lines show the estimated prevalence based on the combination of all individual effects. The percentages in the bottom give the same prevalence, but aggregated into categories delimited by the vertical lines.

Distributional analyses also show significant associations with the prevalence of driver sleepiness for the following categorical contextual variables.

10. Having a full-time job (8%)
11. Having a master's degree (7%)
12. Being an employee (7%) or a manager (9%)
13. Dealing with circumstances with a chronic negative effect on sleep quality: stress/depression (8%), long lasting sleep interruptions (7%), obligation to get up early (11%), superficial sleep (8%), difficulties falling asleep (9%), irregular working hours (12%), excessive snoring (8%), family members with sleep problems (9%) and chronic insomnia (12%)

Figure B. The estimated prevalence of driver sleepiness (Y-axis) as a function of driving frequency, sleep duration, sleep consistency, driver age, alcohol consumption, daytime sleepiness, travel distance and departure time (X-axes).



Conclusions and recommendations

This study reveals that, at the level of individual trips, on average 4.8% of the Belgian car drivers shows signs of sleepiness. Although there are no exact Belgian data on the role of sleepiness in crash causation, international numbers suggests that sleepiness at the wheel accounts for about 20% of all severe crashes. The combination of a relatively low prevalence and a relatively large share in crash causation implies a very important risk and shows similarities with driving under the influence of alcohol. According to the most recent estimates, 2.4% of all driving in Belgium occurs under the influence of alcohol (Riguelle, 2014) whereas the share in severe accident causation amounts up to 25% (SafetyNet, 2009). Hence, like driving under the influence of alcohol, the importance of sleepiness at the wheel for road safety should not be underestimated.

This study clearly demonstrates that the prevalence of sleepiness at the wheel varies greatly with specific circumstances. The majority of these circumstances have been documented before, but it is the first time that they become quantified jointly in a Belgian context. Based on this quantification the scenario with the highest risk for driver sleepiness appears to be the following: A young person who caught less than 8 hours of sleep is driving a car for a long distance around midnight after having consumed some alcohol. He or she drives a car frequently and while doing so, caused a crash or near-crash in the past 12 months. He or she also has an irregular sleep-wake pattern and often feels sleepy during the day.

The following recommendations can be made:

Infrastructure:

It is common practice in Belgium to implement rumble strips to alert drivers when their vehicle is drifting. Several studies have demonstrated a high benefit-to-cost ratio for this measure and further implementation can thus be encouraged. If a sleepy driver is alerted by rumble strips, this does not mean that he/she will stay alert for the rest of the trip, however. The creation of more safe(r) rest areas is an infrastructural investment that is more costly, but also more beneficial since the goal is to eliminate sleepiness (see Reyner et al., 2010). Apart from creating rest areas, signalling their presence to drivers is also an important point of action.

Technology:

Further development of in-car and wearable solutions for detecting sleepiness at the wheel needs to be encouraged. However, to attain maximal transparency about their abilities and limitations, current and future technologies need to be validated through independent research.

Raising awareness:

Campaigns are needed to inform drivers about the risks of drowsiness. The fact that sleepiness at the wheel is potentially as dangerous as driving under the influence of alcohol can help improving awareness. Perhaps more important than informing drivers about the risks of drowsiness, campaigns should focus on effective strategies to fight sleepiness at the wheel and to avoid it in the first place. It is important to acknowledge that suitable rest areas and/or other fit drivers are not always available when drivers start experiencing sleepiness. Hence, it is also critical to encourage drivers to plan their trips in advance.

Sleep hygiene:

Sleepiness at the wheel is part of a broader problem in today's society, namely that of neglecting healthy sleep habits. It therefore needs to be approached from a broader perspective than road safety management alone. At the individual level people need to be informed about the health risks due to poor sleep habits (e.g., obesity, heart disease, diabetes and cancer) and the aspects of their daily lives that compromise a good sleep hygiene (e.g., exaggerated use of multimedia devices). Employers should also become aware about the impact of bad sleep habits among their employees. They can play an important role in reducing sleepiness and driver sleepiness in particular, for instance, by facilitating flexible work schedules and the flexible use of different transport modes for commuting.

Further research:

Investments are needed to further assess the impact of driver sleepiness on road safety. It is crucial to measure sleepiness at the wheel with respect to single journeys, in contrast to what has become common practice. The current method allows to obtain a trip-based prevalence on a large scale and in a relatively cost-effective manner. Provided sufficient resources are available, it is fairly straightforward to monitor the evolution of drowsy driving throughout the year and in different countries using the same method. Investigating the actual impact on road safety nevertheless also requires accurate numbers regarding crash causation. As in many other countries, accurate numbers on the role driver sleepiness in road crashes are lacking in Belgium, mainly because of the existing protocols in crash reporting and the lack of in-depth crash investigations. This is perhaps the area where research investments are needed most urgently.

1 INTRODUCTION

An increasing volume of scientific research links sleep shortage to serious health problems, including obesity, heart disease, diabetes and cancer. At the same time, scientists warn that today's 24-hour society poses significant challenges to healthy sleep habits (e.g., Foster & Kreitzman, 2014). Lack of sleep does not only take its toll in the long run, however. According to different international estimates, about 20% of all severe road crashes is related to driver sleepiness (e.g., AFSA, 2008; Anselm & Hell, 2002; Blazejewski et al., 2012; Connor et al., 2002; Herman et al., 2014; Horne & Reyner, 1995; Kecklund et al., 2011; Klauer et al., 2006; Maycock, 1997; Phillip et al., 2001; Sagaspe et al., 2010; Tefft, 2012).

The true share of sleepiness in motor vehicle crashes is difficult to determine. In contrast to blood alcohol concentration, for instance, there are no exact measurement tools and protocols for sleepiness. When sleepy drivers survive a crash, they are usually wide awake immediately afterwards and they are reluctant to admit sleepiness at the wheel to officials. Hence, it is virtually impossible for the latter to estimate a driver's state of sleepiness right before a crash. When a driver sustains fatal injuries, sleepiness can also only be inferred from secondary data, i.e., survivor testimonials (e.g., Connor et al., 2002) and in-depth crash investigation (e.g., Masten et al., 2006; Summala & Mikkola, 1994). Despite these difficulties, it is imperative to study sleepiness at the wheel because the influence on crash statistics and the associated societal costs are potentially underestimated to a great extent.

The present study was designed to estimate the prevalence of sleepiness among car drivers in Belgium. Historically, research on sleepiness at the wheel has been primarily concerned with professional drivers (e.g., Herdewyn et al., 2010) and relatively large countries where many kilometres are spent driving on monotonous high-speed roads (e.g., Tefft, 2012). In a recent BRSI study, however, it was estimated that more than half (58%) of the Belgian car driver population felt sleepy at least once while driving in the past 12 months. For one out of fifteen respondents (7%) sleepiness at the wheel is even a common phenomenon (Meesmann & Boets, 2014). It also appears that 14.8% of the car crashes in Belgium involve a single car that drifts off the road and collides with an off-road obstacle (BRSI analysis of 2012 Belgian crash data). Such characteristics are clearly consistent with driver sleepiness. These numbers illustrate that the problem is not restricted to professional driving or large countries with sparse, monotonous road networks.

The current Belgian data do not provide a direct estimate of the prevalence (or chance) of driver sleepiness. In accordance with the vast majority of international research, studies have tackled this issue by asking drivers to indicate the frequency by which they have felt sleepy or fell asleep at the wheel within a certain time interval (e.g., last 12 months; e.g., Cestac & Delhomme, 2012; Goldenbeld, 2011; Lucas & Araújo , 2013; Meesmann & Boets, 2014; Sagaspe et al., 2010; Tefft, 2012; Vanlaar et al., 2008). Such data provide valuable information, but need to be combined with (usually crude) estimates of driver kilometres within the interval before they can tell us something about the actual chance of experiencing sleepiness at the wheel. More importantly, it is also impossible to link such data to the properties of specific journeys, including the recent sleep history.

To obtain direct prevalence estimates, sleepiness at the wheel needs to be measured with respect to actual kilometres on the road. This is what the present study was designed for. Estimates that are obtained in this way can be combined with the circumstances of the trip and driver characteristics to investigate contributing/risk factors. In the study of drinking and driving, such prevalence estimates are common. BRSI, for instance, estimates the prevalence of drinking and driving via road-side surveys in which questionnaires are issued to drivers that are stopped by the police for breath analysis (see Riguelle, 2014). This allows to investigate drinking and driving in relation to actual journey characteristics (e.g., time of the day, purpose of the trip, etc.). The present study applies the same concept in the context of driver sleepiness. Only a few earlier studies have tried this.

In New Zealand, Connor et al. (2001) conducted a telephone interview with 588 drivers after they were recruited via a roadside sampling protocol. Herman et al. (2014) used a similar design in Fiji with 752 drivers. In both studies about 15% of the drivers reported "not being fully alert", but it can be argued that this description does not necessarily imply driver sleepiness and that the prevalence is much lower. The problem lies in the specific scales that were used to measure sleepiness. Herman et al. found that besides those that were not fully alert, only 0.1% had "difficulties to stay awake" and 0.9% felt "sleepy and would have preferred to lie down". In the study of Connor et al., the 7-point Stanford Sleepiness Scale (Hoddes et al., 1972) was used. Consistent with Herman et al., only 1% of the drivers indicated a score higher than "not fully alert" (score=3). Even here, it remains uncertain whether this number really concerns driver sleepiness. In all these cases, participants indicated that they "felt a little foggy headed" (score=4). The Stanford Sleepiness Scale in fact only explicitly mentions "sleepiness" in the two most extreme categories (score=6 and score=7). These were never used in Connor et al.'s study.

Klauer et al. (2006) studied driver sleepiness in relation to actual driving via the 100-Car Naturalistic Driving Study (Neale et al., 2005). Fourteen independent observers rated drowsiness of 241 drivers in a total of 20,000 randomly selected 6-second video fragments recorded during the study. In this way, they arrived at a prevalence estimate of 2%, which seems to align with the more extreme scores in the studies of Connor et al. (2001) and Herman et al. (2014).

The present study is original in two ways: (1) it is the first time that sleepiness at the wheel is investigated in a large scale representative sample of Belgian car drivers and (2) the study measures sleepiness with respect to individual driving episodes – instead of aggregating sleepiness at the wheel across a certain time interval. This is achieved by introducing a new method: an online questionnaire that is concerned with a single journey in the last 24 hours. This method improves earlier studies in three important ways. First of all, data are collected from a much larger sample of drivers (2,585 versus 588, 752 and 241). Second, data are collected anonymously to promote truthful responses. Telephone or face-to-face interviews, as used by Connor et al. and Herman et al., involve a higher risk of socially desirable responses - in this case: not admitting sleepiness at the wheel. Third, drivers report their level of sleepiness on a scale that clearly identifies different levels of sleepiness and that has been validated against several objective measures of sleepiness. This scale overcomes the problem of insufficient discrimination between moderate and more serious levels of driver sleepiness in the studies of Connor et al. and Herman et al. At the same time, it avoids an indirect measurement method, like the video analysis used by Klauer et al., which narrows down the evaluation of driver sleepiness to external physical symptoms.

More specifically, BRSI organized a web-based survey, issued to a representative sample of 2,585 Belgian car drivers between June 15th and July 15th 2014. Participants responded anonymously to questions concerning sleepiness at the wheel during a randomly selected trip in the last 24 hours. The main dependent variable was sleepiness rated on the Karolinska Sleepiness Scale (KSS; e.g., Åkerstedt and Gillberg, 1990; Åkerstedt et al., 2010; Anund et al., 2013; Kaida et al., 2006). To investigate contributing/risk factors, drivers also provided information on trajectory features, sleep habits, driving behaviour and several socio-demographic variables. In line with previous studies (e.g., Connor et al., 2001; Lucas & Araújo , 2013), we also included a commonly used measure of chronic (as opposed to acute) sleepiness: the Epworth Sleepiness Scale (ESS; Johns, 1991). The scores of this scale represent the likelihood of falling asleep in common daily life situations like sitting and reading, watching TV and sitting in a car that is stopped for a few minutes in traffic (see Appendix 2). The ESS performs well in discriminating individuals with and without sleep disorders (e.g., Engleman et al., 1999; Johns, 2000) and also correlates with driver sleepiness (e.g., Lucas & Araújo , 2013).

The goal of the present study is twofold. The first aim is a trip-based estimate of the prevalence of sleepiness at the wheel among Belgian car drivers. Sleepiness is measured with respect to an actual driving episode (a trip from A to B) instead of a certain time interval (e.g., during the last 12 months). A trip-based prevalence estimation can be compared with what is done in road-side studies on driving under the influence of alcohol where drivers are stopped to measure their blood-alcohol concentration (e.g., Riguelle, 2014). The second goal is to understand the prevalence of sleepiness at the wheel through a wide range of contextual variables.

2 METHOD

The survey was distributed within a panel of more than 130,000 individuals, representative of the Belgian population above 17 years of age[1]. A total of 3,804 respondents initiated the survey, 2,585 of those indicated that they had driven a car in the last 24 hours and completed the survey accordingly. Detailed sample characteristics, including those of non-respondents, can be found in Appendix 1. At the start of the survey, participants indicated whether they drove a car in any of the following four time slots within the last 24 hours. Participants were clearly instructed that the study only concerned driving on public roads between two different locations, excluding short breaks (at gas stations, for instance).

1. Between 6 am and 12 am
2. Between 12 am and 6 pm
3. Between 6 pm and 12 pm
4. Between 12 pm and 6 am

Immediately afterwards, they were asked to bring one of the journeys to mind and answer questions about that journey as accurately as possible. The journey of interest was determined randomly as either the first or the last journey within a given time slot. If more than one time slot had been checked, one of these slots was sampled. This was done in a pseudo-random fashion, i.e., a random choice was made, except when the 12pm-6am (night-time) slot had been checked. The 12pm-6am slot was automatically selected, if checked by the participant, to avoid underrepresentation of night-time driving[2].

Maximal heterogeneity in the timing of the trips was sought by sending out email requests to panel members in small batches each hour of the day. Requests were sent out evenly across all 7 days of the week, however, to facilitate a balanced statistical comparison between weekday and weekend driving, half of the requests was sent during weekdays (Monday 6am to Friday 6pm) and the other half during the weekend (Friday 6pm to Monday 6am)[3]. Each panel member was only granted access to the survey once. Responses were recorded from June 15th to July 15th 2014.

The survey was structured according to six topics (see Appendix 2 for the full survey):

1. Physical characteristics of the trajectory
    - Departure time
    - Week/weekend
    - Travel distance
    - Passengers
2. Sleepiness during the journey
    - Karolinska Sleepiness Scale (KSS)
    - Actions to prevent or fight driver sleepiness
    - Alcohol consumption prior to driving

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[1] This service was provided by an external partner: Profacts.

[2] It was anticipated that the typical times at which web surveys are completed together with recency effects in memory, would induce an bias towards daytime driving. This is especially undesirable in the light of evidence that sleepiness at the wheel is especially risky at night (e.g., Åkerstedt et al., 2001; Connor et al., 2002). In the analysis, data from night-time driving was weighted downwards to correct for the oversampling (see Results section).

[3] These measures facilitate, but do not guarantee sampling the natural distribution of journeys since participants are free to decide when to take the survey after they received the email request.

3. Last sleep episode[4] before the journey
   - Sleep duration
   - Sleep quality
   - Napping
4. Driving behaviour
   - Mileage
   - Frequency of 30 minute journeys
   - Frequency of night-time driving
   - Frequency of driving more than four hours a day
   - Sleepiness at the wheel during the past year
   - Crash history
5. Fatigue
   - General sleep quality
   - Sleep-wake pattern consistency
   - Daytime sleepiness: Epworth Sleepiness Scale (ESS; Johns, 1991; see Appendix 2)
   - Causes of mental fatigue
   - Work regime
6. Socio-demographics
   - Residence (administrative region)
   - Gender
   - Age
   - Education level
   - Professional activity
   - Employment regime

[4] "Sleep episode" is defined as the interval between what is commonly understood as 'going to sleep' and 'getting out of bed', regardless of whether the interval spans day or night.

3 RESULTS

The first section of this chapter (Section 3.1) includes the results in relation to the *overall prevalence* of driver sleepiness, i.e., the primary variable in this study: scores on the Karolinska Sleepiness Scale. In the two following sections, associations of driver sleepiness with *contextual variables* are discussed[5].

Section 3.2 provides the results of a multiple regression analysis where driver sleepiness was considered as a function of binary and numerical contextual variables (including ordered factors), i.e., *age*, *gender*, *departure time*, *week/weekend*, *travel distance*, *passengers*, *alcohol consumption prior to driving*, *mileage*, *frequency of 30 minute journeys*, *frequency of night time driving*, *frequency of driving more than four hours a day*, *crash history*, *work regime*, *sleep duration*, *sleep quality*, *napping*, *general sleep quality*, *sleep-wake pattern consistency* and *daytime sleepiness*. Methodological details of this analysis are provided at the beginning of Section 3.2.

Section 3.3 presents the results of distributional analyses and is concerned with the association of driver sleepiness with *unordered categorical* contextual variables with more than two levels (binary variables were part of the regression analysis). This involved the following variables: *residence (administrative region)*, *employment regime*, *work regime*, *education level*, *professional activity*, *causes of mental fatigue* and *actions to prevent or fight driver sleepiness*. These variables were not considered in the regression analysis (Section 3.2) for three reasons. First, the categorical variables often contain levels with a clear relationship with those of others (e.g., the level of education and the kind of professional activity) or with one or more of the numerical contextual variables (e.g., being retired and age). In the latter case the association with driver sleepiness was always explained better by the numerical predictor (according to the Akaike Information Criterion; AIC). A second reason for considering the unordered categorical contextual variables separately is that they often did not improve the fit of the regression model, while one or more of their levels nevertheless showed a significant association with driver sleepiness. The third reason is that in for *causes of mental fatigue* and *actions to prevent or fight driver sleepiness* respondents were allowed to select more than one level. Hence, the levels of these variables are not mutually exclusive. For these variables the goal of the analysis is rather to investigate the relative frequency of the levels instead of the power to discriminate between different levels of driver sleepiness.

