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# Diagnosed dementia and the risk of motor vehicle crash among older drivers

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ABSTRACT

Older adults are an active and growing segment of drivers in the United States. We compared the risk of motor vehicle crash among older licensed drivers diagnosed with dementia to crash risk among older licensed drivers without diagnosis of dementia. This retrospective cohort study used data from Group Health (GH), a Washington State health maintenance organization. Research participants were members of GH, aged 65–79 during the study who lived in Washington State from 1999–2009. Participant health records were linked with police-reported crash and licensure records. We estimated the risk of crash for older drivers diagnosed with dementia compared to older drivers without diagnosis of dementia using a Cox proportional hazards model with robust standard errors, accounting for recurrent events (crashes). Multivariable models were adjusted for age, sex, history of alcohol abuse or depression, comorbidities, and medications. There were 29,730 eligible individuals with an active driving license. Approximately 6% were diagnosed with dementia before or during the study. The police-reported crash rate was 14.7 per 1000 driver-years. The adjusted hazard ratio of crash among older drivers with diagnosed dementia was 0.56 (95% CI 0.33, 0.95) compared to those without diagnosed dementia. On-road and simulator-based research showed older adults with dementia demonstrated impaired driving skill and capabilities. The observed lower crash risk in our study may result from protective steps to limit driving among older adults diagnosed with dementia. Future research should examine driving risk reduction strategies at the time of dementia diagnosis and their impact on reducing crash risk.

## 1. Introduction

In 2015, 18% of all licensed drivers in the United States (US) were aged 65 and above (NHTSA, 2015).There are health benefits of driving for older adults; and when driving is restricted, older adults are at greater risk of depression, social isolation, and entry into a long-term care facility (Martin et al., 2011; Breen et al., 2007; Freeman et al., 2006). The annual passenger vehicle fatal crash involvement rate per vehicle miles traveled among drivers aged 65 and above is high, second only to drivers aged 16–29.5 Sustaining a motor vehicle crash may be devastating or fatal for frail older adults and places other road users at risk (Alvarez and Fierro, 2008; Li et al., 2003).

One contributor to high crash rates per mile travelled may be cognitive decline or dementia (Martin et al., 2011; Breen et al., 2007; Horswill et al., 2008; Withaar et al., 2000; Anstey et al., 2005). Dementia is an umbrella term for a group of diseases and conditions wherein nerve cells in the brain die or no longer function normally (Alzheimer's Association, 2012). Cognitive function is a continuum with varying severity of symptoms and underlying pathologies. Individuals' cognitive states range from normal aging to prodromal dementia to diagnosed mild dementia to severe dementia (Alzheimer's Association, 2012; Snellgrove, 2005; Dickerson et al., 2007). One of nine adults over aged 65 has Alzheimer's disease, the most common type of dementia, with prevalence increasing with age. The number of

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individuals with dementia is projected to rise as the US population ages (Alzheimer's Association, 2013).

Simulator, lab, and road-based research has found that people with dementia have impaired driving skills, including impairments of hazard perception, processing of visual cues, attention, and decision-making (Martin et al., 2011; Breen et al., 2007; Horswill et al., 2008; Withaar et al., 2000; Anstey et al., 2005; Ott et al., 2008). Older drivers with cognitive decline may become lost, may struggle to negotiate intersections, and may stray from designated lanes and customary routes (Withaar et al., 2000; Dawson et al., 2009; Wagner et al., 2011; Carr and Ott, 2010; Rizzo et al., 2001; Owsley et al., 1991; Carr et al., 2000; Barco et al., 2015).

