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Medical impairment and road traffic crashes among older drivers in Sweden – A national, population-based, case-control study

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ABSTRACT

Background: Several medical conditions are known to impair sensory, cognitive and motor functions and are associated with road traffic crashes (RTC). For the drivers of today, we lack updated knowledge on how driving-impairing conditions are associated with RTCs, across all driving-impairing conditions in a given population. We aim to determine this among older drivers in Sweden.
Methods: A national, population register-based, matched case-control study comparing acknowledged driving-impairing health conditions among all older drivers (65 years or older) involved in an injurious RTC in the period 2011–2016 (n = 13,701) with those of controls: older drivers not involved in any RTC (n = 26,525) matched to the cases by age, sex and residential area. The medical conditions, extracted from the National Patient Register from 1997 up until date of RTC, were identified based on ICD-10 diagnosis codes and categorized into the 13 groups of medical conditions listed in the Swedish driver's license regulations. Conditional logistic regression was used to estimate crude and adjusted odds ratios (ORs) with 95% confidence intervals.
Results: Unadjusted ORs for RTC were increased for all conditions. After taking the other 12 medical conditions into account, the ORs remained significant in 11 out of the 13. A strong association was found for the group "ADHD and autism spectrum disorders" (OR 2.79, CI 1.47–5.30), although with very low prevalence among cases (0.2%). Moderate associations were found for three conditions with a case prevalence between 1.3% and 8.5%: epilepsy and seizure disorders (OR 1.53, CI 1.25–1.89), substance abuse and dependence (OR 1.45, CI 1.29–1.63), psychological diseases and mental disorders (OR 1.28, CI 1.18–1.39) and for one condition with a case prevalence of 14.7%, diabetes (OR 1.28, CI 1.20–1.36).
Conclusions: In Sweden, in the current generation of older drivers, acknowledged driving-impairing medical conditions at the national and European levels remain a concern. After adjustment for one another, all but 2 of the conditions are associated with RTCs albeit to varying degrees and more pronounced in the age group 65–79 compared to 80 or older. To promote and sustain older people's mobility, addressing this issue will require a blend of interventions where, hopefully, technological and infrastructural innovations may help counteracting individual health-related shortcomings.

1. Introduction

A number of medical conditions are known to affect driving ability by impairing sensory, cognitive or motor functions. Implementing road safety strategies that allow the identification of medically unfit drivers and then restricting their driving is a challenge that countries face worldwide (SafetyNet, 2009). Studies on the association between driving-impairing medical conditions and their association with road traffic crashes (RTCs) are mostly dealing with one or a few conditions at a time, either focusing on generic groups e.g., cardio-vascular diseases or

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specific diagnoses e.g., hypertension. However, this method does not show the full picture of risks for RTC for all medical impairing conditions in the same cohort of older drivers. Earlier studies can also lack in comparability and generalizability for drivers of today as they study a diversity of population groups and consider different reference periods. This has led to mixed results, varying both within and across conditions. While findings of an excess risk of crash are consistent for conditions like depression (Silverstone, 1988; Hill et al., 2017; Aduen et al., 2018) and sleep apnea (Barbé et al., 1998; Terán-Santos et al., 1999; Mulgrew et al., 2008), this does not apply to all conditions. Results on diabetes, for instance, are mixed and findings range from no association (Lonnen et al., 2008), moderately elevated risk (Skurtveit et al., 2009) to highly increased risk, in particular among older drivers (Kagan et al., 2010). Mixed results are also the case for epilepsy and risk levels varies from no increase (Taylor et al., 1996) to a 37% increase (Sundelin et al., 2018) and to a seven-fold increase (Lings, 2001).

