Motor vehicle crashes and dementia: a population-based study

Lynn B Meuleners PhD[1,2], Jonathon Ng PhD[2,3], Kyle Chow PhD[1], Mark Stevenson PhD[4]

[1] Curtin-Monash Accident Research Centre (C-MARC), Curtin University, GPO Box U1987, Perth, Western Australia 6845.

[2] Eye & Vision Epidemiology Research Group (EVER), Perth, Western Australia.

[3] Centre for Health Services Research, School Of Population Health, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009.

[4] Melbourne School of Population and Global Health/ Melbourne School of Design, The University of Melbourne, Melbourne, Victoria 3010

Corresponding Author:

Professor Lynn Meuleners

Tel: +61 8 9266 4636

Fax: +61 8 9266 2608

Email: L.Meuleners@curtin.edu.au

Funding Source: Alzheimer's Australia

Abbreviated title: Dementia and crashes

ABSTRACT

OBJECTIVES: To examine the frequency of motor vehicle crashes for drivers aged 50+ in the three years prior to and three years after an index hospital admission with a diagnosis of dementia, compared to a group without dementia using the Western Australian Data Linkage System (WADLS).

DESIGN: Retrospective population-based study.

SETTING: De-identified data was obtained from Western Australian Hospital Morbidity Data System (HMDS) and the Western Australian Death Registrations using the WADLS from 2004 to 2010. The Integrated Road Information System (IRIS) was used to identify individuals involved in a crash as the driver from 2001 to 2013.

PARTICIPANTS: There were 1,666 (34%) individuals with an index hospital admission for dementia and 3,636 (66%) individuals without dementia who had been involved in at least one motor vehicle crash as the driver from 2001 to 2013.

MEASUREMENTS: Involvement in a police-reported crash as the driver.

RESULTS: The occurrence of one or more crashes as the driver in the dementia group (43%) was higher in the three years before an index hospital admission with dementia than that observed for the comparison group (30%). The risk of a crash significantly reduced by 93% for those with dementia compared to a group without dementia in the three years after an index hospital admission with dementia (Incidence Rate Ratio (IRR) =0.07, 95% Confidence Interval (CI) =0.06 – 0.09) compared to the previous three years, after adjusting for relevant confounders.

CONCLUSION: While older drivers may give up driving following a diagnosis of dementia, they may be at increased risk of crashing before diagnosis or in the early stages of dementia. Better methods are needed to identify 'at risk' drivers with early dementia and prevent crashes.

Key words: dementia, motor vehicle crashes, data linkage

INTRODUCTION

Demographic changes in the Australian population are leading to an increase in the number of older drivers.[1] For people over 65 years, driving is the most common form of transport and is strongly associated with older peoples' independence and social inclusion. In contrast, driving cessation has been linked to poorer health, depression,[2, 3] loneliness, reduced mobility[4] and a higher risk of institutionalisation.[5] The ability to safely operate a motor vehicle may be affected by a wide range of medical conditions, with dementia recognised amongst those carrying an elevated risk of crash.[6-8] In the absence of effective prevention, the number of Australians with dementia is predicted to triple by 2050[9] and hence, the likelihood of older Australians driving with dementia will also increase.

Dementia refers to permanent changes in the normal brain activity that affect memory, speech and the ability to undertake daily tasks.[10] Many forms of dementia are characterised by a gradual, steady decline in cognition, memory, language, problem solving, judgment, and decision making[10] Behavioural changes are also common, including anxiety, emotional instability, aggression, wandering and disinhibition.[11] Driving is a complex task and certain cognitive abilities that are essential for driving such as memory, visual perception, attention and judgment may be affected by dementia.[12, 13] In the early stages of dementia, the risks associated with driving may go unnoticed as the symptoms appear sporadically. This is due, in part, to the estimated average three year lag that exists between the presence of symptoms of dementia and formal diagnosis.[14]

After a diagnosis with dementia, an individual may still be able to drive for a period of 24 months,[14] and in some cases until the most severe stages of the disease.[15] The results of two longitudinal studies comprising 134 drivers with dementia concluded that 69% of drivers with

mild dementia and 88% of drivers with very mild dementia could pass on-road driving assessments.[16] Drivers with dementia were also found to commit more driving safety errors such as lane violations or off-road events than cognitively intact drivers.[11, 17] Previous research also found that the cause of dementia, the presence of co-morbidities, medication use and importantly, disease severity, impacted on the driving ability of people with dementia.[7] As dementia progresses beyond the early stages it can have a serious impact on memory, reactions, perception and the ability to perform even simple tasks with an individual eventually losing the ability to drive. The stage at which this happens will be different for each person but, according to previous research, most people stop driving within two to three years after the first signs of the disease and in some cases not until the most severe stages of the disease.[14, 15]

