Update on the Risk of Motor Vehicle Collision or Driving Impairment with Dementia: A Collaborative International Systematic Review and Meta-Analysis

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Guidelines that physicians use to assess fitness to drive for dementia are limited in their currency, applicability, and rigor of development. Therefore, we performed a systematic review to determine the risk of motor vehicle collisions (MVCs) or driving impairment caused by dementia, in order to update international guidelines on driving with dementia. Seven literature databases (MEDLINE, CINAHL, Embase, etc.) were searched for all research studies published after 2004 containing participants with mild, moderate, or severe dementia. From the retrieved 12,860 search results, we included nine studies in this analysis, involving 378 participants with dementia and 416 healthy controls. Two studies reported on self-/informant-reported MVC risk, one revealing a four-fold increase in MVCs per 1,000 miles driven per week in 3 years prior, and the other showing no statistically significant increase over the same time span. We found medium to large effects of dementia on driving abilities in six of the seven recent studies that examined driving impairment. We also found that persons with dementia were much more likely to fail a road test than healthy controls (RR: 10.77, 95% CI: 3.00–38.62, $z = 3.65$, $p < 0.001$), with no significant heterogeneity ($\chi^2 = 1.50$,

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PROSPERO International prospective register of systematic reviews (CRD42016039018).[1]

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p = 0.68, I^2 = 0%) in a pooled analysis of four studies. Although the limited data regarding MVCs are equivocal, even mild stages of dementia place patients at a substantially higher risk of failing a performance-based road test and of demonstrating impaired driving abilities on the road. (Am J Geriatr Psychiatry 2017; 25:1376–1390)

Key Words: Dementia, Alzheimer disease, driving, neurology

There are over 35.6 million people living with dementia worldwide today.[2] In the United States, the most common form of dementia (i.e., Alzheimer disease [AD]) is expected to rise in prevalence from 5.4 million people in 2016 to 13.8 million in 2050.[3] Many of these individuals will continue to drive for years after diagnosis.[4] A recent cross-sectional study on women's health revealed that 60% of older women (mean age: 84 years) with mild cognitive impairment (MCI) and 40% with dementia were still driving at the time of assessment.[5] Deficits associated with dementia pose strong risks to driving; these include memory impairment, poor decision-making and problem-solving skills, impaired insight and judgment, difficulties with hand–eye coordination, reduced reaction time, visual attention deficits, and decreased visuospatial abilities.[6–8] Clinicians may be wary of advising their patients to stop driving because of negative impacts on driver independence and the doctor–patient relationship.[9–13] These concerns contribute to under-reporting of patients to transportation authorities in jurisdictions with mandatory reporting.[12,14]

We recently adopted the Appraisal of Guidelines Research and Evaluation (AGREE) II tool to evaluate nine national-level, clinical practice guidelines from seven countries for physicians evaluating fitness to drive with medical illness. We identified limitations in their quality with respect to rigor of development, applicability, and editorial independence, with negative implications for uptake of the guidelines in practice.[15] Considering the accelerated rate at which relevant research is being performed and the dearth of timely updates, the currency of these guidelines is also open to question. International collaboration on such clinical practice guidelines may help to reduce barriers to guideline accessibility, which vary by country; improve clinician adherence to guideline recommendations, which is limited even in jurisdictions with mandatory physician reporting of medical conditions; and ensure that healthcare professionals are basing their clinical judgment on the most recent evidence available worldwide. Such guidelines would have a major impact on public safety and patient autonomy;[16,17] thus, it is important that they are informed by a high-quality synthesis of the literature. There has been much published on dementia and driving risks in the last 10 years, and we now update prior syntheses in this area.[18,19]

The goal of this report is to systematically review the literature on the risk of motor vehicle collision (MVC) or driving impairment as measured by on-road testing, in order to inform international guidelines on driving with dementia.