Cognitive impairment has been previously found to be associated with higher crash risk, although the strength and significance of the association differed between studies (Martin et al., 2011; Breen et al., 2007; Withaar et al., 2000; Anstey et al., 2005; Carr and Ott, 2010; Rizzo et al., 2001; Carr et al., 2000; Ball et al., 2006; Carr, 1997; Lincoln et al., 2006; Jones Ross et al., 2015; Duchek et al., 2003; Joseph et al., 2014; Marino et al., 2012). Prior research on dementia and crash risk has been limited by the method of crash ascertainment, brief follow-up time, use of driving simulators (Rizzo et al., 2001; Marino et al., 2012; Fitten et al., 1995), small sample sizes (Martin et al., 2011; Breen et al., 2007; Withaar et al., 2000; Anstey et al., 2005; Ott et al., 2008; Dawson et al., 2009; Wagner et al., 2011; Carr et al., 2000; Duchek et al., 2003; Molnar et al., 2006) and/or measures of cognition with limited clinical relevance (Ott et al., 2008; Duchek et al., 2003; Joseph et al., 2014). Driving tests (Anstey et al., 2005; Snellgrove, 2005; Dawson et al., 2009; Lincoln et al., 2006; Duchek et al., 2003; Marino et al., 2012; Fitten et al., 1995; Charlton et al., 2010; Martin et al., 2013), subject perceived driving ability (Breen et al., 2007; Charlton et al., 2010; Rapoport et al., 2016), recalled crash (Breen et al., 2007; Anstey et al., 2005; Joseph et al., 2014; Charlton et al., 2010; Martin et al., 2013), and simulated driving studies (Rizzo et al., 2001; Marino et al., 2012; Charlton et al., 2010; Martin et al., 2013; Anderson et al., 2004) may be situationally specific, may be non-replicable, and/or may not translate to real world crash risk (Charlton et al., 2010).The few naturalistic longitudinal studies reported an equivalent or lower crash risk associated with cognitive impairment defined using a variety of measures compared to the risk associated with no impairment (Ott et al., 2008; Carr et al., 2000; Joseph et al., 2014; Dow et al., 2013; Meuleners et al., 2016). However, these studies suffered from small sample sizes and/or short follow-up time. Investigators and policy-makers have stressed the need for longitudinal cohort studies with large sample sizes and reliable dementia and crash information (Wagner et al., 2011; Molnar et al., 2006).

State Departments of Motor Vehicles, the National Highway Traffic Safety Administration (NHTSA), medical and neurological associations, and technical and non-technical articles generally support limiting and eventual cessation of driving for individuals with dementia (Carr and Ott, 2010; AGS/NHTSA, 2016; Dickerson, 2014; Tung et al., 2013; Hartford, 2010; AAN, 2017). Older adults can limit driving, e.g. by taking shorter trips or driving only during the day. Studies on self-reported driving habits show that older drivers with dementia implement the above guidance around limiting or cessation of driving (Carr et al., 2000; Duchek et al., 2003; Seiler et al., 2012; Edwards et al., 2008; Lyman et al., 2001; Ka and McCartt, 2008; Stutts, 1998).Two small studies found that, compared with individuals with a Clinical Dementia Rating (CDR) of 0 (normal cognition), self-reported mileage was 15%–42% lower among those with a CDR of 0.5 (cognitively impaired but not demented), and 46% to 64% lower among those with a CDR of 1 (mild dementia) (Ott et al., 2008; Carr et al., 2000). A study of 18 people with dementia and age-matched cognitively normal elderly controls found 45% lower self-reported weekly mileage among people with dementia (Festa et al., 2013). However, self-reported mileage among older adults is often inaccurate (O'Connor et al., 2013), and these inaccuracies may be particularly pronounced in those with dementia

This study aimed to compare the risk of motor vehicle crash among older drivers with diagnosed dementia to the risk of crash among older drivers without dementia using data on cognition and crash routinely generated and collected from administrative sources.

## 2. Materials and Methods

This was a retrospective cohort study examining crash risk for licensed individuals 65–79 years of age with a diagnosis of dementia, compared to crash risk for those without a diagnosis of dementia.