There are a few studies that have addressed multiple conditions simultaneously in a given population for a certain time period. Even if they are all from the North American context, the results in these studies are also mixed due to different methods and study settings. The strongest associations in one study, among drivers in all ages, was found to be coronary heart disease, stroke, diabetic retinopathy and arthritis (McGwin et al., 2000), while another did not find an association for cardiovascular diseases but did so for substance dependence and motor-functional disorders (Vernon et al., 2002). The third, which was the only one adjusting for other conditions and medical treatments, found significant associations for migraines, back problems, arthritis/rheumatism and asthma, while the associations were not significant for cardiovascular disease, diabetes and distress (Vingilis and Wilk, 2012). The study including drivers aged 65 years and older showed a statistically significant association for diabetes only (Koepsell et al., 1994).

Finally, a few literature reviews have investigated specific or all driving-impairing conditions and included drivers of all ages. The ones covering all conditions are conclusive in that most conditions known to affect driving ability were associated with RTC, and that high risks are found for alcohol abuse and dependence, psychological diseases and neurological diseases (Charlton et al., 2010; Vaa, 2003).

Besides from medical conditions affecting abilities vital for driving, age-related changes like lowered cognition, vision and motor-function also impair driving ability (SafetyNet, 2009). Counterintuitively, recent results have shown that in drivers aged 40–69 risks of RTC are increasing with the number of conditions, while this is not the case for drivers aged 70 and older, suggesting that older drivers are more prone to self-regulate their driving (Papa et al., 2014).

From a road safety perspective, rapid development in technology and medical treatments can make studies on older drivers and medical conditions with data collected from the 1960s up until 2000 rather dated. Drivers of today drive safer cars (OECD, 2003), they drive more and the traffic density is generally higher (OECD, 2001; ITF, 2015; IHHS, 2021). Also, medicine is a field undergoing constant evolution and compared to earlier generations older drivers of today have access to better and improved treatments, including the ones that may impair driving ability (Boudoulas et al., 2017).

This national, population-based study aims to present a current picture of how medical conditions which are acknowledged as driving-impairing affect the risk of RTC among the same population of older drivers at national level. And further, we aim to determine the effect of the specific conditions while taking other driving-impairing conditions, crash responsibility and age into account.

2. Materials and method

2.1. Study design and study population

This study was designed as a matched, case-control study using data from four Swedish population-based registries with national coverage. Cases were defined as drivers aged 65 years and older involved in a RTC during the period 2011–2016. The age of 65 was chosen as the lower age limit since it corresponds to the general age of retirement in Sweden. Only RTCs resulting in an injury were considered, but the person(s) injured in the RTC may be someone other than the older driver. The cases therefore consist of both uninjured drivers and drivers with varying injury severity, from minor to fatal. If the cases had been involved in several crashes during the study period (2.1% of the cases) only the first crash was included.

To each case, controls were randomly selected among Swedish residents, not known to have been involved in a RTC as a driver when 65 years or older. This was checked back to 2003, the starting year of the current Swedish national register of RTCs. The controls were individually matched to a case by year of birth, sex and place of residence (municipality) at index date. Index date was set as crash date and was used as reference date (in terms of residency) for choosing the corresponding controls. Diagnoses registered from 1st of January 1997 until the day before the index date was recorded. This starting date was selected since this is when the tenth version of the International Classification of Diseases, ICD (WHO, 2016) was introduced in Swedish healthcare. Before that, ICD-9 codes were used, which are not completely compatible with the 10th version. The reason for the long exposure period was to ensure inclusion of diagnoses of chronic diseases. Diagnoses after index date were not included.

Place of residence was included as a matching criterion due to the geographical differences in driving patterns, e.g., residents in large cities may drive less and be exposed to other traffic situations than drivers in rural municipalities, thus affecting the risk of being involved in a RTC. Furthermore, to minimize controls that never drive, eligible controls should hold a valid driving license (either at the year-end before or after the index date) and own a passenger car at index date according to the Swedish Road Traffic Registry (STA, 2021a). Controls were selected without replacement which means that a control could only be assigned to one case. When possible, two controls were selected to each case. In total, 395 of 14 096 cases were excluded since no matching control could be found. For another 877 cases, only one eligible control existed. This resulted in 13 701 cases and 26 525 controls.