To date, research has not consistently demonstrated a higher crash rate among drivers diagnosed with dementia.[17, 18] While some studies reported no significant differences in crash risk between the dementia and control groups,[19, 20] others found that drivers with dementia had 2 to 10.7 times greater risk of crashes compared to cognitively intact older adults[6, 21, 22] and this risk increased with disease progression.[23] The inconsistencies reported in crash risk however, are likely due to the different study methodologies, small sample sizes and selection bias.[24]
There is limited research, at the population- level, that has examined a driver's crash risk in the early years of dementia. While some drivers will recognise their declining ability and adjust their driving accordingly, others may not and continue to drive. While all dementia patients will eventually become incapable of driving, it is not known when they present a definably increased risk of being involved in a crash, and if so, the relative magnitude of the risk and at what point in the course of the disease the risk may become significantly increased. The aim of this population based study therefore, is to determine the frequency of motor vehicle crashes

for older drivers in the three years prior and three years after an index hospital admission with a diagnosis of dementia compared to a group without dementia.

METHODS

Study Design

A retrospective population-based cohort study was undertaken to examine the frequency of motor vehicle crashes among older drivers aged 50+ in the three years prior and three years after an index hospital admission with a diagnosis of dementia, compared to a group without dementia.

Data Sources

De-identified data was obtained through the WADLS following approvals from the Western Australian Department of Health and the Curtin University Human Research Ethics Committee. The WADLS is a validated, population-based, data linkage system that creates links among state health-related data sets.[25] It is one of only seven such record linkage systems in the world and allows retrospective studies to be conducted many years after exposure and eliminates the burden on respondents and reliance on self-reports. Using the WADLS also overcomes limitations due to small sample size, loss to follow-up and accurate ascertainment of exposures and outcome measures.[25]

The largest component of the WADLS is the Hospital Morbidity Data System (HMDS) which contains records for all individuals who were admitted to public or private hospitals in WA from 1960 onwards. This HMDS was used to identify those with a hospital admission for dementia from 2004 to 2010. The Western Australian Death Registrations was used to identify participants who died between 2004 and 2010. By law all WA deaths are recorded in the Western Australian Death Registrations. The Integrated Road Information System (IRIS) which is maintained by Main Roads Western Australia (WA), was used to identify those involved in a crash from 2001 to 2013 (that is the three year exposure period before and three

year exposure period after the index hospital admission for those with and without dementia). The IRIS database contains crash details including the circumstances and Police reported injury on all motor vehicle crashes (including location and type of crash) in WA. The definition of a crash used in this study is "*any apparently unpremeditated collision reported to the police which resulted from the movement of at least one road vehicle on a road open to and used by the public and involving death or injury to any person, or property damages*".[26]

Participants

Cases

International Classification for Diseases (ICD-10-AM) codes[27] were used to identify cases. Cases were aged 50+, residents of Western Australia, had "dementia" listed as a principal diagnosis or co-morbid condition in any hospital record in the HMDS between 2004 and 2010 and was their first or '*index*' record for dementia as designated by the following diagnosis codes: Alzheimer's dementia G30; vascular dementia F01; fronto-temporal dementia G31.0; Creutzfeldt-Jakob disease A81.0; dementia in Huntington's disease F02.2; dementia in Parkinson's disease F02.3; and non-specific dementia F02.8, F03, F05.1, G31.1, G31.8, G31.9. Those with drug, alcohol or HIV-related dementia in the absence of a specific dementia diagnosis were excluded. A previous study using chart review of HMDS data found that while specificity was good for identifying dementia, sensitivity was low in the WADLS.[28] Because of the low diagnostic accuracy of specific dementia sub-diagnoses in the HMDS the decision was made to include all cases of dementia.