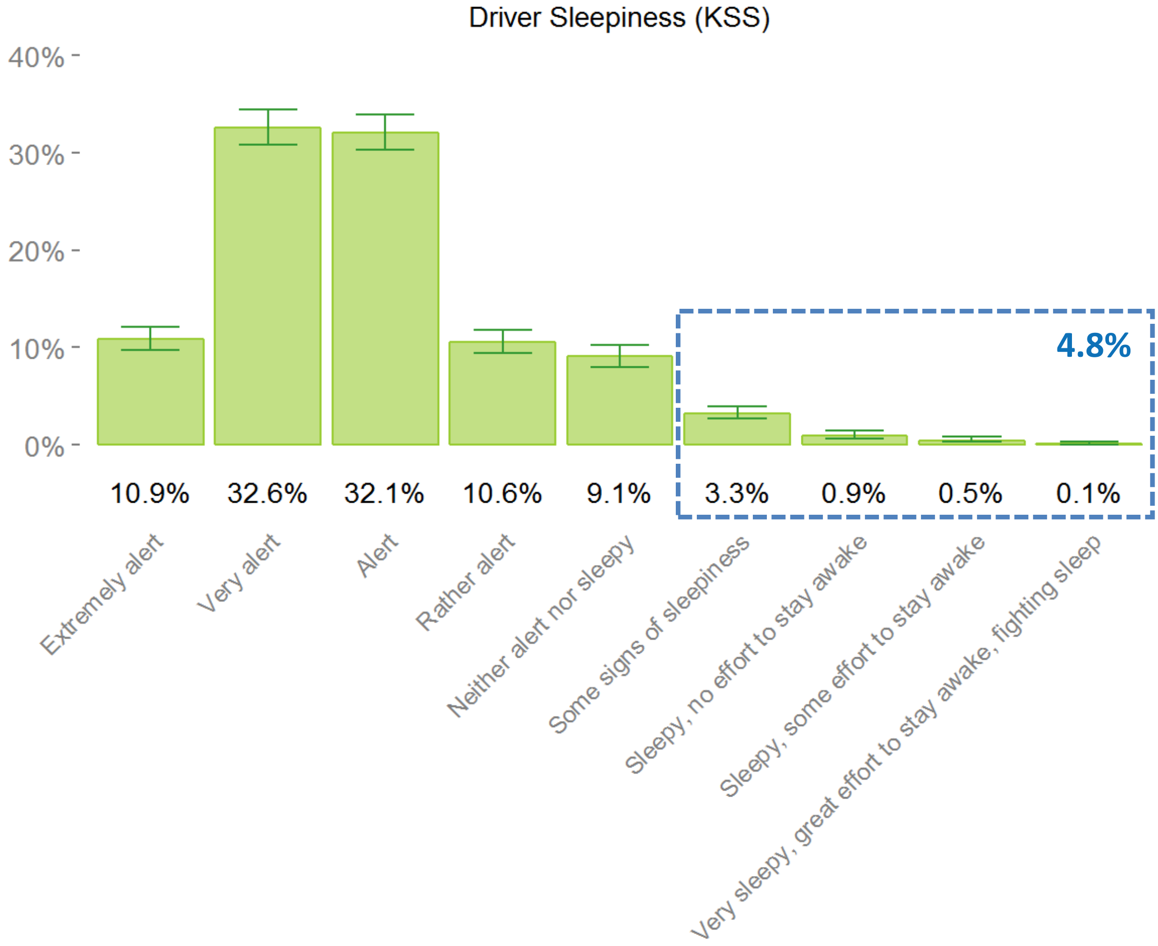
3.1 Prevalence of driver sleepiness

After selecting one particular journey (see Method section), the Karolinska Sleepiness Scale (KSS) was used to measure subjective sleepiness while driving. The key result is that 4.8% of the drivers report sleepiness, ranging from "Some signs of sleepiness" (3.3%) to "Very sleepy, great effort to stay awake, fighting sleep" (0.1%). The 95% confidence interval for this frequency estimate ranges from 4% to 5.7%.

Figure 1 presents the distribution of the scores. The raw percentages were weighted so as to reflect the population values for age (source: Belgian Federal Public Service Economy) and an unbiased distribution of departure time slots. As illustrated in Section 3.2.1 and Appendix 1.6, driver age was a significant predictor of driver sleepiness but the sampled ages deviated from the population estimates in the low range. Age weights were applied to remedy this. The correction for departure time slots was necessary because night-time driving (12pm-6am) was deliberately oversampled in the study design (see Method section for details). Weights were applied such that the distribution of departure time slots reflected the distribution of all departure time slots participants had indicated and not just the particular slots that had been selected with the pseudo-random procedure (as described in the Method section). The underlying assumption is that the data on all time slots that were reported reflects the natural distribution of departures times in the population of Belgian car drivers.

[5] All analyses and visualisations were implemented in R version 3.1.2 (R Core Team, 2014). Statistical significance was always evaluated at alpha = .05.

Figure 1. Prevalence of driver sleepiness as measured with the Karolinska Sleepiness Scale (KSS). Error bars represent the 95% confidence intervals obtained from a fitted proportional odds model.



3.2 Multiple regression analysis

Prior to this analysis the KSS scores were dichotomised, classifying cases with a KSS score larger than 5 as "Sleepy" (1) and the other cases (KSS ≤ 5) as "Non-sleepy" (0). The resulting binary variable was entered as the dependent variable in a logistic regression analysis. Contextual variables that were either binary or measured on a numeric scale (including ordered factors) were assessed as predictor variables via stepwise model selection. For predictor variables measured on interval scale (e.g., driver age), non-linear relationships were modelled using thin plate regression splines (Wood, 2003). For ordinal-scale predictors (i.e., ordered factors, e.g., sleep-wake pattern consistency) this was done via polynomial contrasts.

The final model only contained predictors with regression weight(s) that differ significantly from zero after controlling for the influence of the other contextual variables. These predictors thus explain a unique part of the variance in the binary sleepiness values. The effects of these variables are discussed in sections 3.2.1 to 3.2.9. The discussions and the graphs that accompany them nevertheless focus on the individual regression results, i.e., the estimated regression weight(s) for a given predictor variable *before* incorporating the effects the other significant predictor variables. The reason for this is that for some pairs of predictor variables there was a certain degree of correlation between the values. The strongest correlations occurred (1) between driver age and sleep-wake pattern consistency (r=.37), showing a tendency for higher sleep-wake pattern consistency in older drivers, (2) between driving frequency and travel distance (r=.23), with frequent drivers often travelling for longer distances and (3) between sleep duration and departure time (r=*.20*), showing that drivers travelling closer to midnight often spent less time in bed. Correlations among other pairs of contextual variables were generally low (mean r=.10; inter quartile range r=[.07,.13]). The consequence of these correlations is that, although all significant predictors explain a unique part of the variance, some of them are also associated with a part that is non-unique, i.e., a part of the variance that can also be explained by the correlated predictor(s).

Because there is no way of knowing which part of this shared variation should be assigned to one or the other predictor variable, the most conservative approach is to report individual regression results instead of the partial effects in the full model.

The following binary/numeric contextual variables did *not* show a unique significant relationship with the prevalence of driver sleepiness:

- Gender: There appeared to be no significant difference in the prevalence of driver sleepiness between female and male drivers. The sample distribution is shown in Appendix 1.1.
- Week/weekend: There was no significant difference in the prevalence of driver sleepiness on weekdays and during the weekend. In line with the sampling scheme, the distribution of weekday journeys (52%) and weekend journeys (48%) was approximately balanced.
- Passengers: There was no significant influence of whether or not drivers were travelling alone. The position of passengers (front and/or back seat) also did not result in a significantly different prevalence of driver sleepiness. In 57% of the cases drivers were travelling alone in their vehicle. A front seat passenger was present in 39% of the cases. In 12% of the cases at least one back seat passenger was present.
- Mileage: There was no unique association between the prevalence of driver sleepiness and the average number of kilometres spent driving per year, week (mon-sun) or weekend (sat-sun). More specifically, the effects were outperformed by the frequency of driving more than four hours a day (according to AIC). Appendix 1.11 shows the sample distributions.
- Frequency of 30 minute journeys: The prevalence of driver sleepiness did not depend on how often drivers undertake journeys of 30 minutes or more. The sample distribution is shown in Appendix 1.9a.
- Frequency of night time driving: The prevalence of driver sleepiness did not depend uniquely on how often drivers drive between 12pm and 6am. The frequency of driving more than four hours a day proved to be a better predictor (according to AIC). The distribution is shown in Appendix 1.9b.
- Sleep quality: Self-reported sleep quality, immediately before the journey as well as usual levels, did not explain a unique part of the variance. More specifically, sleep duration proved to be a better predictor of the prevalence of driver sleepiness (according to AIC). Sample distributions are shown in Appendix 1.12.
- Napping: The prevalence of driver sleepiness did not depend significantly on whether or not drivers took a nap in between their last sleep episode and the time of departure. Seven percent of the drivers indicated they took such a nap.
- Work regime: For those respondents that have a job the regression analysis showed no significant differences with respect to the weekly number of days or hours spent working or the frequency of working outside regular office hours. The sample distributions of these variables are shown in Appendix 1.10.

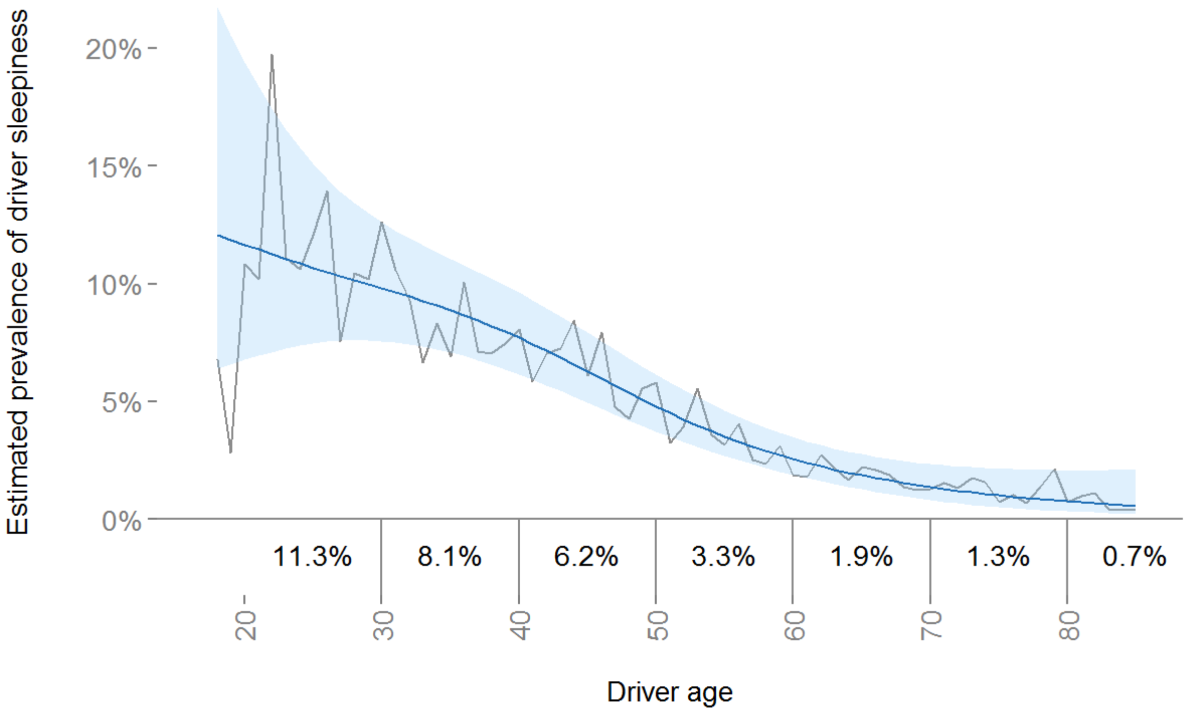
The following subsections present the results of the contextual variables that showed a significant unique association with the prevalence of driver sleepiness. The results were weighted in the same way as in Section 3.1.

3.2.1 Driver age

Sleepiness is especially prevalent among younger drivers. Figure 2 shows a continuously decreasing trend in the prevalence of driver sleepiness with age. The individual effect of driver age together with the 95% confidence band is shown in blue. The irregular grey line shows the estimated prevalence in the study sample based on the additive effects of all significant predictors (i.e., the full regression model). The percentages in the bottom give the same prevalence, but aggregated into age categories, delimited by the vertical line segments (i.e., $18y \leq A \leq 30y < B \leq 40y < C \leq 50y < D \leq 60y < E \leq 70y < F \leq 80y < G$).

Between 18 and 30 years of age, the prevalence of driver sleepiness reaches 11.3%. The prevalence decreases with 1% about every 4 years up to an age of 60. For drivers aged above 60 years, the prevalence is generally low. The sampled age distribution is shown in Appendix 1.3.

Figure 2. Estimated prevalence of driver sleepiness (KSS score > 5) as a function of driver age.

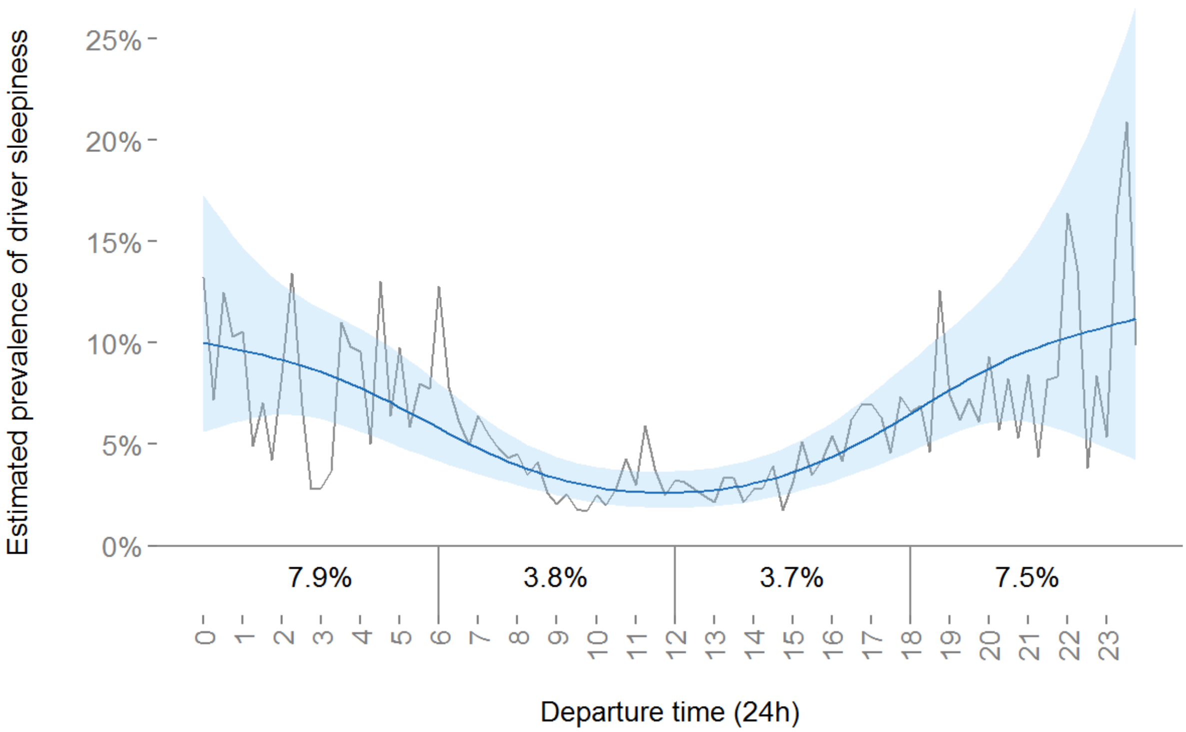


3.2.2 Departure time

There is a continuous relationship between the time of the day and driver sleepiness. This is illustrated in Figure 3. The individual effect of departure time together with the 95% confidence band is shown in blue. The irregular grey line shows the estimated prevalence in the study sample based on the full regression model. The percentages in the bottom give the same prevalence, but aggregated into the four time slots in the study design. The vertical line segments show the boundaries of these slots (i.e., 12am ≤ *A* < 6am ≤ *B* < 12pm ≤ *C* < 6pm ≤ *D* < 12am).

It appears that the prevalence is approximately twice as high for driving in the evening (6-12pm; 7.5%) and at night (12pm-6am; 7.9%) compared to daytime driving (6-12am; 3.8% and 12am-6pm; 3.7%). There is no significant difference in this pattern with respect to weekday and weekend driving. The distribution of the departure times in the sample is given in Appendix 1.4.

Figure 3. Estimated prevalence of driver sleepiness (KSS score > 5) as a function of departure times.



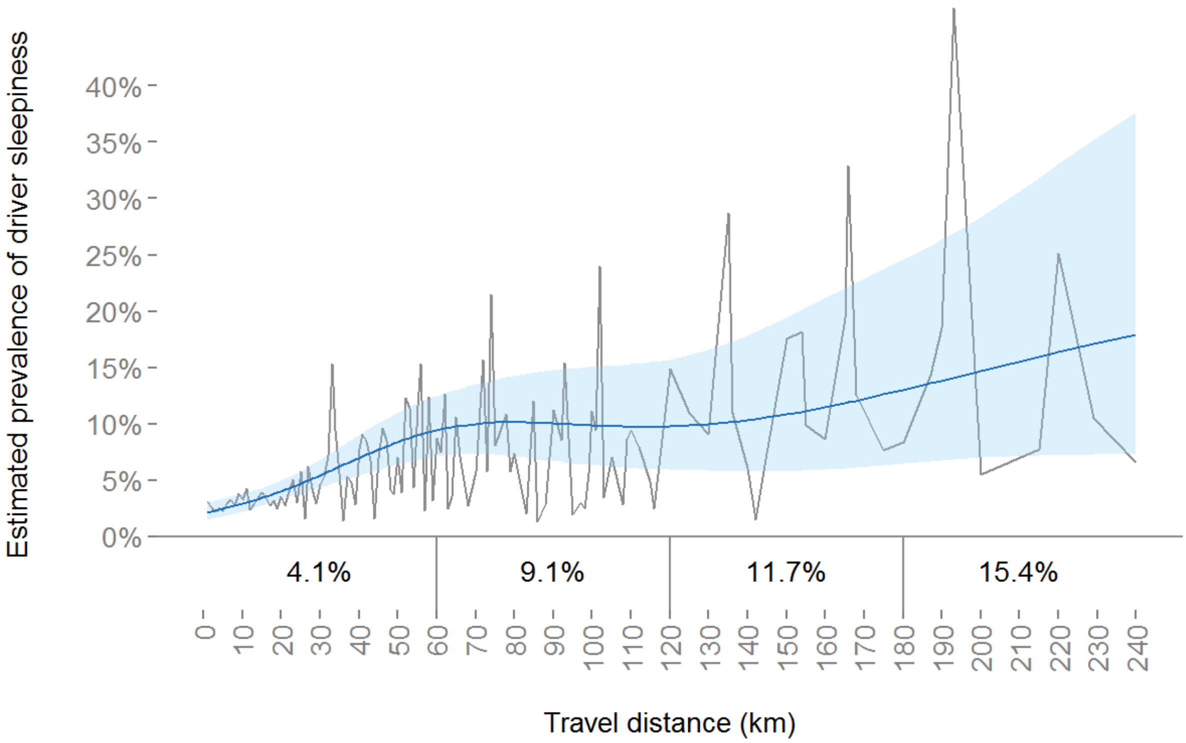
3.2.3 Travel distance

For trajectories up to 60km, there is a steep linear increase in the prevalence of driver sleepiness. This is shown in Figure 4. The individual effect of travel distance together with the 95% confidence band is shown in blue. The irregular grey line shows the estimated prevalence in the study sample based on the full regression model. The percentages in the bottom give the same prevalence, but aggregated into distance categories, delimited by the vertical line segments (i.e., 0km < $A \leq$ 60km < $B \leq$ 120km < $C \leq$ 180km < $D \leq$ 240km)[6].

Up to a distance of 60km, the prevalence increases with 1% about every additional 7.8km at the wheel. For longer trips the prevalence is considerably higher on average, but the increase per additional distance is smaller. Appendix 1.5 shows the sample distribution of the travel distances.

[6] For trajectories longer than 240km the current estimates are too imprecise because of low data density.

Figure 4. Estimated prevalence of driver sleepiness (KSS score > 5) as a function of distance travelled.



