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To cite this article: Åsa Forsman, Anna Anund, Marie Skyving & Ashleigh J. Filtress (2021) Injury crashes and the relationship with disease causing excessive daytime sleepiness, Traffic Injury Prevention, 22:4, 272-277, DOI: [10.1080/15389588.2021.1894639](https://doi.org/10.1080/15389588.2021.1894639)

To link to this article: <https://doi.org/10.1080/15389588.2021.1894639>



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Published online: 26 Mar 2021.



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Injury crashes and the relationship with disease causing excessive daytime sleepiness

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ABSTRACT

Objective: The objective of this study was to understand the relationship between some of the most common diseases that are known to contribute to excessive daytime sleepiness (EDS) and traffic injury crashes. Specific focus was on the relationship between disease and crash type (single-vehicle or multiple-vehicle crash) and between disease and injury severity.

Methods: This registry-based study considered all passenger car drivers involved in a crash in Sweden between 2011 and 2016 who were 40 years or older at the time of the crash ($n = 54,090$). For each crash-involved driver, selected medical diagnoses registered from 1997 until the day before the crash were extracted from the National Patient Register. The drivers were assigned to 1 of 4 groups, depending on prior diseases: sleep apnea (SA; group 1, $n = 2,165$), sleep disorders (group 2, $n = 724$), Parkinson's or epilepsy (group 3, $n = 645$) and a reference group (group 4, $n = 50,556$). Logistic regression analysis compared single-vehicle crashes with multiple-vehicle crashes and moderately/severely injured drivers with slightly/uninjured drivers.

Results: Drivers with EDS-related diseases (groups 1–3) had higher probability of a single-vehicle crash than a multiple-vehicle crash compared to the reference group. The most sizeable effect was found for Parkinson's/epilepsy with an odds ratio (OR) of 2.5 (confidence interval [CI], 2.1–3.0). For multiple-vehicle crashes, the probability of a moderate/severe injury was higher for drivers with other sleep disorders (OR = 1.5; CI, 1.0–2.2) and Parkinson's/epilepsy (OR = 1.6; CI, 1.1–2.3) compared to the reference group.

Conclusions: This study has made first steps toward understanding the relationship between some of the most common diseases that are known to contribute to EDS and crashes. Having Parkinson's/epilepsy, in particular, elevated the probability of a single-vehicle crash compared to a multiple-vehicle crash. A single-vehicle crash was seen as indicative of causing a crash; thus, having Parkinson's/epilepsy could be interpreted as a risk factor for crash involvement. Having Parkinson's/epilepsy, as well as other sleep disorders, was also related to more severe outcomes in multiple-vehicle crashes, given that a crash occurred. This was not identified in single-vehicle crashes.

ARTICLE HISTORY

Received 29 September 2020
Accepted 21 February 2021

KEYWORDS

Road traffic crashes; sleep apnea; Parkinson's; epilepsy; sleep disorders



Introduction


It is well known that driver fatigue, covering both task-related fatigue and sleepiness, is a contributing factor to road crashes. Studies suggest that driver fatigue contributes to approximately 20% of fatal road crashes (Connor et al. 2002). Additionally, drivers reporting sleepiness at the wheel have more than a 2-fold increase in crash risk (Bioulac et al. 2017).

There is no single reason for driver fatigue. Both sleepiness due internal factors like circadian low and the homeostatic effects of time awake (Åkerstedt et al. 2008) and external task factors such as cognitive underload or cognitive

overload (May and Baldwin 2009) need to be considered when seeking to understand crash risk. Furthermore, individual differences covering both internal and external factors affect sleepiness (Gabeheart and Van Dongen 2017). To date the determinants of driver sleepiness with greatest evidence are younger age, male sex, driving time, excessive daytime sleepiness (EDS), and high risk of obstructive sleep apnea (OSA). However, there are many factors that contribute to EDS, including underlying diseases.

OSA is particularly important. Karimi et al. (2015) found a 2.5-fold increased risk of motor vehicle crash in patients suspected to have OSA compared to a control group from

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 Supplemental data for this article is available online at [here](https://doi.org/10.1080/15389588.2021.1894639).