Comparison group

The external comparison group consisted of a random sample of Western Australians aged 50+ years obtained from the State Electoral roll. It is mandatory for all citizens in WA over 18 years

to be enrolled to vote. Persons with dementia are also required to have their names removed from the electoral roll by a relative provided there is written evidence from a medical practitioner.[29] To ensure further misclassification of exposure did not occur, each participant's hospital records were searched from 1970 onwards to identify those with a previous hospital record for dementia and were excluded from the analysis. After ensuring each comparison participant did not have a diagnosis of dementia in their hospital records, their hospital admission was matched as closely as possible to the date of the case's first recorded hospital admission with dementia so that a similar length of exposure history was available.

Socio-demographic data was obtained from the HMDS for all study participants which included age, gender, marital status, comorbidities and residential location. Residential location was defined as metropolitan, rural or remote based on the index hospital record. Marital status was classified as having a partner (married or de facto) or not. Pre-existing comorbidity was classified as having one or more of the following 17 conditions described by Holman et al. recorded during any hospital admission in the five year period prior to the index admission for both groups.[25] Comorbidities due to myocardial infarction, diabetes, congestive heart failure, peripheral vascular disease, cerebrovascular disease, chronic pulmonary disease, rheumatic disease, peptic ulcer disease, hemi- or paraplegia, renal disease, tumors, lymphoma, leukemia, liver disease, acquired immuno-deficiency syndrome and metastatic solid tumor were included in the pre-existing comorbidity index. Dementia was excluded as it was the condition under study. An un-weighted co-morbidity score was assigned to each patient as the cumulative number of different co-morbid conditions identified. The presence or absence of a co-morbid medical condition was used in the analysis.

Statistical Analysis

Descriptive statistics were used to summarise the characteristics of the two cohorts. Baseline characteristics of the cohort were compared using chi-square tests. The outcome measure was involvement in a police-reported crash as the driver. The analysis compared the frequency of crashes for case (an index hospital admission with dementia) and comparison participants (random sample of population with an index hospital admission not related to dementia but similar temporally) using a generalised estimating equation (GEE) Poisson regression model. The use of GEE Poisson regression is appropriate to accommodate the inherent correlation of the longitudinal data where observations within each participant are not independent.[30] GEEs permit specification of a certain working correlation matrix that accounts for this within-subject correlation, thus providing more robust regression coefficients.[30] The data for each patient was censored at either the date of death recorded in the WA Death Registrations or the end of the study period, 31st December 2013. The multivariate model was adjusted for the relevant confounders namely, age, gender, marital status, residential location, and presence/absence of a pre-existing comorbid medical condition. An interaction term was included in the model to examine the number of crashes before and after an index hospital admission for those with dementia and without dementia. Data analysis was undertaken using STATA (version 12) and results were considered significant at the p=0.05 level.

RESULTS

There were 1,666 (34%) individuals with an index hospital admission for dementia and 3,636 (66%) individuals without dementia who had been involved in at least one motor vehicle crash as the driver from 2001 to 2013. Among the cohort with dementia at the index hospital admission, a large proportion were male (67.8%), aged 80+ years (63.0%), married (50.7%), lived in the metropolitan area (75.1%) and had at least one medical comorbidity (67.7%) recorded over the previous five years. A large proportion of the group without dementia at the index hospital admission were male (62.2%), aged between 70-79 years (45.2%), married (62.4%), lived in the metropolitan area (74.8%) and had at least one medical comorbidity (70.8%) recorded over the previous five years (Table 1).

In the three years before the index hospital admission, 43.2% (n=720) of 1,666 participants with dementia were involved in at least one crash as the driver. There were a total of 801 crashes among participants with dementia in the three years before index hospital admission with 56.8% (n=946) having no crashes, 38.8% (n=647) having one crash, 3.9% (n=65) having two crashes and 0.5% (n=8) having three crashes (Table 2). Among the group without dementia, 30.1% (n=1095) of 3636 participants were involved in at least one crash as the driver in the three years before the index hospital admission. There were a total of 1166 crashes among the comparison group in the three years before index hospital admission with 69.9% (n=2,541) having no crashes, 28.3% (n=1,030) having one crash, 1.6% (n=59) having two crashes and 0.2% (n=6) having three crashes (Table 2). In the three years before the index hospital admission, the unadjusted crash risk for the dementia group was almost double (OR= 1.77, 95% CI =1.57 – 1.99) that of the group without dementia.