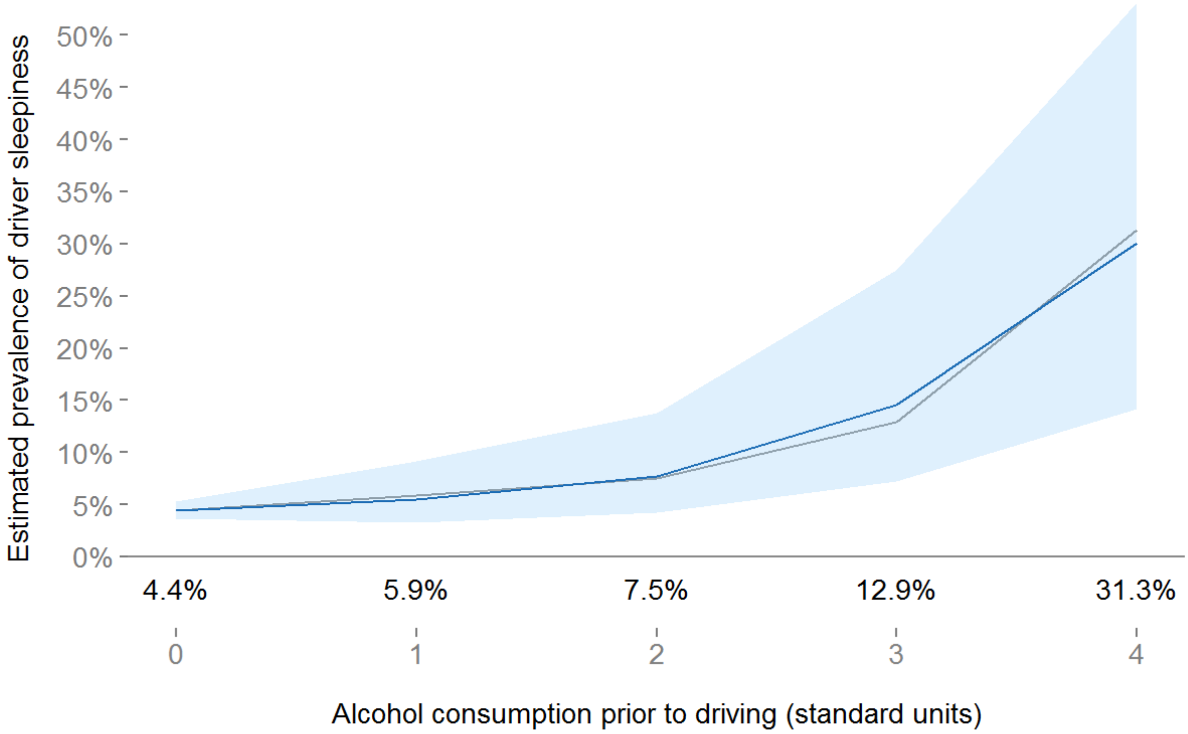
3.2.4 Alcohol consumption prior to driving

As shown in Figure 5, alcohol consumption within the two hours immediately preceding the journey increases the prevalence of driver sleepiness. The individual effect together with the 95% confidence band is shown in blue. The irregular grey line shows the estimated prevalence in the study sample based on the full regression model. The percentages in the bottom give the prevalence found after consuming zero, one, two, three and four standard units of alcohol within the two hours preceding the journey (1 unit = 1 glass of wine [10cl] = 1 glass of beer [25cl] = 1 cocktail [10cl] = 1 aperitif [6cl] = 1 glass of liquor [3cl]) [7].

Up to three units of alcohol the prevalence increases with 1% per additional consumption of about 0.3 units. With more than 3 units there is a steep increase in the prevalence of driver sleepiness. Alcohol consumption before or during driving is reported in 8.5% of the cases, more than one unit in 3.8% of the cases, more than two units in 1.3% of the cases and more than three units in 0.6% of the cases.

[7] For consumption of more than 4 units the current estimates are too imprecise because of low data density.

Figure 5. Estimated prevalence of driver sleepiness (KSS score > 5) as a function of alcohol consumption within the two hours preceding the journey.

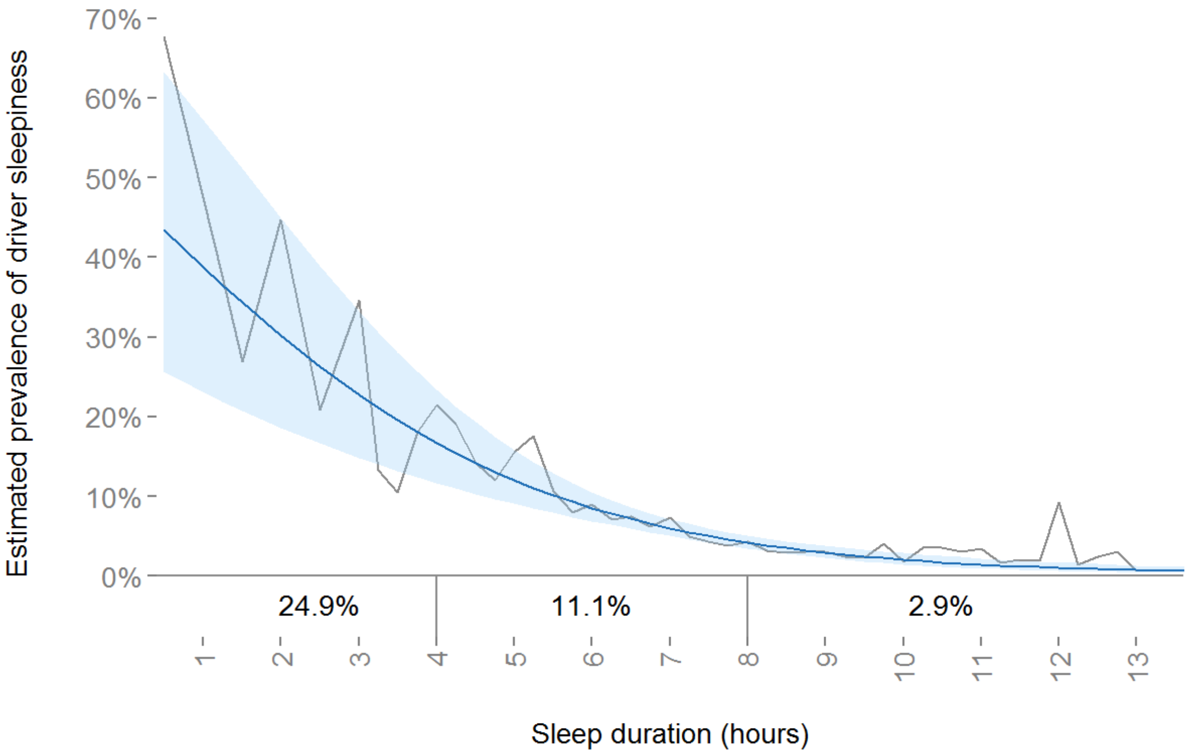


3.2.5 Sleep duration

Sleep duration was calculated on the basis of the answers participants gave to the questions "At what time did you go to sleep?" and "At what time did you get up?" (with respect to the last sleep episode before the journey). As illustrated in Figure 6, longer sleep episodes result in a lower prevalence of sleepiness during subsequent driving. The line and ribbon in blue show the individual effect of sleep duration and the 95% confidence band. The estimated prevalence of driver sleepiness in the study sample, based on the full regression model, is shown in grey. The percentages in the bottom give the aggregated prevalence for the following categories: $A \leq 4\text{h} < B \leq 7\text{h} < C$.

With less than 8 hours of sleep the prevalence of sleepiness at the wheel rapidly increases. Up to 8 hours of sleep the prevalence decreases with 1% about every 12 and a half minutes of additional sleep. Appendix 1.6 shows the sample distribution of the sleep durations.

Figure 6. Estimated prevalence of driver sleepiness (KSS score > 5) as a function of the sleep duration before the journey.

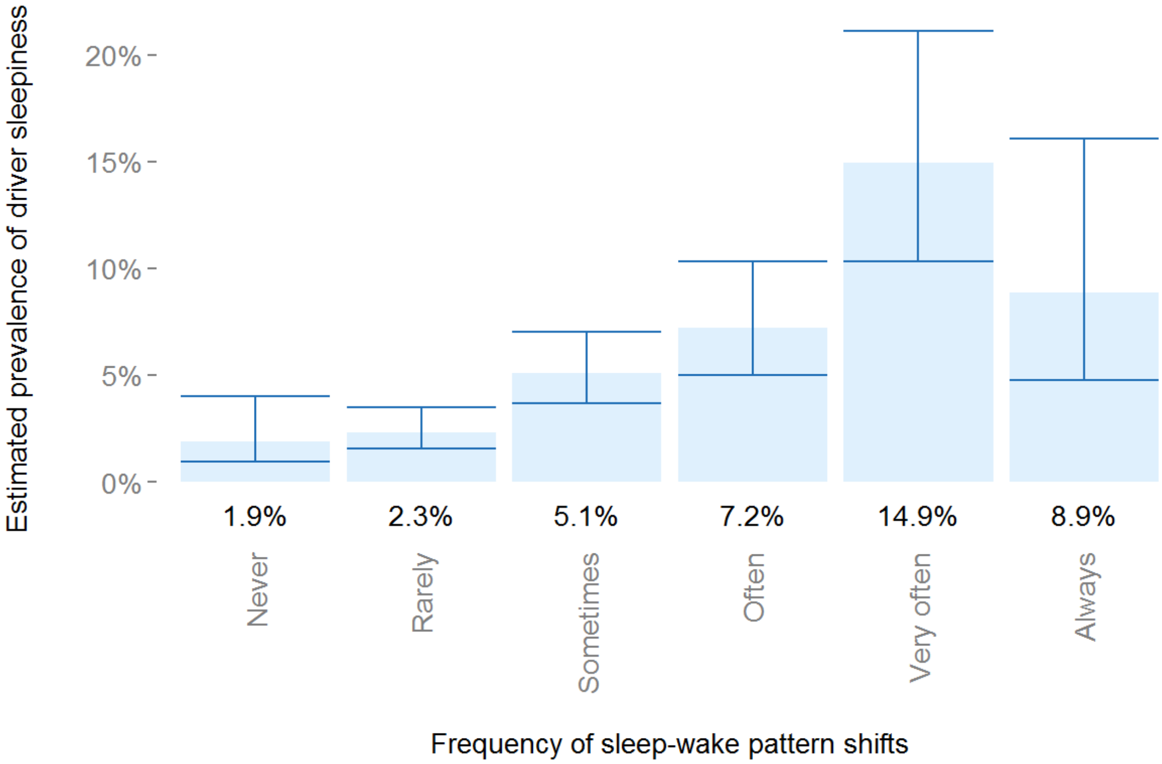


3.2.6 Sleep-wake pattern consistency

Driver sleepiness has a higher prevalence among people with irregular sleep-wake patterns. This is shown in Figure 7. Respondents were asked how often they experience shifts of more than two hours in their sleep-wake pattern (i.e., in the time of going to sleep and/or the time of getting up). The bars illustrate the individual effect of the resulting ordered factor on the prevalence of driver sleepiness together with the 95% confidence intervals.

The prevalence of driver sleepiness generally increases as a function of the frequency by which one experiences more than two hour shifts in the sleep-wake pattern. The increase is not monotonous, however. There is a significant cubic-component showing that drivers who experience sleep-wake pattern shifts all the time ("Always") are less prone to driver sleepiness (8.9%) than drivers that do so very often (14.9%). Appendix 1.7 shows the sample distribution for all categories.

Figure 7. Estimated prevalence of driver sleepiness (KSS score > 5) as a function of the frequency of > 2 hour sleep-wake pattern shifts.



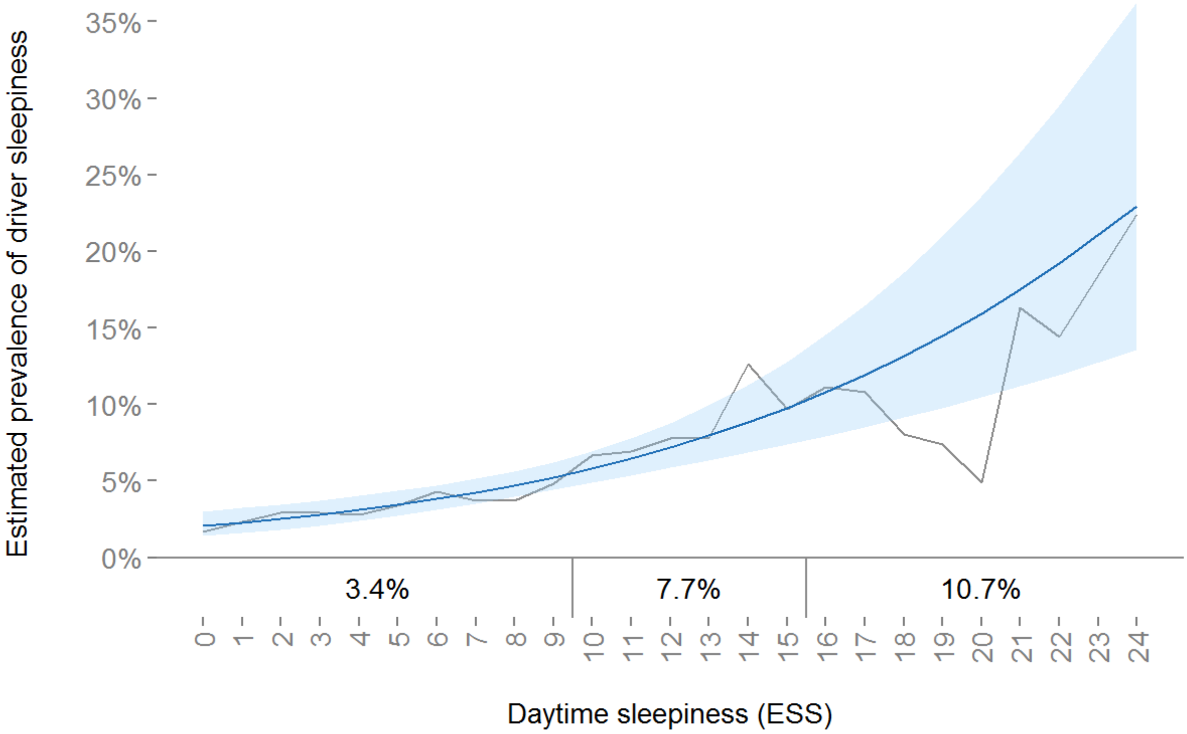
3.2.7 Daytime sleepiness

The Epworth Sleepiness Scale (ESS) was used to measure how likely drivers are to doze off or fall asleep during in everyday situations (see Appendix 2.21), i.e., daytime sleepiness. Scores that exceed 9 are commonly associated with a medical condition (29% of the drivers). Scores above 15 are usually a sign of serious pathology (3% of the drivers). The sample distribution of all the scores is given in Appendix 1.8.

As shown in Figure 8, there is a positive relation between daytime sleepiness and the prevalence of driver sleepiness. The individual effect of the ESS scores together with the 95% confidence band is shown in blue. The irregular grey line shows the estimated prevalence in the study sample based on the full regression model. The percentages in the bottom give the same prevalence, but as a function of the following categories: ESS $0 < A \leq$ ESS $9 < B \leq$ ESS $15 < C \leq$ ESS 24.

Up to an ESS score of 15 the prevalence of driver sleepiness increases with 1% about every two units on the ESS. For scores above 15 there is a much steeper increase.

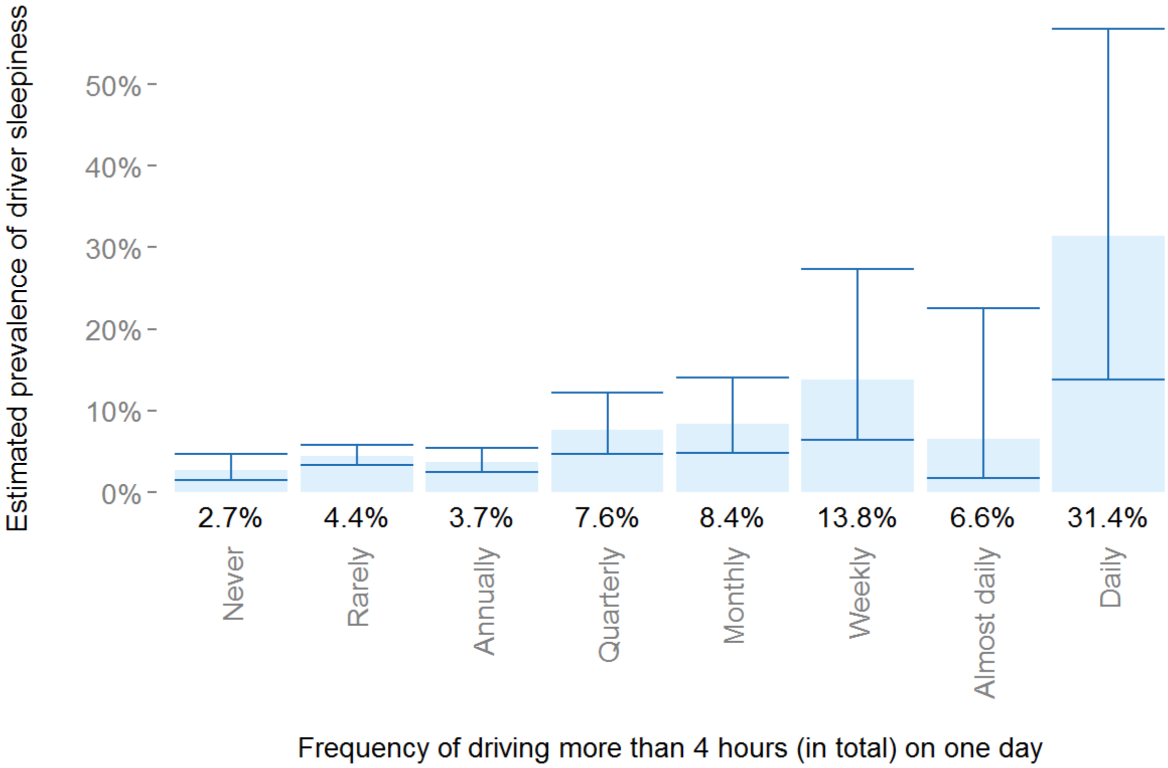
Figure 8. Estimated prevalence of driver sleepiness (KSS score > 5) as a function of daytime sleepiness measured with the Epworth Sleepiness Scale (ESS).



3.2.8 Frequent driving

The prevalence of sleepiness increases as a function of how often drivers spend more than four hours behind the wheel on a single day. This is shown in Figure 9. The bars show the individual effect of the ordered factor. There is a significant linear increase in the prevalence of driver sleepiness. For drivers that spend more than four hours behind the wheel each day, the prevalence reaches up to 31.4%. There appears to be a lower prevalence than expected in the second most extreme category ("Almost daily"), but this trend was not significant. The sample distribution of the different categories is shown in Appendix 1.9c.

Figure 9. Estimated prevalence of driver sleepiness (KSS score > 5) as a function of the frequency of driving more than four hours in a day.



3.2.9 Crash history

The prevalence of driver sleepiness is higher among drivers that have caused a crash (1.9% of the drivers) or a near-crash (5.8% of the drivers) while driving a car during the past 12 months. The estimated sleepiness prevalence corresponds to 10.8% for these drivers (95% confidence interval = [7.1%, 16%]). Although none of the reported crashes was linked to sleepiness, 11.3% of the respondents that report a near-crash link these to sleepiness.

3.3 Distributional analyses

This section is concerned with the association of driver sleepiness with unordered categorical contextual variables with more than two levels. These variables were treated in separate analyses for reasons discussed at the beginning of this chapter. The analysis specifically consisted of Fisher exact tests (alpha=.05) that were applied to each level of the variable. For the variables *employment regime*, *educational level*, *professional activity*, *causes of mental fatigue* and *actions to prevent or fight driver sleepiness*, these tests yielded a significant result for at least one of the levels. These results are described in sections 3.3.1 to 3.3.5. There were no significant associations with driver sleepiness for the following variables:

- Residence: The prevalence of driver sleepiness does not differ significantly between the three administrative regions in Belgium: Brussels-Capital, Flemish and Walloon region. The sample distribution with respect to these regions is described in Appendix 1.2.
- Work regime: There were two categorical contextual variables related to the work regime: the general work pattern (regular; irregular; regularly shifting) and the times at which one works outside regular office hours (evening; weekends; mornings; nights). As for the numerical work regime variables (i.e., weekly number of days/hours spent working and the frequency of working outside regular office hours) there was no significant association with driver sleepiness. Most drivers with jobs had a regular work pattern (regular: 73%; irregular: 22%; regularly shifting: 6%). Drivers that work outside regular office hours most often do so in the evening and weekends (evenings: 33%; weekends: 31%; mornings: 25%; nights: 12%).

3.3.1 Employment regime

Drivers were asked to indicate their employment regime using five categories: [1] a full time job (43.7% of all drivers), [2] unemployed or retired (43.4%), [3] a part time job (10.6%), [4] multiple part time jobs exceeding a 100% employment rate (1.4%) and [5] multiple part time jobs not exceeding a 100% employment rate (0.9%). For the two most frequent categories, full time job and unemployed/retired, the prevalence of driver sleepiness differed significantly from the average (=4.8%; see Table 1). The prevalence is higher than average for drivers with a full time job (7.7%) and a lower than average for unemployed/retired drivers (1.7%).