### 2.1. Participants

Study participants were Washington state residents, 65–79 years of age between January 1, 2003 and December 31, 2009, and enrolled at Group Health (GH), a large Washington State consumer-governed health maintenance organization (Ehlenbach and Hough, 2010; Hansen et al., 2015) (now part of Kaiser Permanente), for at least one year between January 1, 2003 and December 31, 2009. GH covers approximately 600,000 enrollees in Washington State and Idaho, who broadly resemble Washington State residents with respect to age, sex, and race (Hansen et al., 2015). Washington State uses a combination of letters from drivers' names and numbers derived from their birth years to generate driver license numbers. We used Group Health member names and birth years to derive driver license numbers, as we have done previously (Hansen et al., 2015; Gallian, 1991; Hansen et al., 2017). We merged GH electronic health records with licensure data from the State Department of Licensing and police-reported crash data from the State Department of Transportation. Participants were restricted to those with an active Washington State driving license, including those with commercial or motorcycle license.

### 2.2. Data

#### 2.2.1. Diagnosis of dementia

Dementia status was classified using diagnosis codes and prescription records from the electronic health record. The date of diagnosis was assigned as the earlier of (1) the earliest dementia-related International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis code recorded in a medical claim or (2) the earliest prescription for an anti-dementia medication [donepezil (Aricept®) or memantine (Namenda®)]. GH has a prescription drug formulary that does not permit use of these medications to treat mild cognitive impairment. ICD-9-CM diagnosis codes indicating Alzheimer's disease and similar dementias were 294.1, 294.10, 294.11, 294.8, 331, 331.0, 331.1, 331.11, 331.19, 331.2, 331.7, 331.82, 331.89, 331.9, and 294 (Appendix A). Senile dementia and vascular dementia (ICD-9-CM codes 290.0-290.9) were not included in the case definition as codes for these diagnoses were not made available to the study team for analyses. Individuals could be diagnosed with dementia during or before the study.

Exposure and outcome ascertainment began in January 2003, with medical record and prescription data from 1999–2002 serving as a pre-study period during which diagnosis information was gathered. We divided individuals into three groups: (1) patients with no diagnosis of dementia within four years prior to the study and during the study period (1999–2009); (2) patients diagnosed with dementia within the 4-year period prior to the study (1999–2002), (3) patients diagnosed with dementia during the study period (2003–2009).

#### 2.2.2. Crashes

The outcome was any motor vehicle crash (including passenger vehicles, motorcycles, and commercial vehicles) on a non-private road within Washington State reported by or to police or Washington State Patrol (Hansen et al., 2015).Within Washington State, if a law

enforcement officer does not attend, investigate, and/or report a crash at the scene, participants must report crashes involving any injury and/or more than $1000 in property damage, including vehicle damage (Washington State Legistature, 1996; WSP, 2017).

#### 2.2.3. Covariates

Additional covariates in the analytic dataset were age and calendar year at study entry, sex, comorbidities, diagnosis of depression, alcohol use disorders recorded in the electronic medical record, and certain classes of medications associated with crash risk. For each participant, the Charlson comorbidity index was calculated at study entry with a lookback period of one year. The index accounted for chronic comorbidities including myocardial infarction, chronic pulmonary disease, diabetes, and AIDS (Charlson et al., 1987). Although the Charlson comorbidity index adjusts for dementia, there is no overlap between the ICD-9-CM codes identifying dementia within the index (senile and vascular dementias, 290.0–290.9) and the codes available in this data set. Depression and alcohol consumption have been shown to increase crash risk, including among older drivers (Sims et al., 2000). We used ICD-9-CM codes as proxy measures to identify diagnoses of alcohol-related illness (codes 303–303.96) (Rehm et al., 2003; Kilbourne et al., 2012) and depression (codes 296–296.9, and 300–300.94) (Egede et al., 2016).We did not have data on marital status, visual measures, or retirement.

We controlled for potential confounding from four medication classes associated with higher crash risk: sedatives, benzodiazepines, opioids, and antipsychotics (AGS/NHTSA, 2016; Gibson et al., 2009). Individuals were considered exposed to each medication class if two or more prescriptions were filled within any four-month period. Among participants diagnosed with dementia during the study, this exposure to medication was assessed separately for the time periods before and after dementia diagnosis.