In the three years after the index hospital admission, 4.0% (n=66) of the participants with dementia were involved in at least one crash as the driver. There were a total of 70 crashes after index hospital admission with dementia, with 96.0% having no crashes (n=1600), 3.7% (n=62) having one crash and 0.2% (n=4) having two crashes (Table 3). Among the comparison group, 33.2% (n=1207) were involved in at least one crash in the three years after index hospital admission. There were a total of 1305 crashes among the comparison group after index hospital admission with 66.8% (n=2429) having no crashes, 30.7% (n=1,115) having one crash, 2.4% (n=86) having two crashes and 0.2% (n=6) having three crashes (Table 3). The unadjusted risk for a crash in the three years after an index hospital admission for the dementia group was reduced by 92% (OR=0.08, 95% CI =0.06 – 0.11) compared to the comparison group without dementia.

The majority of crashes for both the group with and without dementia occurred at intersections and involved more than one vehicle (hit another motor vehicle, bicyclist or motorcyclist) (Table 4).

Table 5 presents the results of the GEE Poisson regression analysis modelling the risk of a crash in the three years prior to and after an index hospital admission for those with and without dementia. The interaction term showed that the risk of a crash significantly reduced by 93% for those with dementia compared to a group without dementia in the three years after an index hospital admission (Incidence Rate Ratio (IRR) =0.07, 95% Confidence Interval (CI) =0.06 – 0.09) compared to the previous three years, after adjusting for relevant confounders (Table 5). The risk of a crash increased by 9% (IRR=1.09, 95% CI=1.02 – 1.18) for those with at least one reported comorbid medical condition, compared to those without a comorbid medical

condition. Being female decreased the risk of involvement in a motor vehicle crash by 11% (IRR=0.89, 95% CI=0.83 – 0.95) compared to males.

DISCUSSION

The increasing numbers of people being diagnosed with dementia in the community and the importance of maintaining driver safety for this group, particularly in the early stages of dementia, is a significant public health issue. The results of this population-based study found a significant 93% decrease in crash risk in the three years after an index hospital admission for dementia compared to the three years before, after adjusting for relevant person level confounders which included age, gender, residential location, marital status and the presence of comorbidities. This is consistent with previous research that has found that the frequency of crashes declined among drivers with dementia over time, while crashes increased in the comparison group.[31, 32] The lower crash rate after an index hospital admission for the dementia group may reflect that the hospital admission was a pivotal event leading to driving cessation, either because it resulted in another medical problem which warranted driving cessation, or brought the severity of the dementia to attention. It is possible that the cohort with a diagnosis of dementia may have reduced their driving exposure or were monitored more carefully by family members. It is well documented that older drivers and particularly those with dementia, are less likely to venture into unknown situations or risky driving situations such as freeways and night time driving.[33]

However, the results of the unadjusted analysis did find a higher crash risk of almost double among older drivers in the three years before an index hospital admission with dementia, compared to those without dementia. It is possible that the dementia group may have been in the early stages of their disease or were just formally diagnosed. It is well known that there may be a lag of at least three years between the onset of dementia symptoms and diagnosis and that those with dementia may continue to drive for several years after diagnosis.[14] It is also well known that a majority of older drivers with dementia may resist giving up their licence

even when advised to the contrary,[32, 34, 35] chiefly because driving provides a sense of independence and quality of life.[36, 37] These findings suggest that older adults with dementia or their families may not recognise their symptoms or the developing problem particularly in the early stages of the disease, putting them at risk on the road. Previous research has described early changes associated with the disease such as forgetting where the car was parked, with progression to more significant deficits including disorientation in familiar environments, gaps in attention and difficulty with multiple stimuli[38] which may lead to minor incidents (misjudging parking space, striking stationary objects) and/or crashes (misjudging gaps for turning or overtaking, or failing to respond to traffic signals).[39]

Of particular interest in this study is that 4% of the group with dementia had more than one crash before a hospital admission which was significantly higher than the comparison group (1.7%) and they continued to drive after the first crash event. This is consistent with previous research which found that 80% of those with dementia who were involved in a crash continued to drive afterwards, with almost 40% having at least one more crash.[40] A systematic review also identifed a history of previous crashes as indicative of individuals with dementia who are at an increased risk for unsafe driving and a subsequent crash.[41] Currently, there is a lack of agreement among licensing authorities and medical practitioners on determining the level of impairment that identifies when a driver is no longer fit to drive due to the marked variability in the degree of disability and rate of progression among those with dementia. Many clinicians are also reluctant to make decisions about driving because of concerns that this interferes with the doctor-patient relationship. However the current evidence shows that in general, older adults with dementia who continue to drive have a 2-10 times increased risk of a crash, many of which result in injury or death.[7, 39, 42]

Females reported a significantly decreased risk for involvement in a crash as the driver. This is consistent with previous research which found that women cease driving more readily than men and of those women who continued to drive, they did not have a higher crash risk than men.[43] The lower risk may also be due to differences in driving exposure between men and women. It is well documented that men, irrespective of their age, are more often the primary driver in the family and will cover more kilometres during the course of the year,[33, 43] as they continue to drive as long as possible to maintain family mobility.