The study was approved by the Ethical Committee of Linköping, Sweden, case number 2017/205–31.

2.2. Data sources

Crash involvement, i.e., cases of RTC, were identified using the Swedish national register of RTCs, STRADA (STA, 2021b). Additionally, information on injury severity and type of crash (single, turning, intersection, head on/overtaking, rear end, pedestrian/bicycle/moped and other) and time of day (morning 04:00–09:59, daytime 10:00–15:59, evening 16:00–21:59 and night 22:00–03:59) was extracted. STRADA was implemented in 2003 and contains data from two sources: police-reported crashes resulting in an injury and persons seeking healthcare due to a RTC reported by emergency care hospitals. Both sources were used in this study. The police register all drivers in a crash, regardless of injuries or not, and the hospitals only register the persons who seek emergency care due to RTC, with and without admission. The majority of the RTC-involved drivers were registered only by the police (66%), while 12% were registered only by the hospitals, and 22% were registered by both sources. The emergency care hospitals report injuries according to the Abbreviated Injury Scale AIS2005, update 2008 (Gennarelli et al., 2008), where the injury severity for each person is automatically calculated by STRADA into the Injury Severity Score (ISS). Injury severities were categorized as follows; slightly (ISS 1–3), moderate (ISS 4–8), severe (ISS 9-) and fatally injured. The police use the categories slightly injured, severely injured, or fatal assessed at the scene of the crash. When a RTC was reported by both sources, hospital injury data was used to define injury severity. When a RTC was reported by police only, slightly injured was categorized as “slightly (ISS 1–3)” and

Table 1
Categories of medical conditions and corresponding ICD10 diagnoses.

Medical Condition Category	ICD10 codes
Vision disorders	B00.5, C69, D31, H00–H59
Hearing and Balance disorders	H60–H95
Motor functional diseases	B91, M00–M99
Cardiovascular diseases	I00–I99, Q20–Q28
Diabetes	E10–E14
Neurological diseases	A81, A841, B00.3, B00.4, C47, C70–C72, D32, D33, D42, D43, G00–G39, G42–G46, G48–G99
Epilepsy and other seizure disorders	G40, G41
Kidney diseases	N17–N19
Dementia and other cognitive disorders	B20–B24, E00–E07, F00–F05, R41, R42, R54
Sleep and alertness disorders	F51, G47, R40, R55
Substance abuse and dependence	F10–F19, R78
Psychological diseases and disorders	F06, F07, F09, F20–F34, F38–F45, F48, F50, F52–F55, F59–F66, F68, F69, R44, R45
ADHD, autism spectrum disorder and similar conditions	F70–F73, F78–F84, F88–F95, F98

severely injured as "moderate (ISS 4–8)". This categorization was based on a comparison of police-reported injury severity and hospital-reported injury severity in crashes where this was available from both sources in the data material.

The Swedish Road Traffic Registry was used to extract validity of driving license as well as car ownership at index date. Sex, year of birth and place of residence were retrieved from the Swedish Population Register (SCB, 2021) which was also used to select controls. Medical conditions were measured based on diagnoses extracted from the National Patient Register (Socialstyrelsen, 2019) covering all admissions and, since 2001, visits to out-patient specialized hospital clinics.

The linkages between the different registries were performed by Statistics Sweden and the authorities responsible for the registers using the unique personal identity number assigned to all residents in Sweden.

2.3. Medical conditions

In line with the EU directive (2006/126/EC) the Swedish Transport Agency stipulates the medical requirements for driving license holders (STA, 2018). The requirements categorize the medical conditions into 13 categories (see Table 1) and physicians are obliged by law to report a license holder when he or she suffers from any driving-impairing conditions covered by the national regulation. Should the condition be assessed by the physician as negligible the law may be applied in a more relaxed manner for private rather than professional drivers. For instance, drivers with mild dementia might be allowed to drive over a certain period of time but re-evaluations are frequent. For the purpose of this study the conditions in question were sought in and matched against ICD10 diagnosis (WHO, 2016; see Table 1) by experts in the field of traffic medicine.