### 2.3. Data analysis

We estimated the risk of crash as a hazard ratio (HR) and 95% confidence interval (CI) using a Cox proportional hazards model where the exposure of interest was dementia diagnosis. We used the Anderson-Gill approach to account for recurrent crashes (Andersen and Gill, 1982; Kelly and Lim, 2006). We incorporated time-varying exposure status (dementia diagnosis) and robust standard errors. We censored subjects at death, disenrollment in GH, study end, loss of or failure to renew driver license, or at age 80. The age limitation was a requirement from the Institutional Review Board (IRB) due to privacy concerns. We tested the proportional hazards assumption using Schoenfeld residual-based plots and tests; the assumption was satisfied for all models.

### 2.4. Sensitivity analyses

We conducted three additional analyses to check the robustness of our exposure measurement. All three used Cox proportional hazards models adjusted for the same covariates as the primary model.

First, we theorized that individuals in non-urban areas may have greater need to drive due to diminished availability of resources within walking distance (e.g. grocery stores and health care facilities) (Inagami et al., 2015; Todd et al., 2013) and decreased availability and thus use of public transit (Fan et al., 2015). We performed stratified analyses based on Rural-Urban Commuting Area (RUCA) codes, which measure the degree of rurality for U.S. census tracts based on measures including urbanization, population density, population size, and proportion of the population commuting to a more urban area (Inagami et al., 2015). These measures have been cross-walked to ZIP codes. We analyzed individuals residing in a metropolitan core areas (RUCA score of 1) separately from those living in a ZIP code with a RUCA score between 2 and 10 (i.e. metropolitan area with high commuting, micropolitan areas, small towns, and rural areas) (USDA, 2016).

Second, we examined crash risk among older drivers with incident dementia to minimize variation related to disease severity. For this analysis, we used an inception study design (Bernard et al., 2013).The inception study design may also reduce the risk of miscategorization of the cognitive state by excluding the pre-diagnosis time period when cognitive impairment may have been present. We compared the rate of crash for group 1 (no dementia diagnosis) to the rate of crash in the post-diagnosis period for group 3 (drivers diagnosed with dementia during the study); for this analysis, we excluded the people who were diagnosed with dementia immediately before the study (group 2).

Third, we hypothesized that a high-risk crash period exists immediately prior to the formal diagnosis of dementia. During this period, an individual may have impaired driving but may not yet have restricted driving behaviors. We limited this analysis to incident cases (group 3- drivers diagnosed with dementia during the study) and, using a cross-over design, explored whether the diagnosis of dementia was associated with a change in crash risk, using the timeframe from one year before diagnosis until one year after diagnosis. This analysis also accounted for severity by using only the year immediately after diagnosis; dementia does not typically progress rapidly within a year of diagnosis.

We used Stata, Version 13.1 (StataCorp, College Station, TX) for all analyses. This study was approved by the Group Health Research Institute's Human Subjects Review Board.

## 3. Results

### 3.1. Study demographic characteristics

Among 29,730 individuals meeting our inclusion criteria, 827 were diagnosed with dementia before the study start date and another 886 were diagnosed during the study. Individuals diagnosed with dementia before or during the study were older on average at the start of the study, had more co-morbid conditions, and higher proportions had an ICD-9-CM code indicating alcoholism or depression (Table 1). The groups did not differ significantly by sex. Among those with dementia, 65% died during the study, compared to 24% of those without dementia.

significant difference between groups 2 and 3 ($P$-value $< 0.05$)

The overall crash rate was 14.7 crashes per 1000 person-years. There were 32 crashes over 3546 years of study time following dementia diagnosis, or 9.0 crashes per 1000 person-years. 1385 crashes occurred among individuals without a diagnosis of dementia or in the period prior to diagnosis during 88,143 years of study time, or 15.7 crashes per 1000 person-years. Among individuals who crashed, eight crashed three times during the study, 103 crashed twice, and the remainder crashed once. Seven crashes involved fatalities.