The study found no significant association between age and crash risk despite the group with dementia being older than the comparison group and adjustments for increasing age, which is known to compromise driving due to age-related performance deficits.[44] The risk of a crash also increased by 9% in older adults with a comorbid medical condition. It is well known that the presence of chronic medical conditions such as heart disease, hypertension, stroke and diabetes may impact on crash risk for older drivers.[45]

The majority of crashes occurred at intersections for those with and without dementia and is consistent with previous research on the difficulties that older drivers, including those with dementia have negotiating intersections, particularly when changing lanes or approaching traffic signals.[44, 46]

There are several strengths of the study. The WADLS has the advantage of reduced selection bias, detecting small differences by inclusion of a large number of cases, as well as the use of high-quality, objective Police and administrative health data.[25] The random selection of controls from the electoral roll which included a long-look back period was designed to reduce selection bias and misclassification. One of the main limitations of the study is that dementia

may not be the primary diagnosis for an admission to hospital but was recorded as a co-morbid condition.[47] A previous chart review of the HMDC found that while specificity was good for identifying dementia, sensitivity was low.[28] Although the number of participants with dementia was possibly underestimated in our study, this underestimation would in fact result in our estimates being less than the true results. We were also unable to determine the exact onset of dementia and it is possible that a person may have had dementia for some time prior to the index hospital admission. The available administrative health data also did not capture lifestyle factors, the severity of dementia, medication usage or driving exposure – all of which may influence the risk of a crash. However, while we were not able to determine the severity of dementia, there is substantial evidence that severe dementia is incompatible with driving[14] and it is doubtful whether anyone in the database who had severe dementia would still be driving. In this study, comorbid medical conditions were based on hospital records in the past five years, which represented the more serious forms of chronic conditions. It is possible that a participant's medical history before five years prior to the index hospital admission could in some cases, have lasting effects on cognition and driving. However previous research examining lookback periods for co-morbid conditions found that 5 years was the most appropriate lookback period given that the effects of different comorbid conditions may vary depending on the conditions, their recency and duration.[48] The study also did not examine the number of hospital admissions in the three-year period after the index admission, which might indicate additional issues or poorer health that might impede driving and cause driving cessation. Additionally, we were not able to determine who was responsible for the crash as this information is not collected in the IRIS database.

In conclusion, older drivers with dementia are faced with two options – either they continue to drive with an unacceptable crash risk as the disease progresses or they cease driving. However,

the same disease-related impairments that affect driving ability in individuals with dementia also limit their ability to access other transport options (e.g., use of public transport, use of mobility devices), especially for those individuals living in transport deprived rural and regional areas.[49, 50] It is essential that continued collaboration between health professionals, clinicians, driver licensing bodies and government authorities is required to assist and enable people with dementia to make the transition from driver to non-driver with ease and minimal intrusion on their lives. The results of this study suggest that while older drivers may give up driving following a diagnosis of dementia, they may be at increased risk of crashing for a period before diagnosis or in the early stages of dementia. This highlights that better methods are needed to identify 'at risk' drivers including examining previous history of crashes and providing education for the families of older drivers directed at helping them recognise driving difficulties before they become serious enough to cause crashes.

ACKNOWLEDGMENTS

Funding Source: Alzheimer's Australia

Conflict of Interest Checklist

Elements of Financial/Personal Conflicts	**LM**		**JN**		**KC**		**MS**	
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Employment or Affiliation		X		X		X		X
Grants/Funds		X		X		X		X
Honoraria		X		X		X		X
Speaker Forum		X		X		X		X
Consultant		X		X		X		X
Stocks		X		X		X		X
Royalties		X		X		X		X
Expert Testimony		X		X		X		X

Board Member		X		X		X		X
Patents		X		X		X		X
Personal Relationship		X		X		X		X

For all "Yes" responses, provide a brief explanation here:

_____

_____

Author Contributions: LM: Study design, conduct of the project, analysis, and drafting of the manuscript. JN: Study design, interpretation of results, manuscript preparation. KC: statistical analysis and interpretation of data. MS: Study design and manuscript revision. All authors approved the final version. LM is the guarantor.