2.4. Statistical analyses

Descriptive statistics were used to present sociodemographic characteristics and chi-square tests were conducted to compare proportions between cases and controls with respect to the variable number of medical conditions. Conditional logistic regression models were fitted to estimate crude and adjusted odds ratios with 95 percent confidence intervals. The adjusted models included 13 binary explanatory variables, one for each medical condition (value = 1 if diagnosis existed and 0 otherwise) simultaneously, to take into account the difference between cases and controls with regard to suffering multiple conditions. An additional analysis was made for single vehicle crashes only, as a proxy for the older driver being responsible for the crash, increasing the chances of capturing the effects of the conditions in the driver. Further, analyses were conducted to evaluate the robustness of the results with regard to the choice of reference period for exposure. This was done by stratifying on diagnoses within two years before the index date and diagnoses set more than two years before the index date). Finally, a stratified analysis was made on age group (drivers 65–79 years of age and 80 or older) to determine the effect of different medical conditions on RTC by age. Separate logistic regression models were fitted to each strata. Then z-tests were performed on the difference of the beta-coefficients from the logistic regression, for each pair of odds ratios. This test corresponds to testing the ratio of the odds ratios per strata. Bonferroni correction was used to adjust for multiple testing. Due to the small number of exposed cases and controls with the medical condition ADHD, autism spectrum disorder and similar conditions, the effect estimates will be reported only for the main analyses. Statistical analyses were performed using SAS software version V.9.4 (SAS Institute, North Carolina, USA).

Table 2
Characteristics (%) of the study population, stratified by cases and controls.

Characteristics	Categories	Cases (n = 13,701) %	Controls (n = 26,525) %	p-value
Sex	Men	70.7	72.6	–*
	Women	29.3	27.4	
Age	65–69	32.5	32.9	–*
	70–74	26.8	26.8	
	75–79	19.5	19.4	
	80–84	13.2	13.1	
	85–	8.0	7.8	
Number of medical conditions	0	12.3	15.4	<0.001
	1	20.7	23.7	
	2	22.0	23.7	
	3 or more	45.0	37.2	

*P-value not relevant since variables were used for matching.

Table 3
Characteristics (%) of the road traffic crashes (n = 13,701).

RTC Characteristics	Categories	n	%
Injury severity	Uninjured	5958	43.5
	Minor (ISS1-3)	5591	40.8
	Moderate (ISS4-8)	1011	7.4
	Severe (ISS9-)	361	2.6
	Fatal	279	2.0
	Unknown	501	3.6
Crash type	Single	3004	21.9
	Turning	1013	7.4
	Intersection	2336	17.0
	Head on/overtaking	1296	9.5
	Rear-end	2754	20.1
	Pedestrian/bicycle/moped	2429	17.7
	Other	869	6.3
Time of day	Morning (04.00–09.59)	1507	11
	Daytime (10.00–15.59)	7536	55
	Evening (16.00–21.59)	4247	31
	Night (22.00–03.59)	411	3

3. Results

Seven out of ten cases were men, and the largest age category was those between 65 and 69 years old (32.5%) (Table 2). Three or more medical conditions was more common among the cases than controls (45% vs 37.2%).

In 2% of the cases the outcome for the older driver was fatal and in 2.6% the outcome was severe (Table 3). The most common types of RTCs were single crash (21.9%) and rear-end (20.1%). More than half of the RTCs occurred during daytime between 10 am to 4 pm (55%).

The analysis showed statistically significant crude odds ratios for

Table 4
Prevalence of medical conditions, crude and adjusted odds ratios (OR) (with 95% confidence interval (95% CI)) for RTC by medical conditions.