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the general driving population and adjusted for age. The authors also concluded that the apnea-hypopnea index failed to identify patients at risk, stating that new tools are needed. It has also been demonstrated that persons treated with continuous positive airway pressure have a risk of driving incidents equivalent to that of healthy individuals (Filtner et al. 2011). A review by Slater and Steier (2012) categorized factors contributing to EDS, highlighting that EDS, independent of OSA, is often caused by obesity, depression, extremes of age, and insufficient sleep. Reasons for depression are various. One reason is burnout, which is highly correlated to increased sleepiness (Söderström et al. 2004). Occupational burnout is another disease characterized by impaired sleep (Ekstedt et al. 2006), and severe stress is a contributing factor. Furthermore, both Parkinson's disease and epilepsy are correlated with excessive sleepiness, although previous research has shown no clear evidence that this is associated with driving impairments due to sleepiness for either Parkinson's (Amick et al. 2007) or epilepsy (Matsuoka et al. 2019). A metastudy by Vaa (2003) showed a relative crash risk of 1.84 for epilepsy and Charlton et al. (2004) concluded that the relative risk was low to moderate (1.1–5.0). However, not all studies report increased crash risk (Volna and Sonka 2006). A metastudy focusing on patients with Parkinson's concluded that further studies are needed to understand how disturbed sleep in patients with Parkinson's relates to cognition capabilities (Pushpanathan et al. 2016), which in turn may influence driving.

In the field of traffic medicine there is a lack of understanding of the relationship between diseases causing sleepiness and crash prevalence. The aim of this study is to achieve a deeper understanding of the relationship between some of the most common diseases known to contribute to EDS and crashes. Specific focus will be on the relationship between disease and crash type (single-vehicle or multiple-vehicle crash) and between disease and injury severity resulting from the crash. Injury crashes are selected because these have greatest impact on public health. The study uses a data set of crash-involved drivers and their prior diagnoses. The priority for this study is the impact of diseases that may lead to EDS, and because many of these diseases are uncommon among young people, drivers under the age of 40 were excluded from this study.

Method

Data were collected from the Swedish national registry of road traffic crashes (Swedish Traffic Accident Data Acquisition, STRADA) and the National Patient Register (NPR). The study population consisted of passenger car drivers who were involved in a crash between 2011 and 2016 and were 40 years of age or older at the time of the crash. All injury crashes were considered regardless of whether the injured person(s) included the driver or not; however, only drivers were included in the analysis. The population therefore consisted of both uninjured drivers and drivers with different injury severities, from minor to fatal. If a driver was involved in several crashes, only the first

crash was included in the analysis. Drivers suspected of driving under the influence of alcohol or drugs in conjunction with the crash were excluded from the analysis.

Data sources

STRADA

Type and time of crash, driver injury severity, age, and sex were retrieved from STRADA. STRADA was established in 2003 and contains linked data from 2 sources, police crash records and data collected at emergency departments. The latter include self-reported data as well as data from medical records. The police reported all crashes known to them through the study period, and the number of reporting emergency hospitals has gradually increased over time, covering all such units in Sweden from 2016 onwards ($n=55$ in 2011 and $n=69$ in 2016). This study used data from both sources, meaning that drivers could be reported by police or by emergency department or both. The emergency departments report injury severity according to the Abbreviated Injury Scale (Gennarelli and Wodzin 2008) and the police use the categories slightly injured, severely injured, or fatal. The police categorization is based on different criteria than the emergency departments use. For example, a person who is suspected to have a concussion or fracture or to be hospitalized is reported as severely injured by the police.

The majority of drivers in the study population (61%) were registered in STRADA by the police only, 19% were registered by emergency departments only, and 21% were registered by both. This distribution is partly explained by the different registration routines. The police register all drivers in a crash, regardless of injury, and emergency departments only register people who visit the emergency department. Most drivers in the study population who were uninjured were only registered by the police.

NPR

For all crash-involved drivers, selected diagnoses registered from 1997 until the day before the crash were extracted from the NPR. NPR covers all in-patient care in Sweden since 1987 and outpatient doctor visits have been included since 2001. Primary health care is not included. For each care event or visit, all relevant diagnoses are listed. The diagnoses are classified according to the *International Classification of Diseases* (ICD-10; World Health Organization 2016). The current version, ICD-10, has been used since 1997; this year was selected as the starting year for this study. The long exposure period increased the chance of inclusion of diagnoses of chronic diseases, such as epilepsy. A shorter period might have missed such a diagnosis if the driver had not received care at a hospital recently.

The databases were linked using the unique personal identity number assigned to all residents in Sweden.