Sponsor's Role: No role.

REFERENCES

1. Martin AJ, Marottoli R, O'Neill D. Driving assessment for maintaining mobility and safety in drivers with dementia. Cochrane Database Syst Rev 2011;21.
2. Marottoli RA, de Leon CFM, Glass TA et al. Consequences of driving cessation: decreased out-of-home activity levels. J Gerontol B Psychol Sci Soc Sci 2000;55: 334-340.
3. Ragland DR, Satariano WA, MacLeod KE. Driving cessation and increased depressive symptoms. J Gerontol A Biol Sci Med Sci 2005;60: 399-403.
4. Taylor BD, Tripodes S. The effects of driving cessation on the elderly with dementia and their caregivers. Accid Anal Prev 2001;33: 519-528.
5. Freeman EE, Gange SJ, Munoz B et al. Driving status and risk of entry into long-term care in older adults. Am J Public Health 2006;96: 1254-1259.
6. Marshall SC. The role of reduced fitness to drive due to medical impairments in explaining crashes involving older drivers. Traffic Inj Prev 2008;9: 291-298.
7. Charlton J, Koppel S, O'Hare M et al. Influence of chronic illness on crash involvement of motor vehicle drivers: 2nd edition. Melbourne, Australia: Monash University Accident Research Centre 2010.
8. Vaa T. Impairments, diseases, age and their relative risks of accident involvement: Results from meta-analysis. Norway: The Institute of Transport Economics, 2003.
9. Alzheimer's Disease International. World Alzheimer's Report London, UK: Alzheimer's Disease International, 2009.
10. What is Dementia? 2015. Dementia Care Australia (online). Available at: *http://www.dementiacareaustralia.com/index.php?option=com_content&task=view&id=335&Itemid=69*. Accessed July 11, 2015.

11. Frittelli C, Borghetti D, Iudice G et al. Effects of Alzheimer's disease and mild cognitive impairment on driving ability: a controlled clinical study by simulated driving test. Int J Geriatr Psychiatry 2009;24: 232-238.
12. Lloyd S, Cormack CN, Blais K et al. Driving and dementia: A review of the literature. Can J Occup Ther 2001;68: 149-156.
13. Wagner JT, Muri RM, Nef T et al. Cognition and driving in older persons. Swiss Med Wkly 2011;141.
14. Gilley DW, Wilson RS, Bennett DA et al. Cessation of driving and unsafe motor vehicle operation by dementia patients. Arch Intern Med 1991;151: 941-946.
15. Fox GK, Bowden SC, Bashford GM et al. Alzheimer's disease and driving: Prediction and assessment of driving performance. J Am Geriatr Soc 1997;40: 949-953.
16. Ott B, Daiello LA. How does dementia affect driving in older patients? Aging Health 2010;6: 77.
17. Man-Son-Hing M, Marshall SC, Molnar FJ et al. Systematic review of driving risk and the efficacy of compensatory strategies in persons with dementia. J Am Geriatr Soc 2007;55: 878.
18. Hakamies-Blomqvist L. Older drivers' accident risk: conceptual and methodological issues. Accid Anal Prev 1998;30: 293-297.
19. Carr DB, Duchek J, Morris JC. Characteristics of motor vehicle crashes of drivers with dementia of the Alzheimer type. J Am Geriatr Soc 2000;48: 18-22.
20. Trobe JD, Waller PF, Cook-Flannagan CA et al. Crashes and violations among drivers with Alzheimer disease. Arch Neurol 1996;53: 411-416.
21. Friedland RP, Koss E, Kumar A et al. Motor vehicle crashes in dementia of the Alzheimer type. Ann Neurol 1988;24: 782-786.