### 3.2. Primary analysis results

In our primary analyses, the unadjusted HR of crash after dementia diagnosis (diagnosed during or before the study) was 0.55 (95% CI 0.33, 0.89). In a multivariate model adjusted for demographic variables and comorbidities, the HR for the association between diagnosed dementia and police-reported crash was 0.56 (95% CI 0.33,0.94) (Table 2). Males had a significantly higher risk of crash relative to females, as did individuals with an ICD-9-CM code for depression compared to those without.

### 3.3. Sensitivity analyses

#### 3.3.1. Urban and rural analysis results

We identified 3340 participants living in metropolitan core areas, and 6383 in less urban areas or rural areas. Among older drivers living in metropolitan core areas, the adjusted hazard ratio of crash among those with a dementia diagnosis, compared to those without a dementia

**Table 1**
Demographic and health information (n = 29,730).

| | Group 1: No dementia | | Group 2: Dementia diagnosed before study start | | Group 3: Dementia diagnosed during study | |
|---|---|---|---|---|---|---|
| | (N = 28,015) | | (N = 827) | | (N = 886) | |
| | N | % | N | % | N | % |
| Motor Vehicle Crash during the study[b,c] | 1,241 | 4 | 16 | 2 | 41 | 5 |
| Female | 15,320 | 55 | 452 | 55 | 484 | 55 |
| Age Group[a,b,c] | | | | | | |
| 65–69 | 11,437 | 41 | 161 | 19 | 286 | 32 |
| 70–74 | 12,040 | 43 | 498 | 60 | 458 | 52 |
| 75–79 | 4,538 | 16 | 168 | 20 | 144 | 16 |
| Charlson comorbidity index[a,b,c] | | | | | | |
| 0 | 20,160 | 72 | 449 | 54 | 546 | 61 |
| 1–4 | 4,255 | 15 | 194 | 23 | 187 | 21 |
| 5–9 | 2,248 | 8 | 100 | 12 | 86 | 10 |
| 10[c] | 1,350 | 5 | 84 | 10 | 69 | 8 |
| Benzodiazepine use[a,b,c], | 2,942 | 11 | 183 | 22 | 64 | 7 |
| Opioid use[a,b,c] | 8,068 | 29 | 270 | 33 | 156 | 18 |
| Sedative use[a,b,c] | 1,304 | 5 | 76 | 9 | 25 | 3 |
| Antipsychotic use[a,b,c] | 418 | 1 | 229 | 28 | 31 | 3 |
| Alcohol-related diagnosis[b,c] | 267 | 1 | 41 | 5 | 13 | 1 |
| Depression-related diagnosis[a,b,c] | 3,198 | 11 | 336 | 41 | 248 | 28 |
| Median follow-up time (days) | 729 | N/A | 657 | N/A | 415.5 | N/A |

[a] Chi-squared test: statistically significant difference between groups 1 and 2 (P-value < 0.05).
[b] Chi-squared test: statistically significant difference between groups 1 and 3 (P-value < 0.05).
[c] Chi-squared test: statistically significant difference between groups 2 and 3 (P-value < 0.05).

**Table 2**
Hazard ratio for police-reported motor vehicle crash in multivariate analysis using data from all study participants.

| | Hazard ratio | 95% CI | | P-value |
|---|---|---|---|---|
| Dementia diagnosis | 0.56 | 0.33, | 0.94 | 0.03 |
| Female sex | 0.66 | 0.59, | 0.73 | < 0.01 |
| Age | 0.99 | 0.98, | 1.01 | 0.52 |
| Benzodiazepine | 1.07 | 0.90, | 1.28 | 0.44 |
| Sedatives | 0.93 | 0.73, | 1.19 | 0.57 |
| Opioids | 0.98 | 0.87, | 1.11 | 0.80 |
| Antipsychotics | 0.68 | 0.42, | 1.10 | 0.12 |
| Alcohol-related diagnosis | 1.26 | 0.82, | 1.93 | 0.29 |
| Depression-related diagnosis | 1.20 | 1.02, | 1.42 | 0.03 |
| Charlson comorbidity index | | | | |
| 0 | Reference category | | | |
| 1 | 1.16 | 1.00, | 1.34 | 0.05 |
| 2 | 0.90 | 0.72, | 1.13 | 0.35 |
| 3+ | 0.96 | 0.72, | 1.29 | 0.81 |
| Year of study entry | 0.97 | 0.92, | 1.02 | 0.20 |