Medical conditions	Cases (n = 13 701) n	Cases %	Controls (n = 26 525) n	Controls %	Crude OR* (95% CI)	Adjusted OR** (95% CI)
Cardiovascular diseases	7 607	55.5	13 712	51.7	1.18 (1.13–1.23)	1.05 (1.00–1.10) ***
Motor-functional diseases	6 734	49.2	11 805	44.5	1.20 (1.15–1.25)	1.13 (1.08–1.18)
Vision disorders	6 304	46.0	11 305	42.6	1.14 (1.09–1.19)	1.08 (1.03–1.13)
Hearing and balance disorders	2 664	19.4	4 650	17.5	1.14 (1.07–1.20)	1.08 (1.02–1.14)
Neurological diseases	2 377	17.4	3 941	14.9	1.20 (1.14–1.27)	1.09 (1.03–1.15)
Diabetes	2 011	14.7	2 987	11.3	1.38 (1.30–1.47)	1.28 (1.20–1.36)
Dementia and other cognitive disorders	1 908	13.9	3 275	12.4	1.13 (1.07–1.21)	1.00 (0.94–1.07)
Sleep disorders	1 407	10.3	2 215	8.4	1.27 (1.18–1.36)	1.15 (1.06–1.23)
Psychological diseases and mental disorders	1 166	8.5	1 589	6.0	1.45 (1.34–1.57)	1.28 (1.18–1.39)
Substance abuse and dependence	570	4.2	694	2.6	1.65 (1.47–1.85)	1.45 (1.29–1.63)
Kidney diseases	445	3.3	678	2.6	1.29 (1.14–2.13)	1.12 (0.98–1.26)
Epilepsy and seizure disorders	176	1.3	201	0.8	1.73 (1.41–2.13)	1.53 (1.25–1.89)
ADHD, autism spectrum disorder and similar conditions	26	0.2	17	<0.1	3.41 (1.81–6.43)	2.79 (1.47–5.30)

* Adjusted for age, sex and residential area through matching.
** Adjusted for matching factors and the other medical conditions.
*** Lower limit of confidence interval for adjusted ORs is 1.00 due to rounding.

Table 5
Adjusted odds ratios (with 95% confidence interval) for RTC by medical conditions, restricted to single vehicle crashes and stratified on age-group.

Medical conditions**	RTC type* Single vehicle crash n = 3004	Age-group* 65–79 years n = 10,797	80 or older n = 2904
Cardiovascular diseases	1.20 (1.09–1.33)	1.04 (0.99–1.10)	1.04 (0.94–1.16)
Motor-functional diseases	1.20 (1.10–1.32)	1.14 (1.09–1.20)	1.08 (0.99–1.19)
Vision disorders	1.02 (0.93–1.12)	1.08 (1.03–1.13)	1.08 (0.98–1.19)
Hearing and balance disorders	0.95 (0.84–1.07)	1.08 (1.01–1.15)	1.10 (0.98–1.23)
Neurological diseases	1.00 (0.89–1.14)	1.11 (1.04–1.19)	1.02 (0.90–1.15)
Diabetes	1.53 (1.34–1.74)	1.33 (1.23–1.43)	1.10 (0.96–1.25)
Dementia and other cognitive disorders	1.02 (0.89–1.17)	1.05 (0.98–1.14)	0.88 (0.78–0.99)
Sleep disorders	1.33 (1.14–1.56)	1.15 (1.06–1.25)	1.12 (0.96–1.31)
Psychological diseases and mental disorders	1.68 (1.42–2.00)	1.36 (1.25–1.49)	0.93 (0.76–1.14)
Substance abuse and dependence	2.20 (1.74–2.79)	1.43 (1.27–1.62)	1.36 (0.95–1.95)
Kidney diseases	1.26 (0.97–1.62)	1.22 (1.04–1.43)	0.99 (0.81–1.21)
Epilepsy and seizure disorders	2.54 (1.73–3.72)	1.65 (1.30–2.09)	1.23 (0.79–1.91)

* Adjusted for age, sex and residential area through matching and the other studied medical conditions.
** ADHD, autism spectrum disorder and similar conditions are not included due to small numbers.