Table 1. Comparison of the distribution of employment regimes between sleepy (KSS>5) and non-sleepy drivers. The observed frequency of regimes in bold font differ significantly across sleepy and non-sleepy drivers.

	Distribution			Prevalence of
	Overall	*Non-Sleepy drivers*	*Sleepy drivers*	driver sleepiness
Full time job	43.7%	**42.4%**	**70.8%**	7.7%
Unemployed/Retired	43.4%	**44.8%**	**15.0%**	1.7%
Part time job	10.6%	10.6%	11.7%	-
Multiple part time job > 100%	1.4%	1.4%	0.8%	-
Multiple part time job < 100%	0.9%	0.9%	1.7%	-

3.3.2 Educational level

Drivers indicated their highest educational level using 4 categories: [1] below secondary (11% of all drivers), [2] secondary (30%), [3] bachelor (38.7%) and [4] master (20.5%). There were significantly less individuals whose highest degree is a secondary degree among the sleepy drivers. At the same time, there were significantly more drivers with a master's degree in this group (see Table 2). In other words, drivers with a master's degree are overrepresented among sleepy drivers, whereas drivers with a secondary degree are underrepresented. The estimated prevalence of drowsy driving is indeed higher than average (=4.8%) for drivers with a master's degree (6.6%) and lower for those with a higher secondary degree (3.5%).

Table 2. Comparison of the distribution of education levels across sleepy (KSS>5) and non-sleepy drivers. The observed frequencies for the levels in bold font are significantly different for sleepy and non-sleepy drivers.

	Distribution			Prevalence of
	Overall	*Non-Sleepy drivers*	*Sleepy drivers*	driver sleepiness
Master	20.5%	**20.0%**	**28.3%**	6.6%
Bachelor	38.7%	38.5%	41.7%	-
Secondary	30.0%	**30.3%**	**21.7%**	3.5%
Below secondary	11.0%	10.9%	8.3%	-

3.4 Professional activity

Professional activities were classified into 4 categories: [1] employee (36.8% of all drivers), [2] management staff (7.9%), [3] worker (5.8%), [4] self-employed (4.5%). In 44.9% of the cases there either was no professional activity (unemployment/retirement) or it was not provided by the respondent. In line with the employment regime variable, discussed above (Section 3.3.1), the latter category (i.e., "None/Unknown") was observed significantly less frequently among sleepy drivers. On the contrary, there were significantly more employees and management staff in this group (see Table 3). The corresponding prevalence of drowsy driving is 6.9% among employees and 8.9% for management staff.

Table 3. Comparison of the distribution of professional activities between sleepy (KSS>5) and non-sleepy drivers. The observed frequencies for categories in bold font differ significantly across sleepy and non-sleepy drivers.

	Distribution			Prevalence of
	Overall	*Non-Sleepy drivers*	*Sleepy drivers*	driver sleepiness
None/Unknown	44.9%	**46.3%**	**15.8%**	1.8%
Employee	36.8%	**36.0%**	**53.3%**	6.9%
Management	7.9%	**7.6%**	**15.0%**	8.9%
Worker	5.8%	5.7%	8.3%	-
Self employed	4.5%	4.3%	7.5%	-

3.4.1 Causes of mental fatigue

Regardless of whether they reported sleepiness while driving or not, all respondents were presented with a list of circumstances that are known to commonly exert a chronic negative effect on sleep quality. They were asked to indicate the circumstances they suffered from, if any. Specifically, they were asked: "*Are you dealing with one or more of the following circumstances, exerting an important negative impact on your sleep quality?*". Table 4 shows the list of circumstances together with the observed frequencies among sleepy and non-sleepy drivers. The five most frequently reported circumstances are [1] stress and/or depression (21.1% of all drivers), [2] sleep interruptions (20%), [3] obligation to get up early (17.4%), [4] superficial sleep (17.4%) and [5] difficulties in falling asleep (15.8%). Apart from being the most frequently reported, the observed frequency of these circumstances is also significantly higher among sleepy drivers. Additionally, sleepy drivers more frequently report irregular working hours, excessive snoring, family members with sleeping problems[8], and chronic insomnia. Compared to the five most frequent categories, the overall frequency of the latter circumstances is relatively low (see Table 4). Looking at the prevalence of driver sleepiness, it appears that among the most frequent circumstances, the obligation to get up early is associated with the highest level.

[8] Based on additional comments that respondents gave, it appears this mostly involves care for young children.

Table 4. Comparison of the distribution of circumstances with a chronic negative effect on sleep quality between sleepy (KSS>5) and non-sleepy drivers. The observed frequencies for circumstances in bold font differ significantly across sleepy and non-sleepy drivers.

	Distribution			Prevalence of
	Overall	*Non-Sleepy drivers*	*Sleepy drivers*	driver sleepiness
Stress/Depression	21.1%	**20.4%**	**35.0%**	7.7%
Long lasting sleep interruptions	20.0%	**19.4%**	**31.7%**	7.4%
Obligation to get up early	17.4%	**16.3%**	**40.8%**	10.9%
Superficial sleep	17.4%	**16.9%**	**28.3%**	7.6%
Difficulties falling asleep	15.8%	**15.1%**	**29.2%**	8.6%
Snoring partner	15.3%	15.1%	18.3%	-
Family members in need of care	11.5%	11.2%	16.7%	-
Chronic pain	9.7%	9.6%	11.7%	-
Irregular working hours	8.1%	**7.5%**	**21.7%**	12.4%
Excessive snoring	7.9%	**7.5%**	**14.2%**	8.4%
Noise	6.0%	5.9%	8.3%	-
Sleep problems of family members	5.0%	**4.7%**	**10.0%**	9.3%
Gasping/Choking sensation	4.2%	4.2%	4.2%	-
Respiratory problems	3.0%	2.9%	4.2%	-
Chronic insomnia	2.9%	**2.6%**	**7.5%**	12.2%
Alcohol use	2.8%	2.9%	0.8%	-
Movement disorder	2.6%	2.5%	5.0%	-
Sleep apnoea	2.4%	2.5%	1.6%	-
Drug use	0.3%	0.2%	1.7%	-

3.4.2 Actions to prevent or fight driver sleepiness

Regardless of whether drowsy driving had occurred or not, each respondent was asked to indicate strategies he/she had adopted during the trip to prevent or fight sleepiness, if any. They were presented with a list of common actions compiled from the literature. The observed frequencies for each countermeasure are shown in Table 5. Unsurprisingly, the observed frequency for each countermeasure is significantly higher for sleepy drivers. The five most popular strategies are [1] listening to radio or music (18.8% of all drivers), [2] opening the window and/or lowering the air temperature (9.1%), [3] talking to a passenger (7.3%), [4] changing one's posture (3.8%) and [5] turning up the audio volume (2.8%). Importantly, switching drivers and stopping over for a nap, which qualify as the most direct countermeasures, are observed the least frequently (less than 1% of all drivers).

Table 5. Comparison of the distribution of common countermeasures for driver sleepiness between sleepy (KSS>5) and non-sleepy drivers. The observed frequencies for all countermeasures are significantly higher for sleepy drivers.

	Distribution		
	Overall	*Non-Sleepy drivers*	*Sleepy drivers*
Listening to radio/music	18.9%	**17.2%**	**52.5%**
Opening window / Lowering air temperature	8.9%	**7.1%**	**47.5%**
Talking to passenger	7.4%	**6.6%**	**23.3%**
Changing posture	3.8%	**2.6%**	**27.5%**
Turning up volume	2.8%	**1.8%**	**24.2%**
Eating or drinking	2.1%	**1.7%**	**11.4%**
Stretching	1.2%	**0.5%**	**15.0%**
Making stopover	1.0%	**0.7%**	**5.8%**
Consuming energizing food/drink	0.8%	**0.5%**	**5.8%**
Driving faster	0.7%	**0.6%**	**2.5%**
Talking on the phone	0.5%	**0.4%**	**2.5%**
Switching driver	0.2%	**0.1%**	**1.7%**
Taking stimulating substance	0.2%	**0.0%**	**2.5%**
Napping	0.2%	**0.1%**	**1.7%**

4 DISCUSSION

4.1 Main findings

In a large sample (n=2,585) of journeys on Belgian roads between June 15th and July 15th 2014, it appears that 4.8% of the car drivers were experiencing sleepiness at the wheel. The level of self-reported sleepiness ranges from “some signs of sleepiness” (KSS=6; 3.3%), over “sleepy with no effort to stay awake” (KSS=7; 0.9%) and “sleepy with some effort to stay awake” (KSS=8; 0.5%) to “very sleepy; great effort to stay awake; fighting sleep” (KSS=9; 0.1%; see Section 3.1).

Various circumstances result in a prevalence that is considerably higher than the overall estimate of 4.8%. The regression analysis (Section 3.2) reveals the following contextual variables with a significant unique negative effect on the prevalence of driver sleepiness (in decreasing order of effect sizes; prevalence estimates appear between brackets):

1. Spending more than 4 hours a day at the wheel (31.4%; see Section 3.2.8)
2. Having caught less than 8 hours of sleep (4-8 hours: 11.1% on average; 0-4 hours: 24.9% on average; see Section 3.2.5)
3. Having an irregular sleep-wake pattern with frequent shifts of more than 2 hours (14.9%; see Section 3.2.6)
4. Being an adolescent/young adult (18-30 years: 11.3% on average; see Section 3.2.1)
5. Having consumed 2 or more standard units of alcohol prior to driving (2-4 units: 11% on average; see Section 3.2.4)
6. Having caused a crash or a near-crash during the past 12 months (10.8%; see Section 3.2.9)
7. Experiencing excessive daytime sleepiness (9<ESS≤15: 7.7% on average; ESS>15: 10.7% on average; see Section 3.2.7)
8. Long distance driving (>60 km: 10.5% on average; see Section 3.2.3)
9. Driving in the evening or at night (6-12pm: 7.5% on average; 12pm-6am: 7.9% on average; see Section 3.2.2)

From the distributional analyses (Section 3.3) it appears that the following contextual variables also have a significant association with the prevalence of driver sleepiness.

10. Having a full-time job (7.7%; see Section 3.3.1)
11. Having a master’s degree (6.6%; see Section 3.3.2)
12. Being an employee (6.9%) or a manager (8.9%; see Section 3.3.3)
13. Dealing with circumstances with a chronic negative effect on sleep quality: stress/depression (7.7%), long lasting sleep interruptions (7.4%), obligation to get up early (10.9%), superficial sleep (7.6%), difficulties falling asleep (8.6%), irregular working hours (12.4%), excessive snoring (8.4%), family members with sleep problems (9.3%) and chronic insomnia (12.2%; see Section 3.3.4)

The non-orthogonal design of this study implies that some of these effects overlap with each other. For the first group of contextual variables (listed under points 1 to 9 above) correlations occurred between (1) driver age and sleep-wake pattern consistency, showing a tendency for higher consistency in older drivers, (2) driving frequency and travel distance, with frequent drivers often travelling for longer distances and (3) sleep duration and departure time, showing that drivers travelling closer to midnight often spent less time in bed. For the second group (see points 10 to 13) correlations were sometimes very explicit. Professional activities, for instance, are clearly dependent on being employed. There were also correlations with the first group of variables, e.g., being retired and being older.

These correlations need to be considered when deducing the combined effects of the contextual variables listed above. For employees and managers of a given age, for instance, the risk for driver sleepiness will be lower than the sum of the individual effects (i.e., the increments/decrements with respect to the average value of 4.8%). Since employees and managers tend to be younger in age[9], the individual effects of professional activity and age to some extent reflect the same observed variation in driver sleepiness. Knowing which part of the variance truly reflects age and which part reflects professional activity requires a careful orthogonal design in recruiting respondents.

Despite these correlations, all contextual variables listed under points 1 to 9 above had a significant unique effect on the prevalence of driver sleepiness, i.e., they each explained a part of the variance which could not be accounted for on the basis of the other contextual variables. Hence it is safe to conclude that the scenario with the highest prevalence of driver sleepiness is the following: A young person who caught less than 8 hours of sleep is driving a car for a long distance around midnight after having consumed some alcohol. He or she drives a car frequently and while doing so, caused a crash or near-crash in the past 12 months. He or she also has an irregular sleep-wake pattern and often feels sleepy during the day.

4.2 Comparison with other studies

4.2.1 Prevalence of driver sleepiness

The above results provide the first direct insight in the trip-based prevalence of sleepiness at the wheel in Belgium. The result was obtained by developing a new method: an online questionnaire concerned with a single journey in the last 24 hours. Like in most international studies, the previous Belgian data related to the frequency of drowsy driving only consider sleepiness at the wheel during certain time intervals and not during actual journeys. In the BRSI 2012 national survey on attitudes towards road safety, 58% of the respondents reported to have felt sleepy while driving at least once in the past 12 months (Meesmann & Boets, 2014). It is impossible to translate this result, which collapses all single journeys during the past year, to an estimate of sleepiness at the wheel *at a given point in time*. Such level of detail requires measurements of sleepiness with respect to actual trips, as in the current approach (see the effect of departure time in Figure 3). An important additional strength of the current methodology is that sleepiness was estimated in a fully anonymous setting and on a scale with demonstrated external validity.

In order to allow for comparison with the BRSI attitudes survey, the present participants were also asked to report on the frequency of drowsy driving during the past year. Interestingly, 75.4% of the current respondents indicated having experienced sleepiness at the wheel at least once, which is 17.4% more than observed in the 2012 attitudes survey (with an identical question). It is difficult to attribute this difference to differences in sample characteristics. The above percentage was corrected for the lower proportion of younger drivers in the present study and there were similar distributions with respect to weekly mileage, educational levels and professional activities. One explanation is that respondents reflected deeper on sleepiness in the current survey and therefore recalled sleepiness at the wheel more often. A second possible explanation is that the 2012 attitudes survey was administered face-to-face, which might have resulted in a higher level of socially desirable responses (i.e., not admitting sleepiness at the wheel).

The above results can also be compared with Belgian data obtained in a 2013 European survey on sleepiness at the wheel (part of the 'Wake-Up Bus' project; Lucas & Araújo , 2013). The survey indicated that 21.9% of the 954 respondents fell asleep at the wheel at least once during the past 2 years (European average = 20.5%). In the current survey, respondents reported doing so in 21.6% of the cases, but instead within a 1 year interval. Like the present survey, the Wake-Up Bus survey was administered online and was solely concerned with drowsy driving. One interpretation of the apparent discrepancy is that at the intra-individual level, driver sleepiness is correlated to such an extent, that it makes no difference if drivers are asked about falling asleep at the wheel within the past year or the previous 2 years. The result that driver sleepiness is associated with several (relatively constant) individual characteristics clearly supports this.

Only few international studies have tackled the issue of estimating driver sleepiness with respect to actual driving. Based on an observational study with instrumented cars in the US (Neale et al., 2005), Klauer et al. (2006) arrived at an estimate of 2%. It is difficult to compare this number with the present estimate because the 'cases' in this study were a random selection of 6-second video fragments instead of journeys. In contrast, Connor et al. (2001) and Herman et al. (2014) stopped cars randomly and interviewed the

[9] At least part of this correlation reflects retirement.

drivers about sleepiness during the trip. Both report a prevalence estimate of about 1%. However, as discussed in the Introduction, both studies suffer from the risk of underreporting for at least two reasons. First, they both use a sleepiness scale that does not clearly discriminate between sleepy and non-sleepy states. Second, a higher level of socially desirable responses might have occurred. Of course, the difference with the Belgian estimate of 4.8% also needs to be viewed in the light of the radically different road networks and driving behaviour in New-Zealand (Connor et al., 2001) and Fiji (Herman et al. 2014).

4.2.2 Associations with driver sleepiness

Most of the observed associations with sleepiness at the wheel align with earlier findings in the international literature. In contrast to these earlier studies, the present work looked at the effects of a large number of contextual variables jointly. Below the links with the relevant studies are discussed for each of the effects observed in our study.

Driver age. Virtually all drowsy driving studies that stratify results with respect to age find that sleepiness at the wheel is especially prevalent among young people (e.g., Pack et al., 1995; Horne and Reyner, 1995; Maycock, 1995; Masten et al., 2006; Radun and Radun, 2009; Goldenbeld et al., 2011; Teft, 2012; Phillips and Sagberg, 2013; Wheaton et al., 2014). The comparison of the different numbers is, however, not straightforward because it is common practice to cut the age variable in (by definition) arbitrary categories with a great amount of variation in the chosen boundaries. The present study instead treated this variable in full detail (see Figure 2), which allows a direct quantification of the *continuously* decreasing prevalence of drowsy driving with age.

Departure time. The relationship between drowsy driving and time of the day has been repeatedly shown in the analysis of crash reports. In the UK, Maycock (1995) found that 36% of all car crashes between midnight and 4am were sleep-related, whereas this is only 4% for crashes between 8am and 12pm. In the US Masten et al. (2006) estimated that about 40-50% of all night-time but only 10-20% of all daytime crashes were sleep-related (see also e.g., Philip et al., 1999; van den Berg and Landstrom, 2006).

Travel distance. Driving requires a constant high level of alertness and qualifies as a cognitively highly demanding task. Hence, the longer the driving episode (or 'time on task'), the higher the chance of mental fatigue, which is a direct cause of sleepiness. Several studies have illustrated this (e.g., Åkerstedt et al., 2010; Masten et al., 2006; Phillips and Sagberg, 2013).

Alcohol consumption prior to driving. It is well established that even modest levels of alcohol consumption enlarge the deteriorating effects of sleepiness on driving ability (e.g., Rhoers et al. 1994; Horne et al., 2003; Banks et al., 2004; Vakulin et al., 2009; Barret et al., 2005). Investigation of crash data has shown that about 15-20% of sleep-related crashes also involves alcohol use (Pack et al., 1995; Wang et al., 1996; Masten et al., 2006; Radun and Radun, 2009)

Sleep duration. Sleep deprivation is the most immediate cause of sleepiness at the wheel and this relation has been observed in many studies (e.g., McCartt et al., 1996; Philip et al., 1999; Stutts et al., 1999; Masten et al., 2006; Goldenbeld et al., 2011; Wheaton et al., 2014). The effect of limited sleep is also clearly related to the present observation that sleepy drivers more often report about factors with a negative effect on sleep quality (see Table 4).

Sleep-wake pattern consistency. The effect of an irregular sleep-wake pattern is closely related to the well-established problem of drowsy driving among shift workers. An overrepresentation of this sub-population has often been observed in drowsy driving and sleep-related crash statistics (e.g., Gold et al., 1992; McCartt et al., 1996; Hanecke et al., 1998; Masten et al., 2006). The fact that sleepy drivers also more often reported to suffer from irregular working hours in the current study is also consistent with these findings (see Table 4). Despite a general increase in driver sleepiness with an increasing frequency of sleep-wake pattern shifts, we observe a lower prevalence than expected in the most frequent category (see Figure 7). This potentially indicates a certain level of habituation.

Daytime sleepiness. The relationship between driver sleepiness and self-reported daytime sleepiness on the Epworth scale has been demonstrated in many other studies (e.g., Maycock, 1996; Stutts et al., 1999; Masten et al., 2006; Powell et al. 2010; Philip et al., 2010; Sagaspe et al., 2010; Goldenbeld et al., 2011; Lucas & Araújo , 2013). In the Wake-Up Bus sleep study mentioned above, Lucas & Araújo (2013) observed that of 39.7% of the 954 Belgian respondents attained ESS scores larger than 9. This is considerably more than the currently observed 29%. A possible explanation is that participants in the current study reported on daytime sleepiness with respect to a more recent time frame because the survey mainly consisted of questions concerning sleep/sleepiness during the last 24 hours. The Wake-Up Bus study was concerned with sleepiness at the wheel during the past 2 years. It seems not unlikely that in such a context respondents also evaluate daytime sleepiness within broad period with higher scores as a result.