22. Tuokko H, Tallman K, Beattie BL et al. An examination of driving records in a dementia clinic. J Gerontol B Psychol Sci Soc Sci 1995;50: S173-181.
23. Drachman DA, Swearer JM. Driving and Alzheimer's disease: the risk of crashes. Neurology 1993;43: 2448-2456.
24. Meuleners L, Duke J, Lee AH et al. Psychoactive medications and crash involvement requiring hospitalization for older drivers: a population-based study. J Am Geriatr Soc 2011;59: 1575-1580.
25. Holman CD, Bass AJ, Rouse IL et al. Population-based linkage of health records in Western Australia: development of a health services research linked database. Aust N Z J Public Health 1999;23: 453-459.
26. Legge M, Williams HA, Cercarelli LR. Reported Road Crashes in Western Australia 2003. Perth, WA: Road Safety Council of Western Australia, 2006.
27. World Health Organization. International Classification of Diseases and Related Health Problems, Tenth Revision. Geneva: WHO, 1992.
28. Preen DB, Holman CD, Lawrence DM et al. Hospital chart review provided more accurate comorbidity information than data from a general practitioner survey or an administrative database. J Clin Epidemiol 2004;57: 1295-1304.
29. Zilkens RR, Bruce DG, Duke J et al. Severe psychiatric disorders in mid-life and risk of dementia in late-life (age 65-84 years): a population based case-control study. Curr Alzheimer Res 2014;11: 681-693.
30. Twisk JW. Applied longitudinal data analysis for epidemiology: a practical guide. Cambridge: Cambridge University Press, 2003.
31. Dubinsky RM, Stein AC, Lyons K. Practice parameter: risk of driving and Alzheimer's disease (an evidence-based review): report of the quality standards subcommittee of the American Academy of Neurology. Neurology 2000;54: 2205-2211.

32. Ott BR, Heindel WC, Papandonatos GD et al. A longitudinal study of drivers with Alzheimer disease. Neurology 2008;70: 1171-1178.
33. Zuin D, Ortiz H, Boromei D et al. Motor vehicle crashes and abnormal driving behaviours in patients with dementia in Mendoza, Argentina. Eur J Neurol 2002;9: 29-34.
34. Foley DJ, Masaki KH, Ross GW et al. Driving cessation in older men with incident dementia. J Am Geriatr Soc 2000;48: 928-930.
35. Herrmann N, Rapoport MJ, Sambrook R et al. Predictors of driving cessation in mild-to-moderate dementia. Can Med Assoc J 2006;175: 591-595.
36. Byszewski AM, Molnar FJ, Aminzadeh F. The impact of disclosure of unfitness to drive in persons with newly diagnosed dementia: patient and caregiver perspectives. Clin Gerontol 2010;33: 152-163.
37. Johnson DA, Frank O, Pond D et al. Older people with mild cognitive impairment: their views about assessing driving safety. Aust Fam Physician 2013;42: 317.
38. Bradshaw C, Di Stefano M, Catchpole J. Driving and Dementia. Melbourne, Australia: Royal Automobile Club of Victoria (RACV), 2013, pp. 46.
39. Lovell R, Di Stefano M, Unsworth C. Driver Education & Rehabilitation Course Manual for Occupational Therapists. VIC, Australia: La Trobe University, 2009.
40. Cooper PJ, Tallman K, Tuokko H et al. Vehicle crash involvement and cognitive deficits of older drivers. J Safety Res 1993;24: 9-17.
41. Iverson DJ, Gronseth GS, Reger MA et al. Practice parameter update: evaluation and management of driving risk in dementia: report of the Quality Standards Subcommittee of the American Academy of Neurology. Neurology 2010;74: 1316-1324.
42. Oxley J, Charlton J. Attitudes to and mobility impacts of driving cessation: differences between current and former drivers. Top Geriatr Rehabil 2009;25: 43-54.

43. Lafont S, Laumon B, Helmer C et al. Driving cessation and self-reported car crashes in older drivers: the impact of cognitive impairment and dementia in a population-based study. J Geriatr Psychiatry Neurol 2008;21: 171-182.
44. O'Neill D, Neubauer K, Boyle M et al. Dementia and driving. J R Soc Med 1992;85: 199-202.
45. Owsley C, Ball K, McGwin et al. VIsual processing impairment and risk of motor vehicle crash among older adults. JAMA 1998;279: 1083-1088.
46. Viitanen M, Johansson K, Bogdanovic N et al. Alzheimer changes are common in aged drivers killed in single car crashes and at intersections. Forensic Sci Int 1998;96: 115-127.
47. Zilkens RR, Spilsbury K, Bruce DG et al. Clinical epidemiology and in-patient hospital use in the last year of life (1990-2005) of 29,884 Western Australians with dementia. J Alzheimers Dis 2009;17: 399-407.
48. Preen DB, Holman CD, Spilsbury K et al. Length of comorbidity lookback period affected regression model performance of administrative health data. J Clin Epidemiol 2006;59: 940-946.
49. Organsiation for Economic Co-operation and Development. Ageing and Transport. Mobility needs and safety issues. Paris, France: OECD, 2001.
50. Peel N, Steinberg M, Westmoreland J. Transport safety for older drivers: A study of their experiences, perceptions and management needs. *Proceedings of the Road Safety, Research, Policing and Education Conference*. Brisbane, Australia, 2000, pp. 223-228.