RTC in all studied medical conditions (ORs ranging from 1.14 to 3.71) (Table 4). When adjusting for the other medical conditions there was a statistically significant association in 11 out of 13 medical conditions (ORs ranging from 1.05 to 2.79). The strongest associations were found for the groups ADHD, autism spectrum disorder and similar conditions (OR 2.79), epilepsy and seizure disorders (OR 1.53), substance abuse and dependence (OR 1.45), diabetes, and psychological diseases and mental disorders (OR 1.28).

The medical conditions with highest prevalence (above 40%) among both cases and controls showed adjusted odds ratios only slightly higher than 1 (1.05, 1.13 and 1.08 respectively). Among other relatively common medical conditions (with a prevalence between 10 and 20% in both study groups) consisting of hearing and balance disorders, neurological diseases, diabetes and dementia and other cognitive disorders, diabetes had the highest OR; 1.28 (CI 1.20–1.36). The only two conditions showing no statistically significant association were kidney diseases (OR 1.12) and dementia and other cognitive disorders (OR 1.00). Cardiovascular diseases showed a borderline effect (OR 1.05) and while also only slightly higher ORs than 1, associations for hearing and balance, and neurological diseases were still significant (1.08 and 1.09 respectively).

When restricting the analyses to single vehicle crashes, a proxy for crash responsibility, the effects remained with statistically significant increased ORs for 7 of the conditions; cardiovascular, motor-functional, diabetes, sleep, psychological disease and mental disorders, substance abuse and dependence, and epilepsy and seizure disorders (Table 5). Analyses stratified by age group showed generally stronger associations for conditions in the younger age group (Table 5, 65–79-year-old drivers). Amongst those drivers, statistically significant increased ORs were found for motor-functional, vision, hearing and balance, neurological, diabetes, sleep, substance abuse and dependence, kidney, and epilepsy and seizure disorders. Increased odds ratios were also found among the 80 years or older drivers however, with wider confidence intervals. In this age-group, only dementia and other cognitive disorders showed a statistically significant association, with a 12 % protective effect.

Further, an analysis was performed to test the robustness of the choice of reference period for exposure, i.e., time since diagnoses. This stratified analysis on whether odds ratios for each condition significantly differs between diagnosis within two years of RTC compared to more than two years before RTC showed that the odds ratios for all but one condition did not differ significantly. Neurological disease diagnosed within two years of RTC showed statistically significant different odds ratios compared to diagnosis more than two years before RTC. (Supplementary material Appendix 1, Table A1).

4. Discussion

4.1. Main findings

This national study is one of few addressing, in the same population and study period, all known driving-impairing medical conditions and their association with RTC involvement among older drivers. It also encompasses the most recent cohort of 65+ year old drivers. For each of the 13 conditions considered, all of which are listed in the Swedish driving license requirement, effects have been estimated taking into consideration the 12 others. This provides a comprehensive picture of the driving-impairing medical conditions and their associations with RTCs across all conditions. It shows that for all but two conditions, kidney diseases, and the group consisting of dementia and other cognitive impairments, there is an association with RTC with ORs ranging between 1.05 and 2.79. Apart from ADHD, autism spectrum disorder and similar conditions, a group of diagnoses very uncommon in the population where an almost threefold odds of RTC were found, four conditions stand out with stronger associations. Three are relatively uncommon in the older driver population under study: epilepsy and seizure disorders, substance abuse and dependence, psychological diseases and mental disorders, and one is relatively common: diabetes.