Frequent driving. The fact that professional drivers are especially at risk for sleepiness at the wheel is clearly consistent with this finding (e.g., Horne & Reyner, 2001; Masten et al., 2006; Philip et al., 2010; Goldenbeld et al., 2011). McCartt et al. (1996), Stutts et al. (1999), Masten et al. (2006) and Goldenbeld et al. (2011) also specifically report a relation between drowsy driving and the number of hours spent at the wheel on a daily basis (see Figure 9).

Crash history. A number of studies have established a relation between sleepiness at the wheel and crash statistics at the individual level. Powell et al. (2010) found a significant correlation between individual crash rates and the occurrence of sleepy driving near-misses. Likewise, Sagaspe et al. (2009) observed that experiencing at least one episode of sleepiness at the wheel in the previous year qualified as one of the best predictors of both near-miss and crash incidence (see also Stutts et al., 1999). As argued by Powell et al. (2010), near-misses could provide a valuable starting point for road safety management strategies against sleepiness at the wheel, by analogy with so-called "near-miss management systems" that have been applied in various industrial contexts (e.g., Andriulo & Gnoni, 2014).

Employment regime. The finding that unemployed/retired individuals are underrepresented among sleepy drivers was also found in a number of earlier studies (e.g., Wheaton et al., 2014; Goldenbeld et al., 2011). Stutts et al. 1999 also found that unemployed/retired individuals are underrepresented in sleep-related car crashes.

Educational level. This topic has received limited attention. Nevertheless, a number of studies do support the hypothesis that driver sleepiness is especially prevalent among more educated individuals (e.g., McCartt et al., 1996; Sagberg, 1999; Goldenbeld et al., 2011).

Professional activity. Apart from an overall relation with professional driving, the link between driver sleepiness and different professional activities does not appear to have been established before (e.g., Philip et al., 2010). Nevertheless, the current findings (higher prevalence of driver sleepiness among employees and managers) align with results of Maycock (1997) and Goldenbeld et al. (2011) who found a higher prevalence of driver sleepiness among lease car drivers. Intuitively, the profile of lease car drivers seems to align with that of employees and managers.

Gender. Somewhat surprisingly, the present results do not replicate a significant association of gender with driver sleepiness. The vast majority of the international literature shows that male drivers engage in sleepy driving more often than female drivers. This was also clearly the case in the BRSI 2012 national survey on attitudes towards road safety (Meesmann and Boets, 2014). This might be related to the fact that the penetration of the present survey was lower in young drivers[10]. More specifically, a number of studies have shown that the higher frequency of male sleepy drivers primarily holds for young drivers (e.g., Radun & Radun, 2009). The current data replicate this interaction numerically: as illustrated in Appendix 3, among younger drivers the prevalence of driver sleepiness was on average higher for male drivers but this interaction did not reach significance.

Actions to prevent or fight driver sleepiness. A final comparison to be made with the international literature concerns the actions drivers undertake to prevent or fight sleepiness. As noted in the Results section, the two most effective countermeasures, leaving the wheel to someone else and stopping over to take a nap occur the least frequently. This pattern has been observed many times before. Vanlaar et al. (2008), for instance, asked drivers which strategies they used to prevent/fight sleepiness and to rate their effectiveness. They found that asking a passenger to drive and stopping for napping or sleeping were rated as most effective, but at the same time these appeared among the least frequently adopted strategies (see also e.g., Maycock, 1997; Stutts et al., 1999; van den Berg and Landström, 2006; Gershon et al. (2011); Nordbakke & Sagberg, 2007; Anund et al., 2008; Goldenbeld et al. 2011). Of course, the fact that (1) passengers who are able to take over the wheel are not always present and (2) an appropriate (safe)

[10] Hence, the results were weighted by age.

location for napping is often not available play an important role in this pattern. Related to the latter issue, we also find a relatively low frequency of sleepy drivers that stop to take a regular break (i.e., without napping) compared to other studies. In the Netherlands, Goldenbeld et al. (2011) found that taking a break is the third most popular strategy to fight sleepiness at the wheel (similar results by Maycock, 1997; Nordbakke & Sagberg, 2007; Anund et al., 2008; van den Berg and Landström, 2006; Van Laar et al., 2008). In the European Sartre4 project, it was also found that Belgian drivers are far less probable to stop for a break compared to the European average (see Meesmann & Boets, 2012). It could be interesting to investigate whether or not this difference is related to the availability of rest places or the average distance travelled per individual journey. A study by Gershon et al. (2011) showed that non-professional drivers have a preference for in-car strategies, i.e., strategies that do not involve special/unusual measures before or during driving. Like the majority of other studies, including the present one, the present study showed that the most popular in-car strategies are lowering the air temperature and listening to the radio/music. Interestingly, Schwartz et al. (2010) conducted experiments to evaluate the effects of exactly these two actions. They were unable to find any effects of opening the window on driver sleepiness (using blink durations and KSS scores as a proxies). Turning on the radio did show a reduction of sleepiness, but it was transient and very modest in size (see also Cummings et al., 2001).

4.3 Scope of the results

The many factors that influence the prevalence of driver sleepiness illustrate the complexity of this issue and demonstrate that it is very important to treat the overall prevalence of 4.8% only as an indicative appreciation of the scope of the phenomenon. The above relationships undoubtedly represent only a subset of a larger collection of variables with an important role in drowsy driving.

For the interpretation of the current results and for future research it is important to keep in mind, for instance, that the present study was conducted at a specific point during the year: mid-June to mid-July. Few studies have addressed seasonal variations in the prevalence of sleepiness at the wheel, but the available data suggest a potential critical role. Sixty-six percent of the bus and lorry drivers that were interviewed by van den Berg and Landström (2006) judged autumn to be the most troublesome for drowsy driving (followed by winter: 21%). Radun and Radun (2009) on the other hand, report a peak in Finnish fatigue-related offenses in July. The effect of the time of the year is likely related to sociological, meteorological and lighting variations. In Belgium, July is the start of the summer holiday season. The analyses did not reveal a significant difference in driver sleepiness between the responses gathered in June (60%) and July (40%), however.

Regarding meteorological conditions, Masten et al. (2006) found that sleep-related crashes occur more often when there is mist and less often when it is there is rain/snow fall. Klauer et al. (2006) found that driver sleepiness was clearly linked to reduced lighting. Lightning conditions of course vary with other daily patterns, but given the interaction with the human circadian system (e.g., Duffy and Wright, 2005), lighting variations could cause important seasonal differences in drowsy driving.

It should also be kept in mind that the current study was only concerned with car drivers. This was a deliberate choice. For lorry and bus drivers sleepiness at the wheel needs to be viewed within a fundamentally different context. In contrast to car driving, there are strict (EU-level) regulations regarding driving times for lorry and bus drivers: driving time should not exceed 9 hours a day or 56 hours a week. Drivers must also take a break of at least 45 minutes each 4½ hours on the road. Given this legal framework, the prevalence of drowsy driving and the association with contextual variables most likely follows a different pattern in this population. The current study also did not include van drivers. Although these drivers are not bound to driving time regulations, the phenomenon of driver sleepiness potentially also has different characteristics in this subpopulation. Driving a van often occurs in a professional context, but in contrast to lorry and bus driving it is not generally associated with long distance driving.

Severe sleepiness at the wheel has often been studied in relation to the obstructive sleep apnoea syndrome (OSAS). Individuals with OSAS suffer from non-restorative sleep because of abnormal breathing interruptions caused by upper airway obstructions during sleep which can last for as long as 2 minutes. Different degrees of severity are defined on the basis of the frequency of these obstructions (minimum 10 seconds each). The link with an increased risk for sleep-related motor vehicle crashes has been demonstrated in a wide range of different studies. Meta-analyses suggest that for *untreated* OSAS patients, the risk for a crash increases up to 300% compared to the reference population (Vaa, 2003). In Belgian driver's licence legislation OSAS is clearly mentioned as an excluding condition[11]. Because of this legislation as well as the fact that effective treatment exists[12], the problem for road safety is not as much the diagnosis of OSAS per se, but the fact that in many cases OSAS remains undiagnosed (e.g., Kushida et al., 2000). The current results support this concern. Two and a half percent of the respondents reported being diagnosed with OSAS. There was no higher prevalence among the sleepy drivers, but this is in line with the presence of effective treatment. Importantly, 7.9% of the respondents indicated that their sleep quality chronically suffers from excessive snoring and this percentage was significantly larger in the subset of sleepy drivers (14.2% vs. 7.5%; see Table 4). Although excessive snoring is not in itself a diagnosis for OSAS, the association with reduced sleep quality and driver sleepiness are in line with a significant degree of under-detection.

In order to properly evaluate the risks associated with drowsy driving, the current results need to be combined with sleepiness data from Belgian motor vehicle crashes. Perhaps the most challenging part in this effort is to quantify sleepiness in these cases and to raise awareness and expertise for such quantification among the officials that deal with these crashes. Today international estimates of the prevalence of sleep-related crashes vary greatly. Some speak of less than 1%, others of more than 20%. It appears that a great part of the variance is due to the fact that studies based on police records typically yield small percentages, whereas studies based on post-hoc interviews show larger percentages (e.g., Maycock, 1995). One of the problems is that sleepiness is not always uniquely identifiable as the cause of a crash. However, researchers agree that the numbers based on police records are very likely to be underestimations because of the inherent difficulties of measuring the level of sleepiness just before a crash occurred. Masten et al. (2006), for instance, modelled patterns of circumstances in sleep-related US crash reports. When this statistical model was then applied to crash reports where information about the driver's alertness had been omitted, the percentage of fatal sleep-related crashes raised from 3.6 to 16.5%. As already mentioned in the Introduction, in Belgium, 14.8% of the car crashes in 2012 involved a single-vehicle drifting off the road and crashing into an off-road obstacle. These are exactly the circumstances identified by Masten et al. (2006) as the most indicative of a sleep-related crash. If indeed, the prevalence of sleep-related crashes in Belgium would correspond to 14.8%, the present overall prevalence of 4.8% clearly indicates that driver sleepiness substantially increases the crash risk. A factor that adds greatly to the seriousness of this issue is that crashes caused by a driver falling asleep at the wheel tend to be particularly severe: they often involve a vehicle that hits an obstacle at high speed without braking.

A growing body of scientific evidence points out that sleepiness in general, and not just sleepiness at the wheel, is symptomatic of poor sleep habits in today's society. The high prevalence of daytime sleepiness across all respondents in the present study (29%) is clearly in line with such a broader perspective. Many researchers have argued that societies have become more and more ignorant about adequate sleep habits ever since the Industrial Revolution (e.g., Ekirch, 2001).

More recently, with the rise of the Digital Age, researchers have been simultaneously making two critical observations. First, the amount of information individuals are exposed to on a daily and even hourly basis, has grown exponentially. The neural activity associated with the processing of such large volumes of information has made adequate sleep increasingly important. Recent findings show, for instance, that (potentially toxic) waste products that originate from neural activity when we are awake are removed from the brain during sleep (Xie et al., 2013).

The second critical observation is that the technology behind the Information Age (i.e., computers and most recently, smartphones and tablets) is posing an additional challenge for an appropriate sleep hygiene. A large proportion of the population is surrounded by information bearing devices practically on a round-the-clock basis. According to the 2014 Sleep in America Poll, for instance, 89% of adults and 75% of children have at least one electronic device in their bedrooms. Around 30% of the respondents reported having a smartphone or tablet in their bedrooms that is sometimes left on at night (National Sleep Foundation). Several negative consequences of this behaviour have been documented. In a Norwegian survey, for instance, respondents who often used a mobile telephone in their bedrooms at night turned off the lights to go to sleep later than those who only rarely engaged in this behaviour (Brunborg et al., 2011).

[11] In July 2014, the EU issued a directive which also identifies OSAS as such (2014/85/EU).

[12] In most cases, effective treatment is possible through a continuous positive airway pressure (CPAP) device.

These devices have also established that today's social networks expect a 24hour 'online' status, urging many members to regularly interrupt activities, including sleep, to interact with the network (e.g., Eisner, 2010). In a study with Belgian adolescents, Van den Bulck (2007) found that no less than 62% of the subjects used their phones after the lights were turned off. Importantly, this behaviour was associated with increased daytime sleepiness. At the biological level, it has been demonstrated that high frequency exposure to artificial (blue) light emitted by electronic devices disrupts circadian rhythms by suppressing the 'sleep hormone' melatonin (e.g., Wood et al., 2013).

5 CONCLUSIONS AND RECOMMENDATIONS

This study reveals that, at the level of individual journeys, on average 4.8% of the Belgian car drivers shows signs of sleepiness. Although there are no exact Belgian data on the role of driver sleepiness in crash causation, international research suggests that sleepiness at the wheel is involved in about 20% all severe crashes. The combination of a relatively low prevalence and a relatively high frequency in crash causation implies a very important risk. In fact, the numbers can be compared with driving under the influence of alcohol. According to the most recent estimates, 2.4% of all driving in Belgium occurs under the influence of alcohol (Riguelle, 2014). The share in severe accident causation nevertheless amounts up to 25% (SafetyNet, 2009). Like driving under the influence of alcohol, sleepiness at the wheel is thus poses an important challenge for road safety management.

This study clearly demonstrates that the prevalence of sleepiness at the wheel is highly dependent on specific circumstances. The majority of these circumstances have already been identified in previous studies, but it is the first time that they are quantified jointly in a Belgian context. Based on this quantification the scenario with the highest risk for driver sleepiness appears to be the following: A young person who caught less than 8 hours of sleep is driving a car for a long distance around midnight after having consumed some alcohol. He or she drives a car frequently and while doing so, caused a crash or near-crash in the past 12 months. He or she also has an irregular sleep-wake pattern and often feels sleepy during the day.

Recommendations can be made at different levels. At the level of infrastructure, it is common practice in Belgium to implement rumble strips to alert drivers that their vehicle is drifting. Several studies have demonstrated a high benefit-to-cost ratio for this measure and further implementation can thus be encouraged. However, according to a study by Anund et al. (2008) the alerting effect of hitting a rumble strip is very short-lived. In other words, if a sleepy driver is alerted by rumble strips at a given place and time, this does not mean that he/she will stay alert for the rest of the trip. The creation of more safe(r) rest areas is an infrastructural investment that is more costly, but also more beneficial since the goal is to eliminate sleepiness itself. A study by Reyner et al. (2010) also clearly showed a beneficial effect of rest areas on sleep related collisions. In Belgium, the PITSTOP campaign (De Dobbeleer et al. 2010) included the creation of dedicated rest areas, but on a very small scale. Apart from creating rest areas, investments could also be made in signalling their presence to drivers.

From the car manufacturing side, there is a growing amount of in-car warning systems, specifically designed to detect drowsy driving. These systems vary greatly with respect to the information that is used to detect drowsiness (see Horne 2013 for an overview). A basic distinction can be made between driving parameters (e.g., lateral deviation, driving time, trip monotonicity, speed, etc.) and biometric parameters (e.g., eye movements, head movement, respiration, heart rhythm, etc.). Most systems try to predict a drivers' state of drowsiness based on a combination of these parameters. Apart from in-car systems, there are also wearable devices on the market that use specific biometric information (e.g., glasses that record eye movements, behind-the-ear devices that detect nods, rings that measure galvanic skin responses). Further development of efficient warning systems should be encouraged. However, it is also critical to invest in the independent validation of current and future technologies. Validation not only needs to be concerned with the question whether or not sleepiness at the wheel is detected, but also whether it is detected in time and whether effective signals are emitted to alert drivers subsequently.

As with any other technology, a potential unwanted effect is that drivers become dependent on it and fail to make their own responsible judgements about their fitness to drive. This is clearly an issue that also needs to be considered in validation studies, but it also illustrates that it remains critical to remind drivers about the risks of sleepiness at the wheel and to promote responsible driving behaviour. The danger and societal costs of sleepiness at the wheel seem to be equally important as those of driving under the influence of alcohol. By consequence, investments in road safety campaigns should be balanced with respect to these two topics. Perhaps more important than informing drivers about the risks of drowsiness, campaigns should focus on effective strategies to fight sleepiness at the wheel and to avoid it in the first place. When sleepiness occurs while driving, it is clear that drivers should be encouraged to stop for a nap or to pass the wheel to someone that is fit to drive. However, a suitable rest area is not always immediately available when this occurs and a second driver is not always present. Hence, it also critical to encourage drivers to plan their trips in advance.

Making sure one is rested before undertaking a journey is a principal recommendation, but identifying suitable rest areas in advance and/or making sure that there is a second driver are equally important.

The present results support that sleepiness at the wheel is part of a broader problem in today's society, namely that of neglecting healthy sleep habits. It therefore needs to be approached from a broader perspective than road safety management alone. Both at the level of policy makers and at the individual level, people should become aware of the benefits of a good sleep hygiene and the costs of poor sleep habits. An important question to be asked in this regard is to what extent in some societal contexts there is pressure to continue driving when sleepy. Among the causes of poor sleep quality, the current survey shows that the obligation to get up early has the highest overall prevalence and the strongest relationship with sleepiness at the wheel. Together with the association of driver sleepiness with employment variables, this suggests that at least part of the respondents that felt sleepy while driving did not have a choice to opt for a different transport mode or to stop for a nap. Other research has also indicated that younger people are more likely to continue driving while sleepy, presumably because of employment responsibilities (e.g., Nordbakke & Sagberg, 2007). There is also a clear link between driver sleepiness and shift work (e.g., McCartt et al., 1996). It thus appears that employers could play an important role in helping to reduce the prevalence of driver sleepiness, for instance, by facilitating flexible work schedules and the flexible use of different transport modes for commuting.

The increased risk for traffic injuries represents only one of the serious health risks and societal costs that result from lack of sleep. Research is discovering complex interactions between low sleep quality and serious physical conditions (e.g., cancer, heart disease, diabetes obesity) and psychological disorders (e.g., Foster & Kreitzman, 2014). An important outcome in this regard is that in the present study no less than one out of five drivers (20.3%) indicated to suffer from stress and/or depression and that this negatively affected their sleep quality. This portion was also 1.7 times larger in the subset of sleepy drivers (35%). As argued by Åkerstedt (2006), there is a close relation between psychosocial stress and sleep deprivation, with the anticipation of high demands or effort the next day as the main determinants. To address driver sleepiness it is therefore also important to examine sources of psychosocial stress and develop adequate coping strategies. There should also be attention for the indirect effects of such stress on road safety, for example, through the use of psycho-active substances (whether prescribed or not; e.g., Schulze et al., 2012). Clearly this requires coordinated actions by much more instances than road safety management alone.

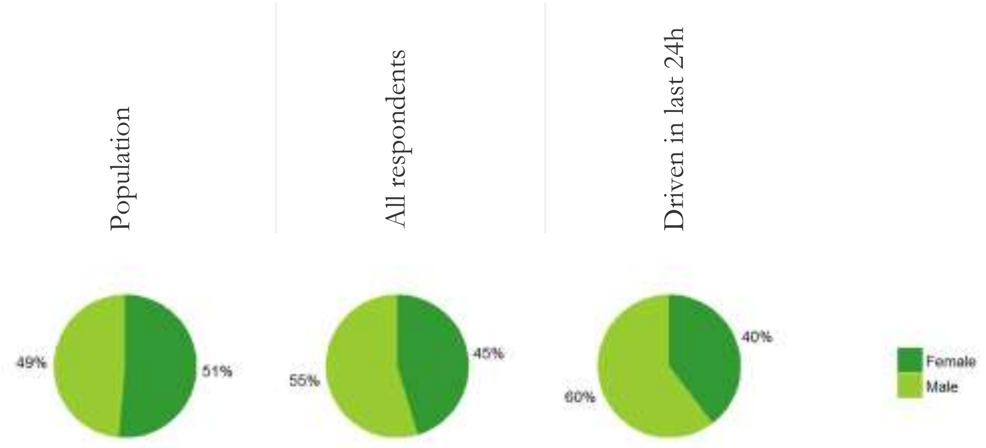
A final recommendation is that investments should be made to improve studying sleepiness at the wheel. The impact on road safety is most likely very large, but at the same time it is very difficult to quantify drowsy driving. Different methods have been used in the past to estimate the prevalence of sleepiness at the wheel. The vast majority of these methods do not allow to draw conclusions with respect to single journeys. Moreover, given their diversity, it is not straightforward to compare the results from different studies. The current method provides a way to estimate sleepiness at the wheel comprehensively, with respect to single journeys, on a large scale and in a relatively cost-effective manner. Provided sufficient resources are available, it is fairly straightforward to monitor the evolution of drowsy driving throughout the year and in different countries using the same method. Investigating the actual impact on road safety nevertheless also requires accurate numbers regarding crash causation. As in many other countries, accurate numbers on the role driver sleepiness in road crashes are lacking in Belgium, mainly because of the existing protocols in crash reporting and the lack of in-depth crash investigations. This is perhaps the area where research investments are needed most urgently.