Details of diagnoses extracted from the NPR were selected to match the Swedish Transport Agency's regulations on traffic medicine, which describe the medical requirements for holding a driving license (results from this

previous study are presented in Skyving et al. (2018). Therefore, the data comprise a large number of diagnoses, but only those diagnosed conditions associated with EDS were considered in the current analysis. A consequence of matching the traffic medicine regulations was that only the first 4 characters in the ICD-10 code were included; therefore, it was not possible to separate diagnoses on a more granular level.

Selection of diseases

The drivers in the study population were assigned to 4 different groups, depending on prior diseases. All drivers diagnosed with sleep apnea (SA; G47.3) were included in group 1. Group 2 consisted of drivers with any sleep disorder diagnoses (G47, F51, or R40) or severe stress (F438) not included in group 1. Group 3 consisted of drivers with Parkinson's (G20–G22) or epilepsy (G40–G41) and group 4 is a reference group including drivers with no diagnoses or other diagnoses. Other diagnoses were included because 88% of drivers aged 65 or older had at least 1 diagnosis (Skyving et al. 2018) and excluding them would lead to an unrepresentative reference group. Drivers with a diagnosed substance abuse or dependence (F10–F19 and R78) were excluded from the study.

Statistical analyses

Descriptive statistics present characteristics of the study population with respect to age, sex, and crash data. Type of crash was divided into single-vehicle crash, multiple-vehicle crash, and other. A multiple-vehicle crash was defined as a collision involving at least 2 motor vehicles. Car-to-cyclist and car-to-pedestrian crashes were classified as other.

Two main analyses were conducted using binary logistic regression. The first analysis compared single-vehicle crashes with multiple-vehicle crashes. If a driver has an elevated risk of causing a crash, the risk of having a single-vehicle crash as well as being involved in a multiple-vehicle crash is elevated. However, the risk of a single-vehicle crash is elevated more than the risk of a multiple-vehicle crash. Therefore, the odds of a single-vehicle crash compared to a multiple-vehicle crash was considered an indicator of the risk of causing a crash. Note, however, that the odds ratio (OR) comparing a disease group with a reference group will underestimate the effect of the disease, because the risk of being involved in a multiple-vehicle crash is also elevated. The response variable was set to 1 for a single-vehicle crash and 0 for a multiple-vehicle crash. The explanatory variables were disease group, sex, age class (40–49, 50–59, 60–69, 70–79, and ≥ 80), and time of day (morning: 6:00 a.m.–11:59 a.m.; daytime: 12:00 p.m.–5:59 p.m.; evening: 6:00 p.m.–11:59 p.m.; night: 12:00 a.m.–05:59 a.m.).

The second analysis compared moderately/severely injured drivers with slightly/uninjured drivers. Injury severity were classified by Injury Severity Score (ISS) value based on the Abbreviated Injury Scale values set by the hospitals, if available (ISS 1–3 = slight injury and ISS 4 = moderate/severe

injury). Otherwise, the police classification was used, which is standard procedure in STRADA. Thus, the categorization of injuries is based on 2 sources with partly different criteria, but we believe that the data are still appropriate for the current application. Fatalities were included in the moderately/severely injured category. Separate models were fitted to single-vehicle crashes and multiple-vehicle crashes. Group, sex, age class, and time of day were used as explanatory variables.

In both analyses, all main effects were included in the model and a stepwise method was applied to select 2-way interactions. Summary Tables 2 and 3 show which interactions were selected by the stepwise procedure. No interaction including the variable *group* contributed significantly to the model. Because this was our main variable of interest and to simplify the presentation, reported ORs are based on logistic regression including only main effects. However, ORs with respect to interactions are included in the Appendix (see online supplement).

Statistical analyses were performed using SAS software v9.4 (SAS Institute, Cary, NC, USA). This research was approved by the regional ethical review board of Linköping, Sweden.

Results

In total, 54,090 drivers met the inclusion criteria and were included in the analyses; 2,165 (4.0%) were found to have the diagnose SA, 724 (1.3%) had other types of sleep disorders (excluding SA), and 645 (1.2%) had Parkinson's or epilepsy (excluding SA or other sleep disorders). The remaining 50,556 (93.5%) were included in the reference group.

The proportion of women and men in the groups varied (see Table A1, online supplement). Thirty-nine percent of those in the reference group were women, which was higher than among those with SA (18%) and those with Parkinson's or epilepsy (30%). The reverse was seen for the group with other sleep disorders, in which the majority (53%) were women.

The proportion of drivers in the different age classes also varied between disease groups. Those with sleep disorders excluding SA had a higher proportion of persons aged 40 to 49 compared to the other groups and the proportion of persons with Parkinson's or epilepsy was higher among older age classes.