When comparing the results of this study to the results of other studies with similar research questions, the methodology often differs, something that needs to be taken into consideration. Previous studies on several conditions, like ours, have also been set up as case-control studies but they vary in terms of methods for data collection, study population, setting and performed analysis. There are also small differences in the categorization and diagnosis inclusion of medical conditions but overall, they are comparable. Although, the medical conditions investigated in this study are known as conditions with increased risk of RTC, most of the condition categories include several specific diagnoses. Due to this, the results may hide a variation in effects for a single diagnosis. For instance, the condition category cardiovascular diseases includes both diagnoses leading to acute incapacitation, like myocardial infarction, and also chronic conditions like hypertension. Different mechanisms, treatment and recovery of functions affect driving ability and hence the risk of RTC. The ORs presented in this study is a mean value of the associations for all the diagnoses in each medical condition category. The low but significant associations observed for cardiovascular disease, motor-functional diseases, vision disorders, and hearing and balance disorders are not fully in line with previous studies which generally did not find such associations. This can be a result of different categorization and inclusion of diagnoses. Our inclusion of many diagnoses in these condition categories might dilute the effect of a specific or a smaller group of diagnoses that other studies have chosen to analyze specifically. The biggest contrasts to our results are for the excess risks observed for arthritis/rheumatism (Vingilis and Wilk, 2012), and visual acuity (Vernon et al., 2002). However, these are subgroups of motor-functional diseases and vision disorders respectively and as mentioned, analysis on subgroups specifically might result in both stronger and weaker associations than our broader groups of medical conditions.

The high OR found for ADHD, autism spectrum disorder and similar conditions, are in line with previous studies on young adult drivers (Louzã, 2017, Curry et al., 2017) and adult drivers (Bron et al., 2018). It is of note that, in this recent cohort of older, Swedish adults, such conditions are very uncommon compared to younger adults, suggesting likely underdiagnosis. Hence, the results should be interpreted with caution. Epilepsy and seizure disorders, albeit uncommon in the adult population in general (Fiest et al., 2017), showed one of the strongest associations with RTC in this study, similar to the results of Vernon et al. (2002) when studying drivers of all ages. Results similar to ours were also shown by a large and recent cohort study focused on epilepsy, including drivers of all ages (Sundelin et al., 2018). Data was not available to investigate whether the drug treatment of epilepsy is partially accountable for the effect observed, but previous studies have not shown reduced risks of RTC with the use of antiepileptic drugs (Orriols et al., 2013; Sundelin et al., 2018).

The association found for substance abuse and dependence, has also been observed in a range of previous studies (Del Rio et al., 2001; Vernon et al., 2002; Vaa, 2003). Our study is however not able to show whether the effect is through the acute substance intoxication, a carry-over or a more long-term accumulated effect. This information is also lacking in previous research but has recently been studied specifically for alcohol abuse disorders in drivers of all ages (Yao et al., 2018). After taking into account current blood alcohol levels at the time of the crash, drivers with alcohol abuse disorders were not more likely than their controls to be involved in a RTC, suggesting that earlier associations between alcohol abuse disorders and RTC could be overestimated (Yao et al., 2018).

The third strongest associations were found for diabetes, and psychological diseases and mental disorders. In the case of diabetes, as indicated earlier, the evidence to date is mixed for drivers of all ages, but our results confirm earlier research on older drivers specifically (Kagan et al., 2010).

Contrary to previous research (Vaa 2003; Charlton et al. 2010), our results did not show elevated risk of RTC for drivers with dementia compared to those without. For the older age-group (80 or older) there was a protective effect, contrary to the effect among the other conditions. This might be explained by similarly reduced driver exposure for both cases and controls with dementia – the older people get the more they reduce their driving, and particularly so after a dementia diagnosis. This is supported by previous literature, showing that drivers with dementia had an increased risk of RTC three years prior to diagnosis and a decreased risk of RTC after they had been diagnosed (Meuleners et al., 2016). When it comes to the other conditions with non-statistically significant effects in the oldest age-group, the results could partially be explained by lower statistical power, with 21% of the RTC-involved drivers in that age-group. In the younger age group, the effects of the conditions on RTC were similar to the results in the main analysis, showing statistically increased ORs for all but two conditions which showed no association: cardiovascular disease and dementia and other cognitive disorder.