diagnosis, was 0.50 (95% CI 0.28, 0.91) (Fig. 1). Among those with less urban to rural residences, individuals with a dementia diagnosis, compared with individuals without a dementia diagnosis, had an adjusted hazard ratio of crash of 0.88 (95% CI 0.30, 2.62). There was no statistically significant interaction between urbanicity and dementia in relation to risk of crash.

### 3.3.2. Inception design analysis results

We estimated the risk of crash immediately following dementia diagnosis using data from those diagnosed during the study (group 3) compared to those never diagnosed (group 1) using an inception design. Adjusted for age, co-morbidities, depression, alcohol use, and medication use, the risk of crash was similar to the rate found in our primary analyses, though this did not reach statistical significance (HR = 0.60, 95% CI 0.35, 1.02) (Fig. 1).

### 3.3.3. One year pre- and post- diagnosis analysis results

We found no association between dementia diagnosis and crash risk during the year following diagnosis of dementia (HR = 1.07, 95% CI 0.19, 5.99) compared to up to one year prior to diagnosis among those diagnosed during the study (group 3) (Fig. 1).

## 4. Discussion

Our primary findings suggest that patients with dementia have a lower risk of crash compared to those without dementia. This finding may initially seem counter-intuitive, as prior research has indicated that drivers with cognitive impairment have poor performance on road tests and simulated driving scenarios (Breen et al., 2007; Ott et al., 2008; Carr and Ott, 2010; Rizzo et al., 2001; Carr et al., 2000; Ball et al., 2006; Carr, 1997; Lincoln et al., 2006; Jones Ross et al., 2015; Duchek et al., 2003). We suspect the discrepancy between our findings and those expected based on prior studies documenting the impacts of impaired cognition on driving performance may be related to our lacking data on miles driven.

Other longitudinal observational studies that lacked data on driving exposure similarly did not find a higher crash risk associated with cognitive impairment (Duchek et al., 2003; Joseph et al., 2014). In a relatively large international study 28 the crash risk appeared to be lower among people with more advanced stages of dementia. Studies using medical records and police-reported crash data from Western Australia and Quebec found a lower risk of crash among individuals with dementia compared to those without dementia (Anderson et al., 2004; Dow et al., 2013). None of these studies showing a protective effect of dementia accounted for exposure to driving. A study with 38 participants reported a lower crash rate among those with a Clinical Dementia Rating (CDR) of 0, compared to a CDR of 0.5 and 1 (cognitively impaired with no dementia and mild Alzheimer's disease), adjusted for self-reported weekly mileage (Ott et al., 2008).We suspect that our findings, which demonstrated lower crash risk for people diagnosed with dementia, reflect purposeful changes in driving habits among some older adults diagnosed with dementia, or changes imposed by families or caregivers (AGS/NHTSA, 2016; The Hartford, 2016aa; The Hartford, 2010; The Hartford, 2016bb). Our results suggest that exposure to driving among licensed drivers may differ by dementia status, and that lower driving exposure among older drivers with dementia may more than offset the higher risk associated with impaired decline in driving abilities.