APPENDICES

Appendix 1: Distributional characteristics of the surveyed variables

A.1.1. Gender

Below the distribution is shown of the gender of the respondents along two categories: (1) individuals that initiated the survey, (2) individuals that indicated having a driver's licence and that drove a car within the last 24 hours. It can be seen that, compared to the population counts, female drivers were slightly underrepresented in the sample, but that this was partly due to the fact that they more often reported not having a driver's licence or having driven a car in the last 24 hours. Results were not weighted to correct for this, since no significant effect of gender occurred.



A.1.2. Administrative region

The graph below shows the distribution of the administrative region the respondents belonged to along two categories: (1) individuals that initiated the survey, (2) individuals that indicated having a driver's licence and that drove a car within the last 24 hours. It can be seen that, compared to population counts, respondents belonging to the Brussels-Capital and Walloon regions were slightly underrepresented in the sample. Results were not weighted to correct for this, since no reliable difference were found between the different regions.

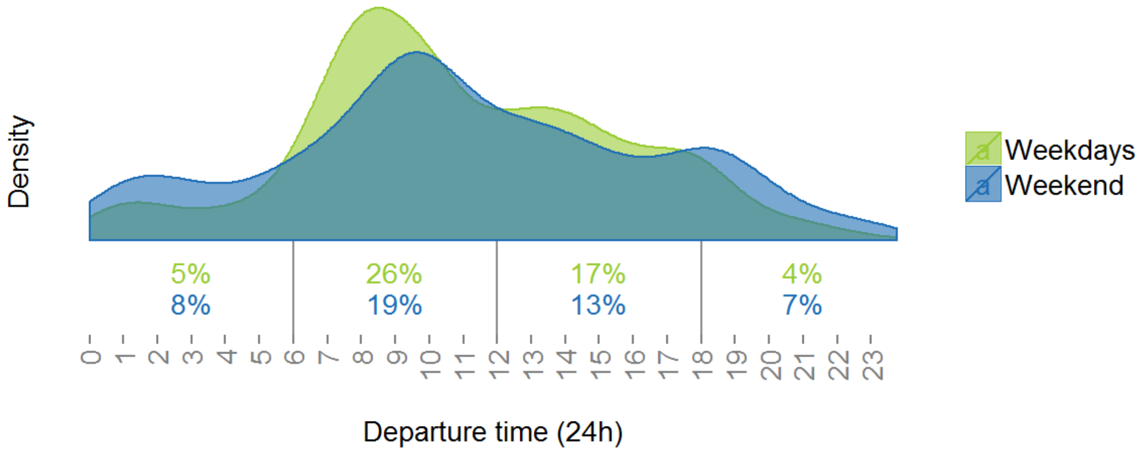
A.1.3. Age

Below the distribution is shown of the age of the respondents along two categories: (1) individuals that initiated the survey, (2) individuals that indicated having a driver's licence and that drove a car within the last 24 hours. It can be seen that compared to the population counts, younger drivers were underrepresented in the sample, but that this was at least partly due to the fact that they more often reported not having a driver's licence or having driven a car in the last 24 hours. Given the significant effect of age on driver sleepiness (see Results section), results were weighted to correct for the disproportional age distribution.

A.1.4. Departure time

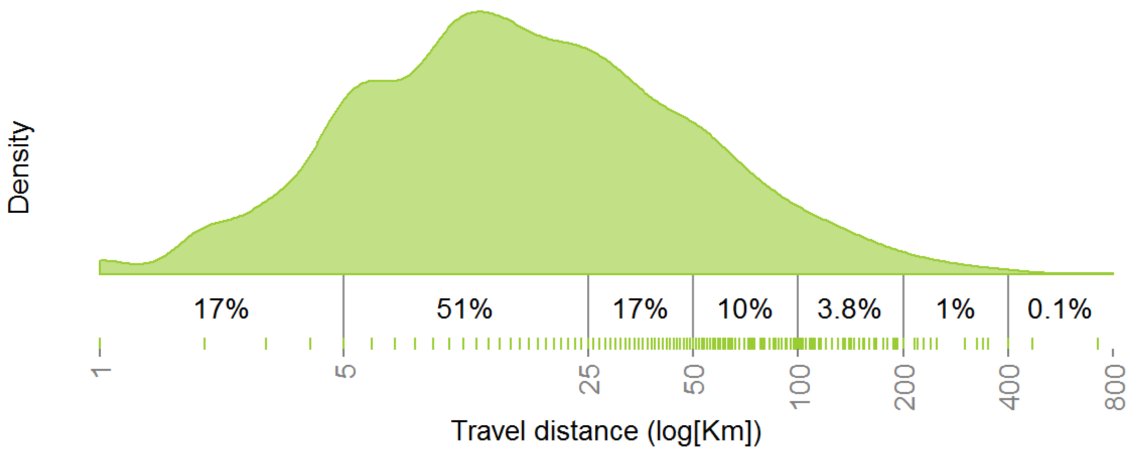
The figure below shows the distribution of the reported departure times as a function of the part of the week: weekdays or weekend. The estimated continuous density is plotted and the raw frequencies for the 4 time slots in the design are printed underneath each slot (i.e., 12am ≤ *A* < 6am ≤ *B* < 12pm ≤ *C* < 6pm ≤ *D* < 12am). For reasons discussed in the Method section, we targeted a balanced sample of weekday and weekend journeys. The results meet this objective since 52% of the trajectories were initiated on weekdays (Monday 6am to Friday 6pm) and 48% during the weekend (Friday 6pm to Monday 6am).

The following observations can be made. Unsurprisingly, daytime driving is most frequent (i.e., "between 6am and 12am" and "between 12am and 6pm"). There is a gradual decrease between 6pm and 12pm. This downward trend starts slightly earlier on weekdays (±6:30pm versus ±7:30pm). There is a marked increase in trajectories initiated after 12pm. This reflects the pseudo-random sampling of the time slots, which favoured night time driving (see Method section for details). Further comparing weekdays and weekend, there is (1) a higher frequency of evening and night time (6pm-6am) driving during the weekend and (2) a higher frequency of early morning (6-10am) and afternoon (12am-6pm) driving on weekdays.



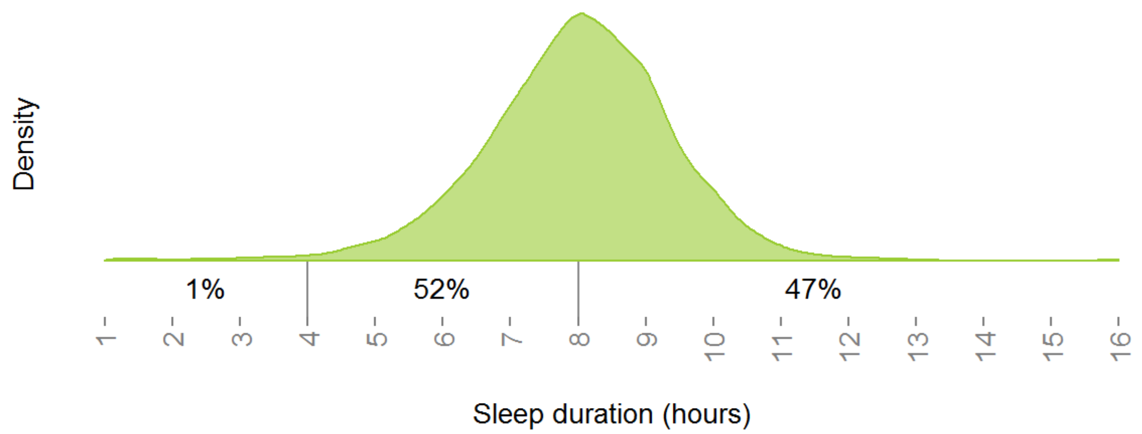
A.1.5. Travel distance

The distribution of travel distances is illustrated below. The percentages that are printed underneath the plot give the observed frequencies within each category (0km < A ≤ 5km < B ≤ 25km < C ≤ 50km < D ≤ 100km < E ≤ 200km < F ≤ 400km < G) . The average self-reported travel distance was 30km, with 25% of the journeys below 7km, 50% below 15km, 75% below 35km and 95% below 100km.



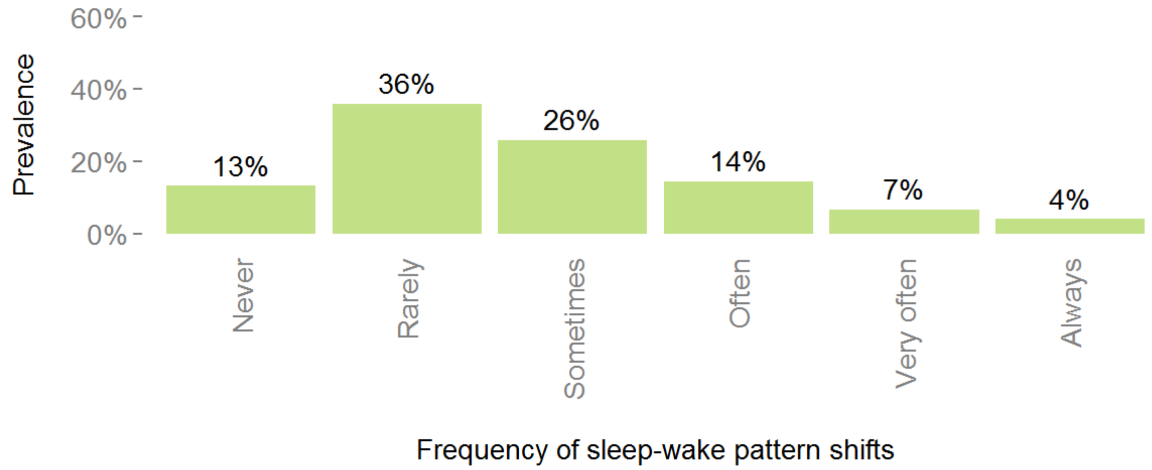
A.1.6. Sleep duration

The distribution of sleep durations before the reported journey is shown below. The percentages in the bottom give the observed frequencies within the three indicated categories (0h < $A \leq$ 4h < $B \leq$ 8h < C). The average sleep duration was 8 hours and 6 minutes, with 25% of the reported durations below 7h15m, 50% below 8h and 75% below 9h.



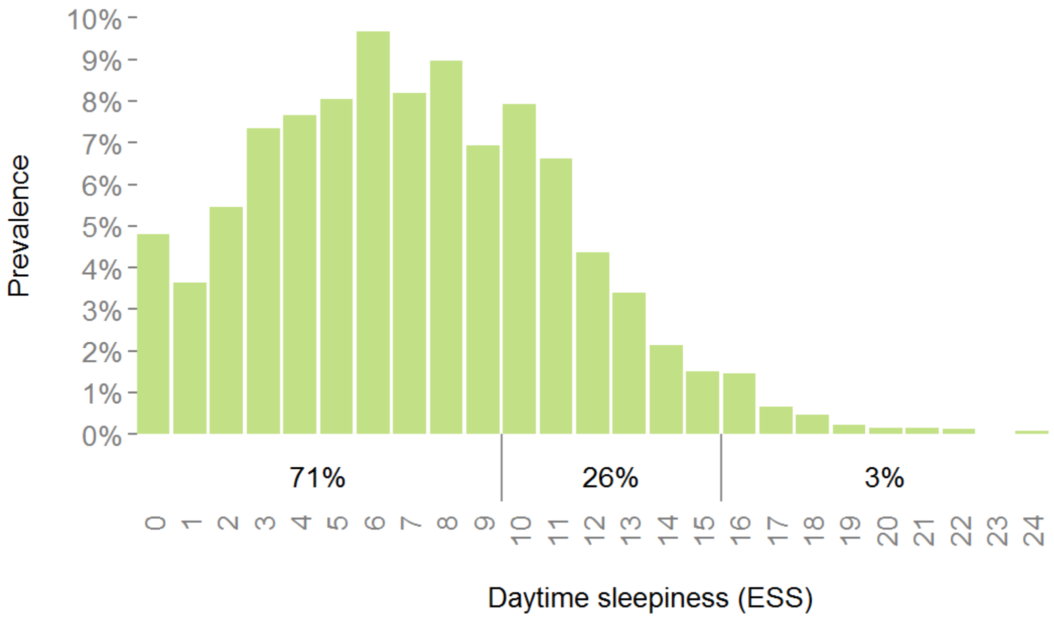
A.1.7. Sleep-wake pattern consistency

Below, the distribution of the frequency of 2 hour shifts in the sleep-wake pattern of respondents is illustrated.



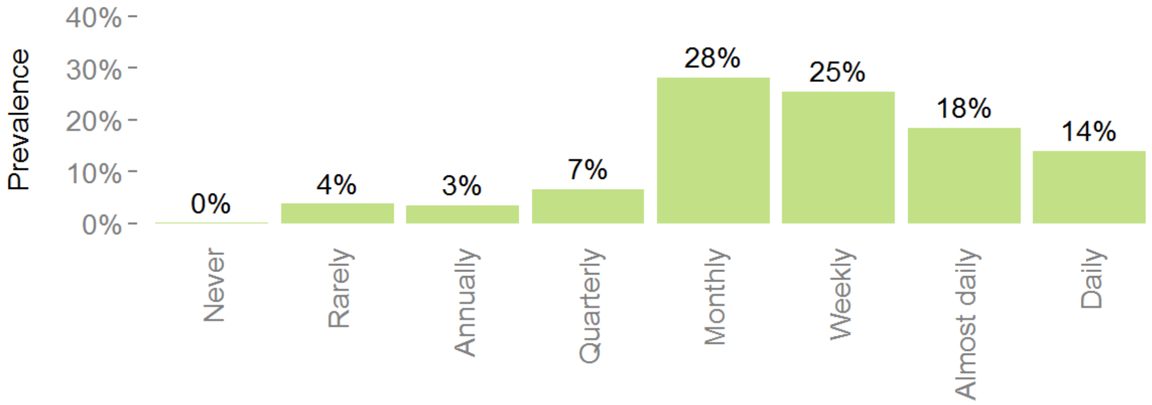
A.1.8. Daytime sleepiness

The distribution of the Epworth Sleepiness Scale scores is shown below. Values between 0 and 9 are considered to reflect normal sleepiness degrees. With scores of 10 or above medical advice is favourable since values around 10-15 have been shown to reflect an increased chance of (mild) sleep apnoea and scores above 15 are often associated with severe sleep apnoea and narcolepsy.

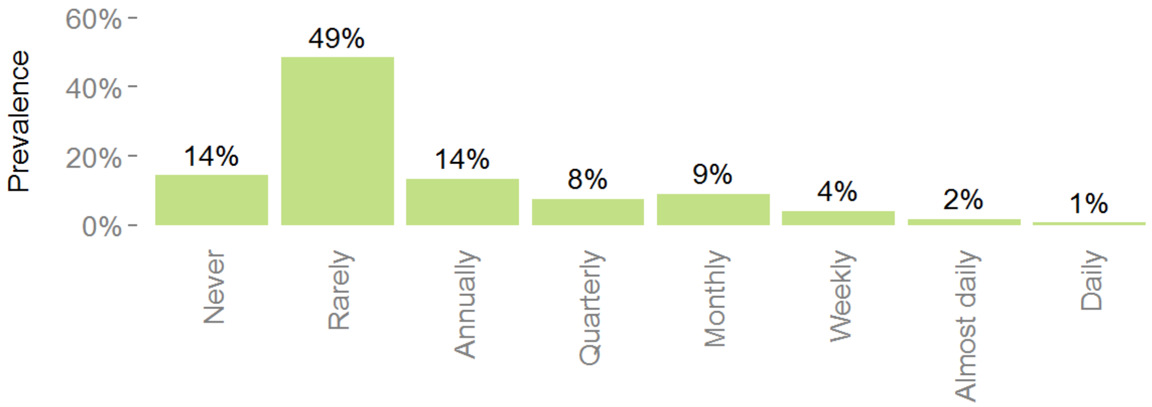


A.1.9. Driving frequency

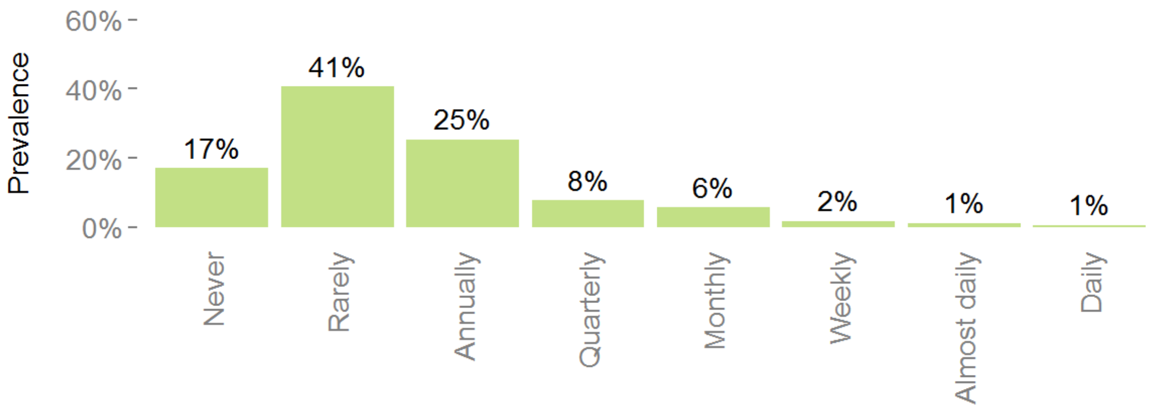
The distribution of the frequency of ≥30 minute journeys, night time driving and driving more than 4 hours on one day is shown below. Only the latter variable is significantly related to driver sleepiness (see Results section).