5. Strengths and limitations

Unlike most previous studies, we were able to adjust for other driving-impairing conditions. On the other hand, our study lacks information on driving exposure, although matching on age, sex and residential area can be argued to at least partly achieve similar driver exposure in cases and controls (Vernon et al., 2002). However, an increasing time at risk in traffic has been found to decrease the crash rate per driven kilometres (Langford et al., 2006). To deal with possible differences in driver exposure we further chose to include only controls who had a valid driver's license and owned a car in order to increase the probability of them also being active drivers. Despite this, the study design does not adjust for difference in exposure between drivers with and without diagnosis, and therefore we cannot say to what degree differences in ORs depend on difference in crash risk or can partially be explained by difference in exposure.

Our study is based on register data with national coverage. This advantage minimizes the risk of misclassification and increase our statistical power. However, it lacks information on diagnoses set in healthcare facilities outside hospital and specialized hospital clinics which makes the results generalizable to conditions diagnosed and treated there. The conditions included in this study are likely to be more severe where conditions are more commonly diagnosed and treated in other healthcare facilities like primary health care. Since information on the severity of the diseases was not available this could potentially lead to a misclassification, albeit non-differential, among cases and controls. Even if this underestimation probably does not affect the results obtained, it might lead to an underestimation of the problem's magnitude in the older driver population if the diagnoses missed are as severe as the ones included when it comes to impairment.

Another variable that we were not able to include in our analyses was drug treatment, which could either enhance driving ability or decrease it, i.e., either weaken or strengthen the association to RTC. There are also possible drug-drug interactions we were not able to account for, and drug mechanisms and interactions need to be studied further.

Table A1
Adjusted odds ratios (with 95% confidence interval) for RTC by medical conditions, divided by time since diagnosis.

Medical conditions**	Time of diagnosis*	
	Within two years of RTC n = 13 701***	More than two years before RTC n = 13 701***
Cardiovascular diseases	1.07 (1.02–1.12)	0.98 (0.93–1.03)
Motor-functional diseases	1.15 (1.09–1.22)	1.06 (1.01–1.11)
Vision disorders	1.07 (1.02–1.13)	1.06 (1.00–1.11)
Hearing and balance disorders	1.06 (0.97–1.17)	1.10 (1.03–1.17)
Neurological diseases	0.93 (0.84–1.02)	1.23 (1.15–1.31)
Diabetes	1.28 (1.18–1.39)	1.22 (1.11–1.35)
Dementia and other cognitive disorders	0.97 (0.88–1.07)	1.06 (0.99–1.15)
Sleep disorders	1.10 (0.97–1.25)	1.20 (1.11–1.31)
Psychological diseases and mental disorders	1.35 (1.19–1.54)	1.27 (1.15–1.41)
Substance abuse and dependence	1.69 (1.40–2.05)	1.38 (1.20–1.59)
Kidney diseases	1.13 (0.97–1.25)	1.13 (0.90–1.42)
Epilepsy and seizure disorders	1.42 (1.06–1.91)	1.71 (1.28–2.30)

* Adjusted for age, sex and residential area through matching and the other studied medical conditions.
** ADHD, autism spectrum disorder and similar conditions are not included due to small numbers.
*** These are not distinct groups. Which group you belong to differs between different medical conditions.

6. Conclusion

This national study shows that, in contemporary Sweden, nearly all driving-impairing medical conditions acknowledged as such at national level and in Europe remain a concern. After adjustment for one another, all but two (dementia and other cognitive disorders, and kidney diseases) of those 13 conditions are associated with RTCs, albeit to varying degrees and more pronounced so in the younger age group. Further, more controlled studies may help quantify with greater precision the level of risk associated with those conditions in older drivers of today. Meanwhile, the promotion of older people's mobility, in particular those with driving impairing conditions, will require a blend of interventions with the potential to counteract individual health-related shortcomings.

CRediT authorship contribution statement

Marie Skyving: Conceptualization, Methodology, Writing – original draft, Project administration, Funding acquisition. **Åsa Forsman:** Methodology, Formal analysis, Data curation, Validation, Writing – original draft, Writing – review & editing. **Tania Dukic Willstrand:** Writing – original draft, Writing – review & editing. **Lucie Laflamme:** Validation, Writing – review & editing, Visualization. **Jette Möller:** Validation, Writing – review & editing, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1

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