There was no major difference between the groups of diagnoses regarding crash characteristics, time of day, type of crash, and injury severity (Table 1). Among those slightly or uninjured, 36% to 46% were uninjured, depending on the disease.

Comparing single-vehicle crashes with multiple-vehicle crashes

The regression model used to estimate the probability of a single-vehicle crash compared to a multiple-vehicle crash include significant main effects for disease group, age class, and time of day; see Table 2. No main effect was seen for sex, but interaction effects were found for sex and age and sex and time of day. In addition, there was an interaction effect between age class and time of day.

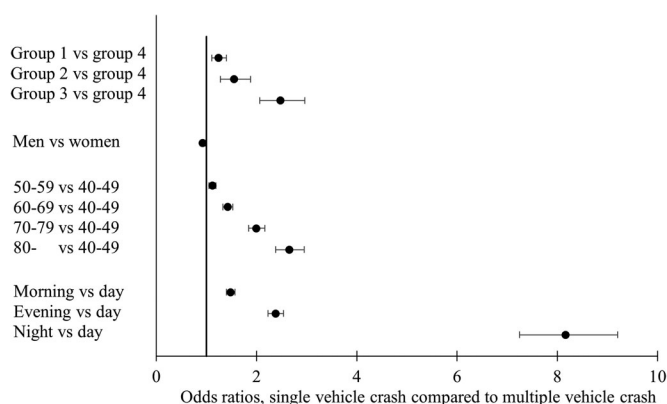
Table 1. Crash characteristics (number and proportion of drivers).

		SA (<i>n</i> = 2,165)	Other sleep disorders (<i>n</i> = 724)	Parkinson or epilepsy (<i>n</i> = 645)	Reference (<i>n</i> = 50,556)
Time of day	Morning	565 (0.27)	200 (0.28)	162 (0.26)	14,077 (0.28)
	Day	1,171 (0.55)	373 (0.53)	359 (0.57)	26,422 (0.53)
	Evening	332 (0.16)	110 (0.16)	101 (0.16)	7,742 (0.16)
	Night	61 (0.03)	24 (0.03)	12 (0.02)	1,518 (0.03)
Type of crash	Collision	1,318 (0.61)	421 (0.58)	329 (0.51)	32,176 (0.64)
	Single	416 (0.19)	163 (0.23)	214 (0.33)	8,151 (0.16)
	Other	431 (0.20)	140 (0.19)	102 (0.16)	10,229 (0.20)
Injury severity	Moderate/severe ^a	182 (0.09)	66 (0.09)	72 (0.11)	3,616 (0.07)
	Slight/uninjured	1,923 (0.91)	635 (0.91)	561 (0.89)	45,560 (0.93)

^aIncluding fatal injuries.**Table 2.** Results of the final logistic regression model for type of crash estimating the probability of a single-vehicle crash compared to a multiple-vehicle crash.

Main effects	df	Chi-square	<i>P</i> value	Two-way interactions	df	Chi-square	<i>P</i> value
Type of disease	3	124.93	<.001	Sex * Age class	4	9.74	.045
Sex	1	0.008	.927	Sex * Time of day	3	55.09	<.001
Age class	4	58.19	<.001	Age class * Time of day	12	116.35	<.001
Time of day	3	382.64	<.001				

Significant values are shown in bold.

**Figure 1.** Odds ratios based on logistic regression including only main effects. An odds ratio greater than one indicates a higher probability for single crashes when comparing one level of a class variable with the reference level. The error bars represent confidence intervals (95% level).

The ORs for the main effects are shown in Figure 1 (ORs with respects to interactions are shown in Figure A1, see online supplement). All disease groups (groups 1–3) had an OR higher than 1 when compared to the reference group, meaning that the probability of a single-vehicle crash was higher for these groups. The largest effect was found for Parkinson's/epilepsy, with an OR of 2.5 (CI, 2.1–3.0). The ORs for the other groups of diagnoses were 1.2 (CI, 1.1–1.4) for SA and 1.6 (CI, 1.3–1.9) for other sleep disorders.

There was only a marginal difference between sexes. Comparing the youngest class (40–49 years old) with the other age classes, an increased probability of single-vehicle crashes was observed with increasing age. The highest odds for single-vehicle crashes in relation to time of day were observed for nighttime (OR = 8.2; CI, 7.2–9.2).