Frequency of 30 minute journeys



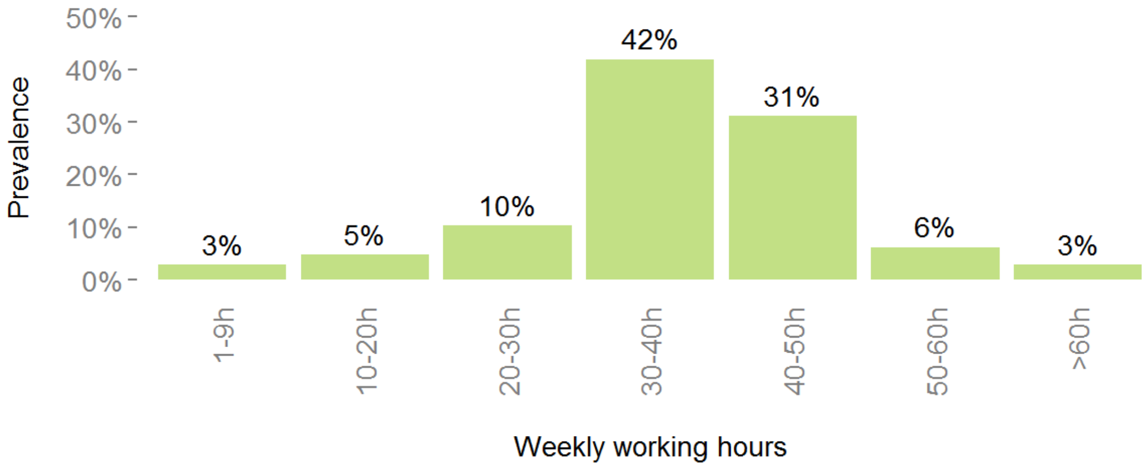
Frequency of nighttime (12pm-6am) driving

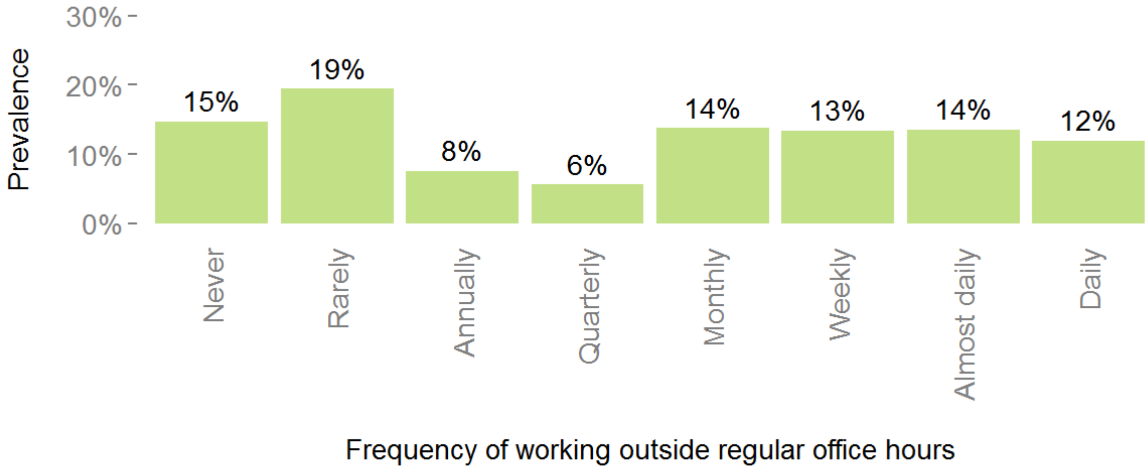


Frequency of driving more than four hours (in total) on one day

A.1.10. Work regime

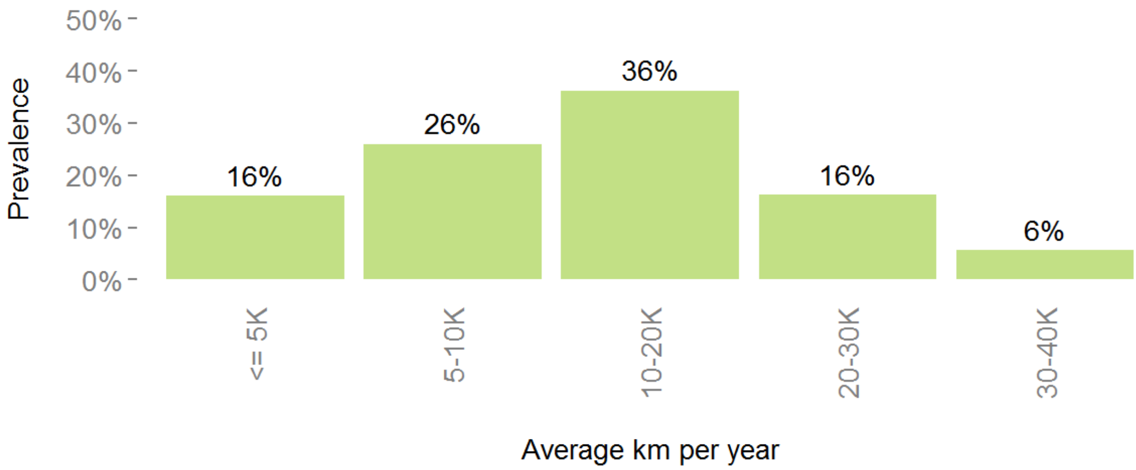
Although being employed or not clearly has an effect on driver sleepiness (see Results section), we find no consistent differences with respect to the work regime for those respondents that have a job. Respondents that work, do so 4.8 days per week on average. The first figure below shows the distribution of the number of hours drivers spend working each week. The second figure shows the distribution of the responses for the question “How often do you work outside the regular office hours?”.

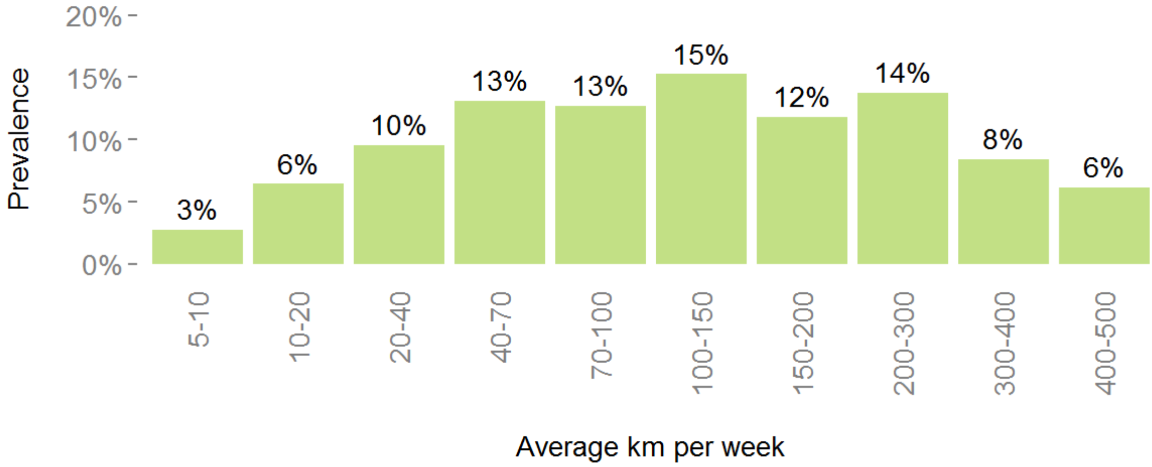


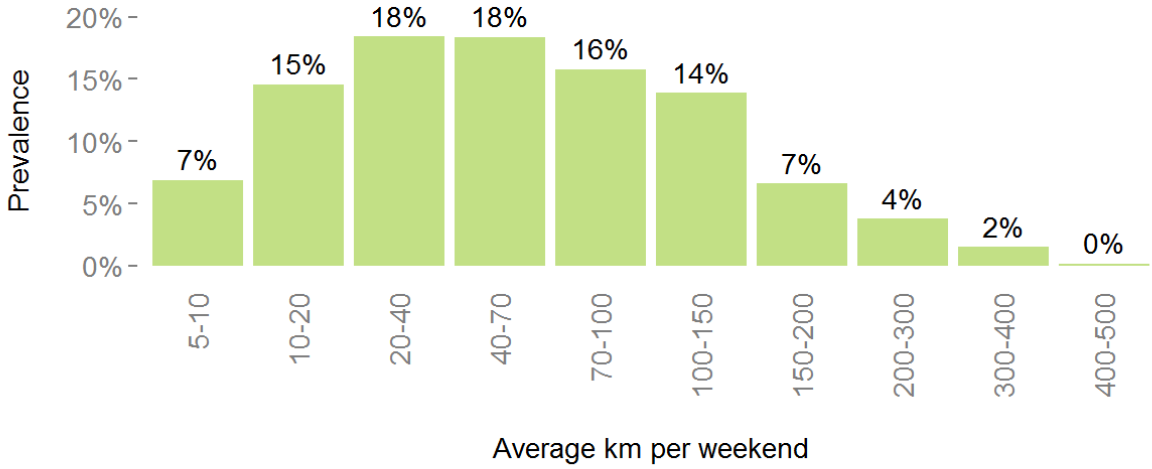


A.1.11. Mileage

The figure below illustrates the distribution of the average number of kilometre spent driving a car or a van per year, week (mon-sun) and weekend (sat-sun), respectively. None of these measures shows a systematic (monotonic) relationship with driver sleepiness.

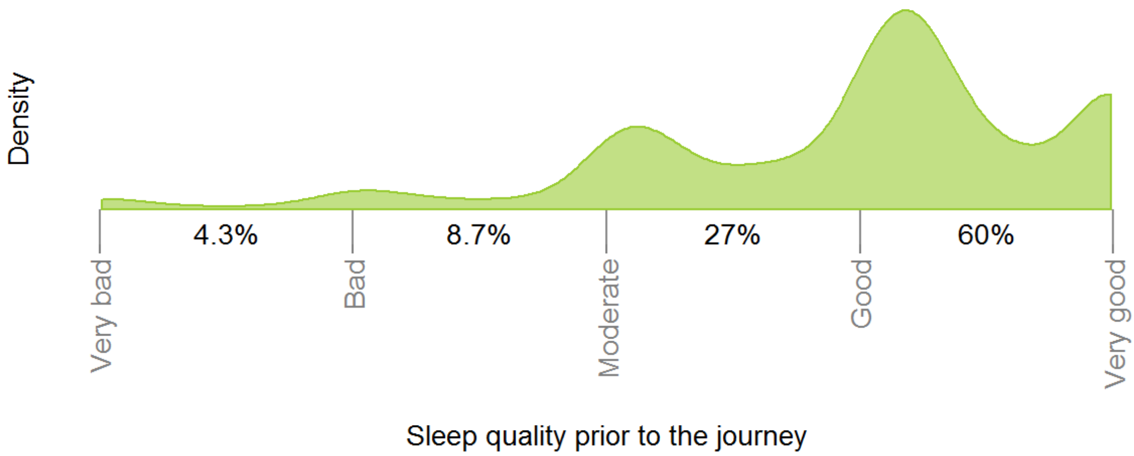


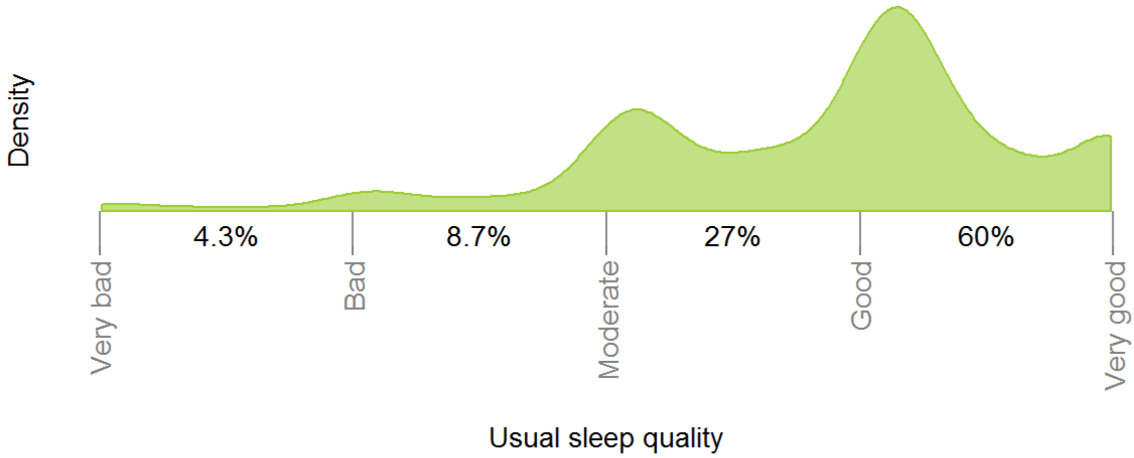




A.1.12. Sleep Quality

Higher levels of self-reported sleep quality, immediately before the journey as well as usual levels, are associated with a lower prevalence of driver sleepiness. The majority of the drivers (87%) rate the quality of their last sleeping episode as moderate to very good. For 4.3% it is rated as bad to very bad. The 'usual sleep quality' variable yields a very similar distribution, but there is variability at the level of individuals. These quality variables, although related to driver sleepiness, were not retained in the final regression model because the effects disappeared after controlling for the total time spent in bed.





Appendix 2: Questionnaire

A.2.1. Please select the province and postal code of your residence. *Selection List*

A.2.2. What is your gender? *Male; Female*

A.2.3. How old are you? *Numeric input*

A.2.4. Do you have a car driver's licence (permit B)? *Yes, a permanent licence; Yes, a temporary licence; No* [*end of survey*]

A.2.5. Did you drive a car in the past 24 hours? *Yes; No* [*end of survey*]

A.2.6. During which of the following time intervals did you make one or more trips (*) while driving a car in the past 24 hours?

- ◻ *Between 6 am and 12 am*
- ◻ *Between 12 am and 6 pm*
- ◻ *Between 6 pm and 12 pm*
- ◻ *Between 12 pm and 6 am*

(*) ATTENTION:

- This refers to trajectories between two different locations.
- Short breaks, such as stops at gas stations, do not count as departure/arrival locations unless they are the main objective of the trip.
- If the timing of the journey involves more than 1 of the time intervals, please use the departure time for indicating the corresponding interval.

A.2.7. [*Pseudo-random selection of 1 interval: INTERVAL*]

A.2.8. [*Random selection of first or last journey: FIRST/LAST*]

A.2.9. Please, try to bring the journey of the *FIRST/LAST* trip you made between *INTERVAL* to mind as clearly as possible and to answer the following questions as precisely as possible:

- Number of kilometres driven approximately: *Numeric input*
- Departure time: *Selection List; 15mins sequence*
- Arrival time: *Selection List; 15mins sequence*
- Where there any passengers? *Yes, only in the front; Yes, only in the back; Yes, both in the front and in the back; No*

[*The purpose of the following questions is to obtain detailed view on your level of alertness or sleepiness during this trip. Sleepiness at the wheel is a frequent phenomenon, but at the same time very difficult to measure. Thank you for your help!*]

- To what extend have you felt sleepy (*) while driving?
  - *Very sleepy, with great effort to stay awake, fighting sleep*
  - *Sleepy, with some effort to stay awake*
  - *Sleepy, with no effort to stay awake*
  - *Some signs of sleepiness*
  - *Neither alert nor sleepy*
  - *Rather alert*
  - *Alert*
  - *Very alert*
  - *Extremely alert*

(*) definition "sleepy": tendency to fall asleep

- Regardless of the degree of sleepiness you just indicated, did you undertake any of the following actions to prevent or fight sleepiness at the wheel? *Yes; No*
  - □ Making stopover
  - □ Napping
  - □ Consuming energizing food/drink
  - □ Taking stimulating substance
  - □ Switching driver
  - □ Opening window / Lowering air temperature
  - □ Listening to radio/music
  - □ Turning up volume
  - □ Talking to passenger
  - □ Talking on the phone
  - □ Driving faster
  - □ Stretching
  - □ Changing posture
  - □ Eating or drinking
- Did you consume any alcoholic beverages in the 2 hours immediately preceding the journey? If yes, how many standard units (*) did you consume? *0; 1; 2; …; 9; 10 or more*
  (*) 1 standard unit = 1 glass of wine = 1 glass of lager = 1 cocktail = 1 aperitif = 1 glass of liquor

[*The following questions concern the sleep episode (*) that preceded the journey just described.*

(*) ATTENTION:

- *What is intended here is the usual night's rest and not napping*
- *If you were awake at night instead of during the day (in the context of shift-work, for instance), you should interpret "night's rest" as "day's rest"*]

- At what time did you go to sleep? *Selection List; 15mins sequence*
- At what time did you get up? *Selection List; 15mins sequence*
- On which day of the week did you get up? *Monday; Tuesday; Wednesday; Thursday; Friday; Saturday; Sunday*
- Is there a difference of more than 24 hours between the time you got up and the departure time of the trip you just described? *Yes; No*
- To what extent did you feel rested when you got up? *Very well; Well; Moderately; Badly; Very badly*
- Did you take one or more naps after getting up and before the journey you just described? *Yes; No*

A.2.10. How many kilometres did you drive with a car or a van in the past year? *Less than 5,000 km; 5,000 to 9,999 km; 10,000 to 19,999 km; 20,000 to 29,999 km; 30,000 to 39,999 km; 40,000 km or more*

A.2.11. How many kilometres do you drive with a car or a van on weekdays? *Less than 5 km; 5 to 9 km; 10 to 19 km; 20 to 39 km; 40 to 69 km; 70 to 99 km; 100 to 149 km; 150 to 199 km; 200 to 299 km; 300 to 399 km; 400 to 499 km; 500 km or more*

A.2.12. How many kilometres do you drive with a car or a van during the weekend? *Less than 5 km; 5 to 9 km; 10 to 19 km; 20 to 39 km; 40 to 69 km; 70 to 99 km; 100 to 149 km; 150 to 199 km; 200 to 299 km; 300 to 399 km; 400 to 499 km; 500 km or more*

A.2.13. How often (approximately) do you drive a car or a van for 30 minutes or more non-stop? *Daily; Almost daily; Weekly; Monthly; Quarterly; Annually; Rarely; Never*

A.2.14. How often do you drive a car or a van between 12pm and 6am? *Daily; Almost daily; Weekly; Monthly; Quarterly; Annually; Rarely; Never*

A.2.15. How often do you drive a car or a van for more than 4 hours in total on one day? *Daily; Almost daily; Weekly; Monthly; Quarterly; Annually; Rarely; Never*

A.2.16. How often did you experience sleepiness at the wheel in the past year? *Almost always; Very often; Often; Sometimes; Rarely; Never*

A.2.17. How often did you unintendedly fall asleep at the wheel in the past year – even if only very briefly? *Daily; Almost daily; Weekly; Monthly; Quarterly; Annually; Rarely; Never*

A.2.18. Did you cause a crash or near-crash in the past year while driving a car? *Yes; No*

[*If yes*] Was this situation related to sleepiness at the wheel?

A.2.19. Usually my sleep quality (*) is … *Very good; Good; Moderate; Bad; Very bad*

(*) this equally refers to the amount of sleep and the sleep depth

A.2.20. How often do you experience shifts of more than 2 hours in your sleep-wake pattern? *Always; Very often; Often; Sometimes; Rarely; Never*

A.2.21. How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? (*) *0 = would never doze; 1 = slight chance of dozing; 2 = moderate chance of dozing; 3 = high chance of dozing*

(*) This question refers to your usual way of life in recent times. Even if you haven't done some of these things recently try to work out how they would have affected you.

- Sitting and reading
- Watching TV
- Sitting, inactive in a public place (e.g. a theatre or a meeting)
- As a passenger in a car for an hour without a break
- Lying down to rest in the afternoon when circumstances permit
- Sitting and talking to someone
- Sitting quietly after a lunch without alcohol
- In a car, while stopped for a few minutes in the traffic

A.2.22. Are you dealing with one or more of the following circumstances, exerting an important negative impact on your sleep quality?