We looked for but did not find evidence to support temporal changes in crash risk. Results from our inception design analyses were similar to those from our primary analyses, which suggests that older drivers with newly acquired dementia diagnoses had a similar crash risk as older drivers with established dementia diagnoses. We also did not see differences in crash rates from the year immediately prior to and the year immediately following dementia diagnosis. Research using large numbers of older drivers that captures driving exposure is needed to better characterize crash risk related to the onset of dementia

Many studies have used licensure status to adjust for exposure to driving in older driver and cognition research (Ott et al., 2008; Rizzo et al., 2001; Owsley et al., 1991; Carr et al., 2000; Duchek et al., 2003; Vance et al., 2006; Cheung and McCartt, 2011; Staplin et al., 2003; Sims et al., 1998; Lundberg and Hakamies-Blomqvist, 1998; Hakamies-Blomqvist, 1998; Owsley et al., 1998; Rapoport et al., 2013; Ball et al.,

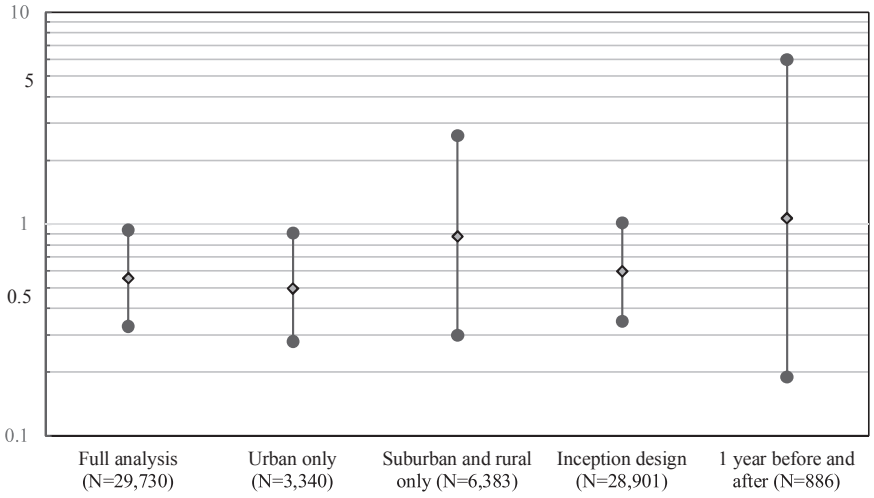


**Fig. 1.** Sensitivity analyses: results of adjusted hazard rates (aHR) associated with crash (sample size in parentheses).

1998).We used this same approach. The lower risk we found associated with dementia diagnosis suggests that licensure status alone may not be sufficient to account for exposure to driving. Data on exposure to driving may be quantitative, such as vehicle miles traveled, or qualitative, such as data on driving circumstances, familiarity with the route, or weather (Wagner et al., 2011; Molnar et al., 2006). The authors of previous studies have called for large, longitudinal studies to help elucidate relationships between dementia and crash risk (Wagner et al., 2011; Molnar et al., 2006). Our findings suggest that data that includes some indication of driving exposure may be necessary.

Future research on driving habits among older adults may consider technologic approaches to accurately measure driving time and distance in addition to driving skill and crash risk. Cell phone applications, in-vehicle technology such as cameras, accelerometers, and yaw rate sensors, or personal actigraphs may present important opportunities to assess older adult driving habits.

As hypothesized, we found a lower risk of crash among urban-dwelling older adults with dementia, but not among suburban or rural residents. The relevance of rural versus urban setting has not previously been explored in research on relationships between cognitive impairment and crash risk. It may be easier for urban dwellers to reduce their exposure to driving due to availability of public transportation and support services (e.g., grocery delivery services). For older adults with dementia, crash risk may be further reduced with extension of services that support reduced driving exposure.

Results from the sensitivity analyses using an inception design and using only individuals diagnosed during the study did not show a relationship between new diagnosis of dementia and crash risk. However, there were few crashes recorded among drivers with dementia, which limited power to find differences.

Within the primary analysis, we additionally identified a higher crash risk among individuals diagnosed with depression and among males that was independent of dementia status. Both of these findings agree with previous research around older drivers (IIHS, 2016; Dow et al., 2013). The majority of individuals had zero comorbidities as identified by the Charlson. It is possible the number of individuals with zero comorbidities is due to the capture period. It could also originate because the comorbidities captured in the Charlson are relatively severe, and with this population of “younger” older drivers, these conditions (and diagnoses) may not have occurred.