Comparing moderately/severely injured drivers with slightly injured/uninjured drivers

When looking at single-vehicle crashes only, type of disease had no detectable effect on injury severity (Table 3 and Figure 2). A higher odds of moderate/severe injury was

observed for all age classes compared to the reference age group (40–49) when looking at main effects. There was no significant main effect for time of day or sex. There were significant interactions between sex and time of the day and between age and time of day; see Table 3 (ORs with respects to interactions are shown in Figures A2 and A3, see online supplement).

For multiple-vehicle crashes there were significant main effects for disease, with the highest probability of moderate/severe injury for group 2, other sleep disorders (OR = 1.5; CI, 1.0–2.2), and group 3, Parkinson's/epilepsy (OR = 1.6; CI, 1.1–2.3); see Table 3 and Figure 3. There was also a significant effect of age class, with the highest probability of moderate/severe injury those in older age classes, and time of day, with the highest odds at night. A significant interaction between sex and time of the day was also seen (see Figure A4, online supplement, for ORs).

Discussion

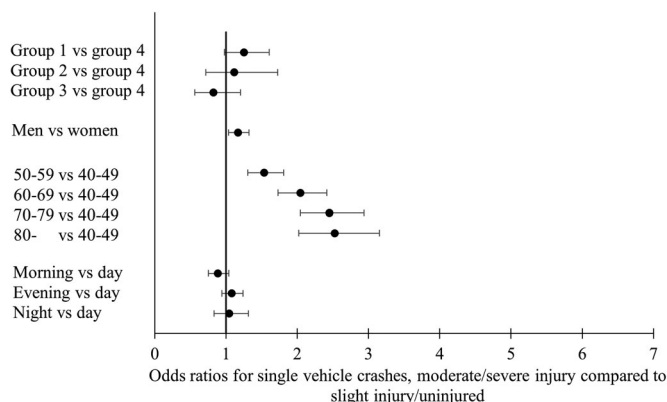
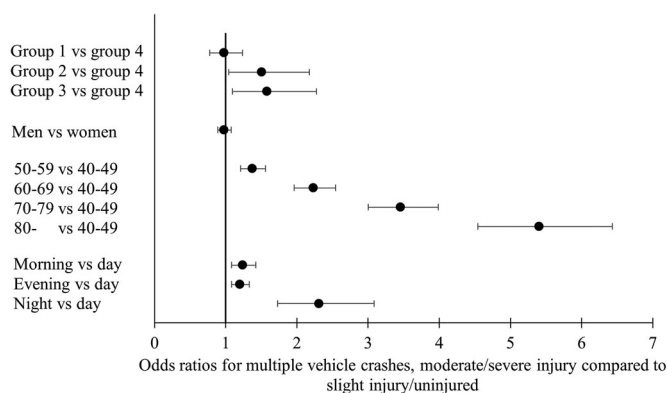
Comparing crash statistics with medical records showed that drivers with EDS-related diseases (SA, sleep disorders, Parkinson's, and epilepsy) have a higher probability of a single-vehicle crash than a multiple-vehicle crash compared to the reference group. The most sizeable effect was for Parkinson's/epilepsy, with an OR of 2.5 (CI, 2.1–3.0). Unfortunately, there are no exposure data, so it is not possible to calculate crash risk. Instead, a single-vehicle crash was seen as indicative of causing a crash and thus having Parkinson's or epilepsy could be interpreted as a risk factor. The ORs for the other groups of diseases were smaller, 1.2 (CI, 1.1–1.4) for SA and 1.6 (CI, 1.3–1.9) for drivers with other sleep disorders. The finding that diseases with a higher risk for sleepiness are a risk factor for road traffic crashes is generally in line with previous research (Vaa 2003; Volna and Sonka 2006), but it is not possible to compare risk levels due to differing methodologies.

When looking at single-vehicle crashes only, type of disease had no detectable effect on injury severity. For multiple-vehicle crashes, on the other hand, the odds of a

Table 3. Results of final logistic regression models for single-vehicle crashes and multiple vehicle crashes estimating the probability of a moderate/severe injury.

	Single-vehicle crash			Multiple-vehicle crash		
	df	Chi-square	P value	df	Chi-square	P value
Type of disease	3	4.16	.245	3	10.95	.012
Sex	1	3.31	.069	1	6.19	.013
Age class	4	101.81	<.001	4	548.03	<.001
Time of day	3	5.32	.150	3	50.18	<.001
Sex * Time of day	3	8.46	.037	3	10.98	.012
Age class * Time of day	12	24.60	.017			

Significant values are shown in bold.