- □ Excessive snoring
- □ Respiratory problems
- □ Chronic insomnia
- □ Chronic pain
- □ Alcohol use
- □ Drug use
- □ Movement disorder
- □ Stress/Depression
- □ Gasping/Choking sensation
- □ Difficulties falling asleep
- □ Superficial sleep
- □ Long lasting sleep interruptions
- □ Noise
- □ Snoring partner
- □ Sleep problems of family members
- □ Family members in need of care
- □ Obligation to get up early
- □ Irregular working hours

- □ Sleep apnoea

A.2.23. Do you have a job? *No; Yes, a fulltime job; Yes, a part time job; Yes, multiple jobs not exceeding a 100% regime; Yes, multiple jobs exceeding a 100% regime*

A.2.24. [*if A.2.23. yes*] How many days do you usually work in a week? *1-7*

A.2.25. [*if A.2.23. yes*] How many hours do you usually work in a week? *1 to 9 hours; 10 to 19 hours; 20 to 29 hours; 30 to 39 hours; 40 to 49 hours; 50 to 59 hours; 60 or more*

A.2.26. [*if A.2.23. yes*] What kind of schedule corresponds best with your work regime? *Regular working hours; Irregular working hours; Fixed pattern of variable shifts*

A.2.27. [*if A.2.23. yes*] Do you ever work outside the regular office hours? *No; Yes, including nights; Yes, including mornings; Yes, including evenings; Yes, including weekends*

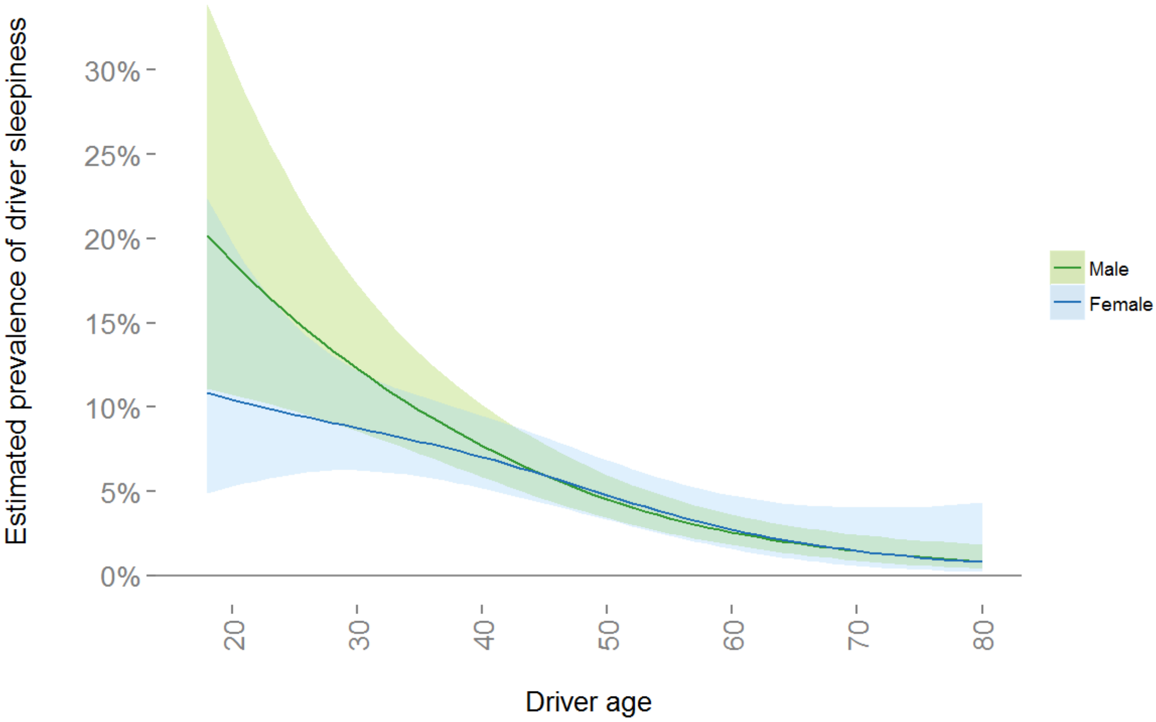
A.2.28. [*if A.2.23. yes*] How often do you work outside the regular office hours? *Daily; Almost daily; Weekly; Monthly; Quarterly; Annually; Rarely; Never*

A.2.29. What is your educational level? *Below secondary; Secondary; Bachelor; Master or higher*

A.2.30. What is your professional activity? *None; Self-employed; Employee; Labourer; Management*

Appendix 3: Effect of driver age by gender

The figure below shows the estimated prevalence of driver sleepiness separately for female and male drivers as a function of their age. The average prevalence appears to be higher for male drivers in the sample, but only at a young age. Nevertheless, this interaction does not reach significance, as shown by the overlapping 95% confidence bands.



LIST OF TABLES AND FIGURES

REFERENCES

ASFA (2008). Analyse des accidents mortels 2007 sur autoroutes concédées. ASFA, Paris.

Åkerstedt, T. (2006). Psychosocial stress and impaired sleep. *Scandinavian Journal of Work, Environment and Health*, *32*, 493-501.

Åkerstedt, T. & Gillberg, M. (1990). Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience*, *52*, 29-37.

Åkerstedt, T., Kecklund, G., & Hörte, L. G. (2001). Night driving, season, and the risk of highway accidents. *Sleep*, *24*, 401-406.

Åkerstedt, T., Ingre, M., Kecklund, G., Anund, A., Sandberg, D., Wahde, M., Philip, P., & Kronberg P. (2010). Reaction of sleepiness indicators to partial sleep deprivation, time of day and time on task in a driving simulator - the DROWSI project. *Journal of Sleep Research*, *19*, 298-309.

Andriulo, S. & Gnoni, M. G. (2014). Measuring the effectiveness of a near-miss management system: An application in an automotive firm supplier. *Reliability Engineering and System Safety*, *132*, 154-162.

Anselm, D. & Hell, W. (2002). Einschlafen am Steuer: eine häufig unterschätzte Unfallursache. *Verkerhsunfall und Fahrzeug Technik*, 3, 62-66.

Anund, A., Kecklund, G., Peters, B. & Åkerstedt, T. (2008). Driver sleepiness and individual differences in preferences for countermeasures. *Journal of Sleep Research*, *17*, 16-22.

Anund, A., Kecklund, G., Vadeby, A., Hjälmdahl, M. & Åkerstedt, T. (2008). The alerting effect of hitting a rumble strip: A simulator study with sleepy drivers. *Accident Analysis & Prevention*, *40*, 1970-1976.

Anund, A., Fors, C., Hallvig, D., Åkerstedt, T., Kecklund, G. (2013). Observer rated sleepiness and real road driving: An explorative study. *PLoS ONE*, *8*, e64782, doi:10.1371/journal.pone.0064782.

Banks, S., Catcheside, P., Lack, L., Grunstein, R. R., & McEvoy R. D. (2004). Low levels of alcohol impair driving simulator performance and reduce perception of crash risk in partially sleep deprived subjects. *Sleep, 27*, 1063-1067.

Barrett, P. R., Horne, J. A., & Reyner L. A. (2005). Early evening low alcohol intake also worsens sleepiness-related driving impairment. *Human Psychopharmacology*, *20*, 287-290.

Blazejewski, S., Girodet, P. O., Orriols, L., Capelli, A., & Moore, N.; CESIR Group. (2012). Factors associated with serious traffic crashes: a prospective study in southwest France. *Archives of Internal Medicine*, *172*, 1039-1041.

Brunborg, G. S., Mentzoni, R. A., Molde, H., Myrseth, H., Skouverøe, K. J., Bjorvatn, B., & Pallesen S. (2011). The relationship between media use in the bedroom, sleep habits and symptoms of insomnia. *Journal of Sleep Research*, *20*, 569-575.

Cestac, J., & Delhomme, P. (2012). European road users' risk perception and mobility, The SARTRE 4 survey. Lyon, France.

Connor, J., Norton, R., Ameratunga, S., Robinson, E., Wigmore, B., & Jackson, R. (2011). Prevalence of driver sleepiness in a random population-based sample of car driving. *Sleep*, *24*, 688-694.

Connor, J., Norton, R., Ameratunga, S., Robinson, E., Civil, I., Dunn, R., Bailey, J., & Jackson, R. (2002). Driver sleepiness and risk of serious injury to car occupants: population based case control study. *BMJ*, *324*, 1125.

Cummings, P., Koepsell, T., Moffat, J., & Rivara, F. (2001). Drowsiness, counter-measures to drowsiness, and the risk of a motor vehicle crash. *Injury Prevention*,*7*, 194-199.

De Dobbeleer, W., Nathanail, T., & Adamos, G. (2009). CAST Deliverable 5.2. Pan European road safety campaign: Campaign Design, Campaigns and Awareness-raising Strategies in Traffic Safety.

Eisner, A. (2010). Is Social Media a New Addiction? *Retrevo Blog*, March 15th.

Duffy, J. F., & Wright, P. W. Jr. (2005). Entrainment of the human circadian system by light. *Journal of Biological Rhythms*, *20*, 326-338.

Ekirch, A. R. (2001). Sleep we have lost: Pre-industrial slumber in the British isles. *The American Historical Review*, *106*, 343-386.

Engleman, H. M., Kingshott, R. N., Wraith, P. K., Mackay, T. W., Deary, I. J., & Douglas, N. J. (1999). Randomized placebo-controlled crossover trial of continuous positive airway pressure for mild sleep Apnea/Hypopnea syndrome. *American Journal of Respiratory and Critical Care Medicine*, *159*, 461-467.

Foster, R. G., & Kreitzman L. (2014). The rhythms of life: what your body clock means to you! *Experimental Physiology*, *99*, 599-606.

Gershon, P., Shinar, D., Oron-Gilad, T., Parmet, Y., & Ronen, A. (2011). Usage and perceived effectiveness of fatigue countermeasures for professional and nonprofessional drivers. *Accident Analysis & Prevention*, *43*, 797-803.

Gold, D. R., Rogacz, S., Bock, N., Tosteson, T.D., Baum, T.M., Speizer, F.E., & Czeisler, C. A. (1992). Rotating shift work, sleep, and accidents related to sleepiness in hospital nurses. *American Journal of Public Health*, *82*, 1011-1014.

Goldenbeld, C., Davidse, R., Mesken, J., & Hoekstra T. (2011). Vermoeidheid in het verkeer: Een studie naar prevalentie en statusonderkenning bij automobilisten en vrachtautochauffeurs. *Institute for Road Safety Research SWOV*, Netherlands, Leidschendam, Report 2011-4.

Hänecke, K., Tiedemann, S., Nachreiner, F., & Grzech-Sukalo H. (1998). Accident risk as a function of hour at work and time of day as determined from accident data and exposure models for the German working population. *Scandinavian Journal of Work, Environment & Health*, *24*, 43-48.

Herdewyn, B., Slootmans, F., Dupont, E., Martensen, H., & Silverans, P. (2010). Pilootproject multidisciplinair diepte-onderzoek van ongevallen met vrachtwagens in Oost- en West-Vlaanderen Eindrapport jaar 1. *Belgisch Instituut voor de Verkeersveiligheid - Observatorium voor de Verkeersveiligheid*, Brussel, België.

Herman, J., Kafoa, B., Wainiqolo, I., Robinson, E., McCaig, E., Connor, J., Jackson, R., & Ameratunga, S. (2014). Driver sleepiness and risk of motor vehicle crash injuries: a population-based case control study in Fiji (TRIP 12). *Injury*, *45*, 586-591.

Hoddes, E., Dement, W., & Zarcone, V. (1972). The development and use of the Stanford Sleepiness Scale. *Psychophysiology*, 9:150.

Horne, J. A. & Reyner, L. A. (1995). Sleep related vehicle accidents. *British Medical Journal*, *310*, 565-567.

Horne, J. & Reyner, L. (2001). Sleep-related vehicle accidents: some guides for road safety policies. *Transportation Research Part F: Traffic Psychology and Behaviour*, *4*, 63-73.

Horne, J. (2013). Methods to fight sleepiness at the wheel. In: Åkerstedt, T. (Ed.) *Sleepiness at the wheel – White Paper*.

Horne, J. A., Reyner, L. A., & Barrett, P. R. (2003). Driving impairment due to sleepiness is exacerbated by low alcohol intake*, Occupational and Environmental Medicine*, *60*, 689-692.

Johns, M. (1991). A new method for measuring daytime sleepiness: the Epworth sleepiness scale. *Sleep*, *14*, 540–545.

Johns, M. W. (2000). Sensitivity and specificity of the multiple sleep latency test (MSLT), the maintenance of wakefulness test and the Epworth sleepiness scale: Failure of the MSLT as a gold standard. *Journal of Sleep Research*, *9*, 5-11.

Kaida, K., Takahashi, M., Åkerstedt, T., Nakata, A., Otsuka, Y., Haratani, T., & Fukasawa, K. (2006). Validation of the Karolinska sleepiness scale against performance and EEG variables. *Clinical Neurophysiology*, *117*, 1574-1581.

Kecklund, G., Anund, A., Wahlström, M. R., Philip, P., & Åkerstedt, T. (2011). Sleepiness and the risk of car crash: a case control study. *Swedish National Road and Transport Research Institute (VTI)*, Sweden, Report 12A-2011.

Klauer, S. G., Dingus, T. A. , Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. (2006). The impact of driver inattention on near-crash/crash Risk: An analysis using the 100-car naturalistic driving study data. *NHTSA Report No. DOT HS 810 594*. Blacksburg, VA: Virginia Tech Transportation Institute.

Kushida, C. A., Nichols D. A., Simon R. D., Young T., Grauke J. H., Britzmann J. B., Hyde P. R., Dement W. C. (2000). Symptom-based prevalence of sleep disorders in an adult primary care population. *Sleep and Breathing*, *4*, 9-14.

Lucas, R. & Araújo, F. (2013). Wake up bus sleep study: A survey of 19 European countries. The Wake up Bus Project, Portuguese Sleep Association (PSA).

Masten, S., Stutts, J., & Martell, C. (2006). Predicting daytime and nighttime drowsy driving crashes based on crash characteristic models. *50th Annual Proceedings of the Association for the Advancement of Automotive Medicine*.

Maycock, G. (1995). Driver sleepiness as a factor in car and HGV accidents. *Safety and Environment Resource Centre, Transport Research Laboratory*, Crowthorne.

McCartt, A. T., Ribner, S. A., Pack, A. I., & Hammer, M. C. (1996). The scope and nature of the drowsy driving problem in New York State. Accident Analysis & Prevention, 28, 511-517.

Meesmann, U. & Boets, S. (2014). Vermoeidheid en afleiding door GSM - gebruik. Resultaten van de driejaarlijkse attitudemeting over verkeersveiligheid van het BIVV. *Belgisch Instituut voor de Verkeersveiligheid – Kenniscentrum Verkeersveiligheid*, Brussel, België.

Neale, V. L., Dingus, T. A., Klauer, S. G., Sudweeks, J., & Goodman, M. (2005). An Overview of The 100-Car Naturalistic Driving Study and Findings. *National Highway Traffic Safety Administration and Virginia Tech Transportation Institute*, www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/NRD.

Nordbakke, S. & Sageberg, F. (2007). Sleepy at the wheel: Knowledge, symptoms and behaviour among car drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *10*, 1-10.

Pack, A. I., Pack, A. M., Rodgman, E., Cucchiara, A., Dinges, D. F., & Schwab, C. W. (1995). Characteristics of crashes attributed to the driver having fallen asleep. *Accident Analysis & Prevention*, *27*, 769-775.

Philip, P., Taillard, J., Guilleminault, C., Quera Salva, M. A., Bioulac, B., & Ohayon, M. (1999). Long distance driving and self-induced sleep deprivation among automobile drivers. *Sleep*, *22*, 475-480.

Philip, P., Vervialle, F., Le Breton, P., Taillard, J., & Horne, J.A. (2001). Fatigue, alcohol, and serious road crashes in France: factorial study of national data. *British Medical Journal*, *322*, 829-830.

Phillips, R. O. & Sagberg, F. (2013). Road accidents caused by sleepy drivers: Update of a Norwegian survey. *Accident Analysis & Prevention*, *50*, 138-146.

Powell, N. B., Schechtman, K. B., Riley, R. W., Guilleminault, C., Chiang, R. P., Weaver, E. M. (2007). Sleepy driver near-misses may predict accident risks. *Sleep*, *30*, 331-342.

R Core Team (2014). R: A language and environment for statistical computing. *R Foundation for Statistical Computing*, Vienna, Austria. URL http://www.R-project.org/.

Radun, I., & Radun, J. E. (2009). Convicted of fatigued driving: Who, why and how? *Accident Analysis and Prevention*, *41*, 869-875.

Reyner, L. A., Horne, J. A., & Flatley, D. (2010). Effectiveness of UK motorway services areas in reducing sleep-related and other collisions. *Accident Analysis & Prevention*, *42*, 1416-1418.

Roehrs, T., Beare, D., Zorick, F., & Roth, T. (1994). Sleepiness and ethanol effects on simulated driving. *Alcoholism: Clinical and Experimental Research*, *18*, 154-158.

Riguelle, F. (2014). Drinken we te veel als we rijden ? Nationale gedragsmeting "Rijden onder invloed van alcohol" 2012. *Belgisch Instituut voor de Verkeersveiligheid - Kenniscentrum Verkeersveiligheid*, Brussel, België.

SafetyNet (2009) Alcohol, retrieved 2015.03.11, URL http://ec.europa.eu/transport/road_safety/specialist/knowledge/pdf/alcohol.pdf

Sagberg, F. (1999). Road accidents caused by drivers falling asleep. *Accident Analysis & Prevention*, *31*, 639-649.

Sagaspe, P., Taillard, J., Bayon, V., Lagarde, E., Moore, N., Boussuge, J., Chaumet, G., Bioulac, B., & Philip, P. (2010). Sleepiness, near-misses and driving accidents among a representative population of French drivers. *Journal of Sleep Research*, *19*, 578-584.

Schulze, H., Schumacher, M., Urmeew, R., & Auerbach, K. (2012). Driving under the influence of drugs, alcohol and medicines in Europe - findings from the DRUID project. *European Monitoring Centre for Drugs and Drug Addiction (EMCDDA)*. Publications Office of the European Union, Luxembourg.

Schwarz, J. F., Ingre, M., Fors, C., Anund, A., Kecklund, G., Taillard, J., Philip, P., Åkerstedt, T. (2012). In-car countermeasures open window and music revisited on the real road: popular but hardly effective against driver sleepiness. *Journal of Sleep Research*, *21*, 595-599.

Stutts, J. C., Wilkins, J. W., & Vaughn, B. V. (1999). Why do people have drowsy driving crashes? Input from drivers who just did. *AAA Foundation for Traffic Safety*.

Summala, H., & Mikkola, T. (1994). Fatal accidents among car and truck drivers: Effects of fatigue, age, and alcohol consumption. *Human Factors*, *3692*, 315-326.

Tefft, B. C. (2012). Prevalence of motor vehicle crashes involving drowsy drivers, United States, 1999-2008. *Accident Analysis and Prevention*, *45*, 180-186.

Vaa, T. (2003). Impairment, diseases, age and their relative risks of accident involvement: Results from meta-analysis. *Norwegian Centre for Transport Research - Institute of Transport Economics*, Oslo, Report 690/2003.

Vakulin, A., Baulk, S. D., Catcheside, P. G., Antic, N. A., van den Heuvel, C. J., Dorrian, J., McEvoy, R. D. (2009). Effects of alcohol and sleep restriction on simulated driving performance in untreated patients with obstructive sleep apnea. *Annals of Internal Medicine*, *151*, 447-455.

van den Berg, J. & Landström, U. (2006). Symptoms of sleepiness while driving and their relationship to prior sleep, work and individual characteristics. *Transportation Research Part F: Traffic Psychology and Behaviour*, *9*, 207-226.

Van den Bulck J. (2007). Adolescent use of mobile phones for calling and for sending text messages after lights out: Results from a prospective cohort study with a one-year follow-up. *Sleep*, *30*, 1220-1223.

Vanlaar, W., Simpson, H., Mayhew, D., & Robertson, R. (2008). Fatigued and drowsy driving: A survey of attitudes, opinions and behaviors. *Journal of Safety Research*, *39*, 303-309.

Wang, J. S., Knipling, R. R., & Goodman, M. J. (1996). The role of driver inattention in crashes; new statistics from the 1995 Crashworthiness Data System. *40th Annual Proceedings, Association for the Advancement of Automotive Medicine*, October, Vancouver, BC.

Wheaton, A. G., Shults, R. A., Chapman, D. P., Ford, E. S., Croft, J. B. (2014). Drowsy driving and risk behaviors - 10 States and Puerto Rico, 2011-2012. *Morbidity and Mortality Weekly Report*, *63*, 557-562.

Wood, B., Rea, M. S., Plitnick, B., & Figueiro, M. G. (2013). Light level and duration of exposure determine the impact of self-luminous tablets on melatonin suppression. *Applied Ergonomics*, *44*, 237-240.

Wood, S.N. (2003). Thin plate regression splines. *Journal of the Royal Statistical Society Series B (Statistical Methodology)*, *65*, 95-114.

Xie, L., Kang, H., Xu, Q., Chen, M. J., Liao, Y., Thiyagarajan, M., O'Donnell, J., Christensen, D. J., Nicholson, C., Iliff, J. J., Takano, T., Deane, R., Nedergaard, M. (2013). Sleep drives metabolite clearance from the adult brain. *Science*, *342*, 373-377.

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