GRAPHICS

Table 1 Demographic Characteristics of the Cohort

Variables	Dementia (n=1666)		No Dementia (n=3636)		p-value[c]	Total (n=5302)	
	N	%	N	%		N	%
Gender							
Female	536	(32.2)	1373	(37.8)	<0.001	1909	(36.0)
Male	1130	(67.8)	2263	(62.2)		3393	(64.0)
Age (years)							
60-69	107	(6.4)	415	(11.4)	<0.001	522	(9.8)
70-79	510	(30.6)	1644	(45.2)		2154	(40.6)
≥80	1049	(63.0)	1577	(43.4)		2626	(49.5)
Marital status[a]							
Married	827	(50.7)	2221	(62.4)	<0.001	3048	(58.8)
Not married[b]	804	(49.3)	1336	(37.6)		2140	(41.3)
Co-morbid condition							
No	538	(32.3)	1063	(29.2)	0.02	1601	(30.2)
Yes	1128	(67.7)	2573	(70.8)		3701	(69.8)
Location[a]							
Metropolitan	1251	(75.1)	2718	(74.8)	0.81	3969	(74.9)
Rural	311	(18.7)	674	(18.6)		985	(18.6)
Remote	103	(6.2)	242	(6.7)		345	(6.5)

[a]Missing information [b]Single/widow/divorced [c]chi-square test

Table 2: Distribution of Motor Vehicle Crashes for Cohort With and Without Dementia in the Three Years before Index Hospital Admission

Number of Motor vehicle crashes	Dementia		Without Dementia	
	N	(%)	N	(%)
0	946	(56.8)	2,541	(69.9)
1	647	(38.8)	1,030	(28.3)
2	65	(3.9)	59	(1.6)
3	8	(0.5)	6	(0.2)

Table 3: Distribution of Motor Vehicle Crashes for Cohort With and Without Dementia in the Three Years after an Index Hospital Admission

Number of Motor vehicle crashes	Dementia		Without Dementia	
	N	(%)	N	(%)
0	1600	(96.0)	2,429	(66.8)
1	62	(3.7)	1,115	(30.7)
2	4	(0.2)	86	(2.4)
3	0	(0.0)	6	(0.2)

Table 4 Characteristics of Crashes Involving Those With and Without Dementia Before and After Hospital Admission

Crash characteristics	Dementia (n=871 crashes) N (%)	Without Dementia (n=2471 crashes) N (%)
Location of crash		
Intersection	550 (63.2)	1496 (60.5)
Mid-block	321 (36.9)	975 (39.5)
Type of crash[a]		
Multi-vehicle	711 (81.6)	2066 (83.6)
Single vehicle	93 (10.7)	405 (16.4)

[a] *Missing information*

Table 5 Risk of a Motor Vehicle Crash in the Three Years Prior and Three Years After an Index Hospital Admission for Dementia Compared to those Without Dementia

Variable	IRR[a]	95% confidence interval	p-value
Group			
Without dementia	1.00		
With dementia	1.41	1.28 – 1.55	0.001[b]
Period			
Before	1.00		
After	0.98	0.89 – 1.07	0.61
Co-morbid condition			
No	1.00		
Yes	1.09	1.02 – 1.18	0.01[b]
Gender			
Male	1.00		
Female	0.89	0.83 – 0.95	0.002[b]
Age (in years)	1.01	0.99 – 1.01	0.15
Marital status			
Married	1.00		
Single/widow/divorced	1.04	0.97 – 1.12	0.26
Location			
Metropolitan	1.00		
Rural	0.99	0.91 – 1.08	0.82
Remote	0.88	0.77 – 1.01	0.08

Period* group				
	Before without dementia	1.00		
	After with dementia	0.07	0.06 – 0.09	<0.001[b]

[a] *Incidence rate ratio* [b] *significant at p<0.05*