### 4.1. Limitations

The study's main limitation is that we did not have information on exposure to driving beyond our inclusion criterion that all participants had an active driver license. Data on driving exposure would allow us to confirm that reduced exposure to driving is the reason for the observed lower hazard. An older adult may renew a license for identification purposes without intending to drive. In addition, study participants may voluntarily curtail driving before license renewal dates.

Three further limitations related to the study’s definition of dementia. Despite the relatively large sample size and a long period of follow-up, both the exposure (dementia) and the outcome (crash) were relatively rare, which may have impacted power, particularly within the sensitivity analyses. Additionally, an individual diagnosed with dementia before the study period began, but for whom no dementia diagnosis or dementia-related prescription was noted at subsequent GH interactions, could potentially have been misclassified as not having dementia in our analyses. This concern drove the inception design study, the results of which, while not significant, were similar to those of the main analysis. Finally, this study’s operational definition of dementia had two shortcomings: (A) the ICD-9-CM codes related to dementia within the data set were not comprehensive. Notably codes for vascular dementia were not available, and (B) ICD-9-CM codes identifying dementia diagnoses in general and dementia subtypes in particular are notoriously inaccurate (McDavid et al., 2013; Kho et al., 2011). The entire study period preceded the transition to ICD-10. These definitional exclusions limit the generalizability of results to all forms of dementia.

Because of IRB restrictions, we obtained data only for individuals up to age 79. This limits generalizability and may somewhat account for the low prevalence of dementia in the study; 82% of individuals with Alzheimer’s disease are aged 75 or older, an age group that only overlaps by four years with this study sample. Additionally, this study only captures certain types of dementia, notably Alzheimer's disease. Most statistics on the prevalence of dementia do not provide sufficient breakdown to allow for a precise comparison. Within the study, the prevalence of dementia was 5.8%. Perhaps the closest comparison is the Aging Demographics, and Memory study (ADAMS), a subsample from the Health and Retirement Study (HRS), which found that, using data from 2001–2003, among individuals age 70–79, 10.4% had Alzheimer's Disease (Plassman et al., 2007). 2012 data from the HRS showed a prevalence of 4.3% for all dementia for ages 65–75 and 10.6% for ages 75–84 (Langa et al., 2017). The HRS assess cognition within a research context. Conversely, this study used medical records from a health care delivery system. Early dementia especially may not be recognized in regular clinical care, so there may be people with undiagnosed dementia included as controls in our study (AGS/NHTSA, 2016). If dementia was underdiagnosed within this cohort, this misclassification error, in addition to the aforementioned lack of exposure data, biased results toward the null.

Factors other than diminished driving exposure may also contribute

to the lower risk of crash we observed among older drivers with dementia. People with dementia may fail to inform police of a crash or may be more likely to have a non-reportable crash. In Washington State, a collision report is not needed if there are no injuries and damages do not exceed $1000. Crashes in private parking lots or outside of Washington State are also not included in state Department of Transportation crash data.

Lastly, this data set did not include information about vision. Although all drivers were licensed and therefore had sufficient vision to pass the screening (among those renewing licenses in person), further information on vision was not available.

### 4.2. Conclusions

We linked dementia diagnoses from a large healthcare delivery system with state licensing and crash records. We found that people with dementia diagnoses had lower risks of crash than people without dementia diagnosis. The finding of lower crash risks for people with dementia was especially the case for people living in metropolitan cores. Since cognitive impairment and dementia have repeatedly been found to be associated with riskier driving behavior, we suspect that our findings may reflect inadequate control for exposure to driving.

The older adult population of the U.S. is large and growing rapidly (NHTSA, 2014). As adults age, they face new transportation challenges in meeting social, logistical, and medical needs. Further research around cognition among older drivers is central to informing discussions between care providers, older adults, and families on how to maximize older patients' independence while preserving individual and public safety.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.aap.2017.12.021

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