**Figure 2.** Odds ratios based on logistic regression of single crashes including only main effects. An odds ratio greater than one indicates a higher probability for moderate/severe injury when comparing one level of a class variable with the reference level. The error bars represent confidence intervals (95% level).**Figure 3.** Odds ratios based on logistic regression of multiple vehicle crashes including only main effects. An odds ratio greater than one indicates a higher probability for moderate/severe injury when comparing different levels of a class variable. The error bars represent confidence intervals (95% level).

moderate/severe injury was higher for drivers with other sleep disorders (OR = 1.5; CI, 1.0–2.2) and Parkinson's/epilepsy (OR = 1.6; CI, 1.1–2.3) compared to the reference population. This could mean that these crashes are more violent than other crashes. Previous research has shown that high-severity outcomes are more likely in a sleep-related crash than a non-sleep-related crash (Connor et al. 2002; Filtiness et al. 2017). An alternative hypothesis is that the drivers in these groups are more vulnerable than other drivers, but this could not be concluded from this study. Moreover, because the odds ratios are rather small and the effects are only seen in multiple-vehicle crashes, the results should be interpreted with caution.

Additional explanatory variables were included in the models to adjust for other factors that might affect the outcome. Among those, age had an effect in all models. Older drivers had a higher probability of a single-vehicle crash. The reason for this is unknown but might reflect driving patterns; for example, older drivers may choose to drive during hours with less traffic (Hakamies-Blomqvist and Wahlström 1998) and therefore are more seldom involved in multiple-vehicle crashes. Older drivers also had a higher probability of being moderately/severely injured in both single- and multiple-vehicle crashes. This result was expected because older drivers are often more fragile than younger drivers (Meulenens et al. 2006). In addition, time of day had a significant relationship with type of crash and injury severity in multiple-vehicle crashes. Nighttime crashes stand out, with a high probability of a single-vehicle crash and a high probability for moderate/severe injury compared to other time periods. Sex was also included in the models, but the effects were small, if any.

This study has several limitations. First, no data on exposure are available and hence crash risk cannot be calculated. This is a limitation in many similar studies, and better knowledge of driving distances for drivers with different diseases would be an important contribution to this research field. To get an indication of crash risk, we instead calculated the odds of being involved in a single-vehicle crash compared to being involved in a multiple-vehicle crash. If, indeed, EDS contributes to an elevated risk of crash causation, the risk of having a single-vehicle crash increases more than the risk of being involved in a multiple-vehicle crash, because single-vehicle crashes only include 1 driver. However, because the risk of being involved in a multiple-vehicle crash is also elevated, the effect of EDS will be underestimated. An alternative would be to use the quasi-induced exposure method, where not-at-fault drivers in crashes represent the general driving population. This method has been validated by, for example, by Shen et al. (2019). However, STRADA does not include information about at-fault/not-at-fault drivers.

Secondly, we do not know the main cause of the crash and whether sleepiness was a contributing factor or not. In addition, the selected diseases are likely to contribute to EDS, but other diagnosis that could also contribute to EDS may have been missed and consequently included in the reference group. This might have contributed to lower ORs for the disease groups. Thirdly, the diseases we have selected are based on records from 1997 to just before the crash, and we have no information about possible treatments or their effectiveness. There is probably a large individual variation

in the levels of EDS and thus also in crash risk. Finally, the results indicated that diseases with an increased risk of EDS were a risk factor for traffic crashes, but more knowledge is needed to understand whether sleepiness is the main explanation for this or whether there are other causes.

In conclusion, this study has made first steps to understand the relationship between some of the most common diseases known to contribute to EDS and crashes. Diagnosis of SA, sleep disorders, or Parkinson's/epilepsy elevate the risk of single-vehicle crashes. In particular, those with Parkinson's/epilepsy were most likely to have a single-vehicle crash, indicating that this is a risk factor for crash involvement. An elevated risk of high-severity outcome, given that a crash occurred, was found in multiple-vehicle crashes for those with sleep disorders and Parkinson's/epilepsy. This was not identified in single-vehicle crashes. These associations between disorders and crashes suggest that drivers with these disorders are at increased risk. Health care management should take steps to minimize this risk within their treatment plans.

Funding

This work was supported by the project ADAS&ME funded by the European Union's Horizon 2020 research and innovation program under Grant Agreement No. 688900. The data were collected in a previous study with financial support from the Swedish Transport Agency.

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