METHODS

Eligibility Criteria

Types of Studies

We searched for literature pertaining to dementia and MVCs or automobile driving. Our initial search included all relevant studies that addressed four questions identified by our co-authors and a wider group of stakeholders, which focused on determining: 1) the absolute and relative risk of motor vehicle collision or driving impairment (the focus of this paper); 2) the new screening instruments that would distinguish between patients who should be referred to specialized driving centers for assessment; 3) the methods available to assist clinicians with rating dementia severity; and 4) the evidence available to support recommendations on the caregiver's opinion of driving performance and fitness to drive (see Supplemental Digital Content 1 for the precise phrasing of the original research questions)[1]. The search strategy consisted of a combination of MeSH terms and key words that pertained to important concepts within the research questions, such as dementia (e.g., *dementia/* or *cognition disorders/*), road tests (e.g., *automobile driver examination/*), driving (e.g., *automobile driving/* or *motor*

vehicles/), collisions (e.g., *accidents, traffic/*), in-office cognitive screening (e.g., *neuropsychological tests/*), caregiver or health personnel (e.g., *caregivers/* or *allied health personnel/*), and opinion on performance (e.g., *physicians role/* or *duty to warn/* or *directive counseling/*). We included primary papers published between 2005 and 2015, and searched the bibliographies of systematic reviews for additional studies that had not already been included in the search. We excluded reviews, editorials, conference proceedings, dissertations, reports not available in English, and studies pertaining to MCI, to older adults without dementia, or studies using driving simulators. To avoid including duplicate samples, we focused on the principal study and excluded additional studies that used the same group of participants when reporting on MVC risk or driving impairment. We were prudent to ensure that authors with relevant publications were not involved in the screening or data extraction of their own publications (MJR, DBC, SC, NH, JD, SM, JPT, PD, KO).

Study Participants

We considered all research that included participants with dementia of any severity (mild, moderate, or severe) and any diagnosis of dementia reported using well-established criteria (e.g., NINCRS-ADRDA) or as a result of a referral from a healthcare practitioner. No age restrictions were imposed.

Types of Outcome Measures

Our primary outcome measures were related to the following types of behavior: road MVCs (self- or informant-reported data and state/government accident registries [i.e., state-recorded data]), and skill performance and road-test failure rates using on-road driving assessments on formal testing or in naturalistic environments.

Information Sources

The search was initially applied to Ovid MEDLINE In-Process and Other Non-Indexed Citations (October 13, 2015), Ovid MEDLINE without Revisions (1990–October Week 1, 2015), and Ovid MEDLINE (1990–1995); and subsequently adapted for CINAHL (1990–2015), Scopus (1990–2015), Cochrane Central Register of Controlled Trials (CENTRAL) (1990–2015), EMBASE (1990–2015), PsycINFO (1990–2015), and the Transportation Research Information Database (1990–2015). The last search was run on 30 October 2015. Studies before 2005 were manually removed during the subsequent screening process. The complete MEDLINE search strategy is provided in Supplemental Digital Content 2. Similar strategies were used for the other databases.

Study Selection

Studies that presented primary research findings were independently identified by pairs of reviewers from among the coauthors. This study screening process was divided into three stages: screening of titles, abstracts, and then full-text articles. Disagreements between reviewers were resolved by consensus at the title screening stage, and by a third-party arbiter among the coauthors at the abstract and full-text stages. We measured inter-rater agreement between reviewers at the title and abstract screening stages using Cohen's kappa.[20] Three authors narrowed the primary studies down from the full list of four research questions (see Supplemental Digital Content 1) to only those that compared MVCs or driving impairment in patients with dementia with healthy comparison groups by consensus. This scope modification was necessary to ensure feasibility.

Data Processing

Data Collection Process

We extracted information from each of the included studies on: 1) study design (cross-sectional, longitudinal, etc.); 2) methodological considerations (on-road assessment protocols used, techniques used to acquire collision data, etc.); 3) participant characteristics (dementia type and severity, diagnostic criteria utilized, demographics, etc.); 4) results of specific outcome measures (number of collisions or driving errors, rate of failure on road tests, etc.); 5) overall conclusions; and 6) author-identified limitations (shortcomings declared in-text by the authors: the results may have been biased by the inclusion of "professional drivers", the

exclusion of drivers who failed a previous road test and/or have a history of crashes, nonstandardized road traffic conditions, control groups that differed significantly on one or more demographic characteristics, etc.). The data extracted by one of the coauthors were independently verified by another coauthor to identify and rectify any errors, if present. We computed effect sizes (Cohen's d) for all appropriate outcome measures.

Methodological Quality Assessment of Individual Studies

The quality of evidence in each of the included studies containing primary data was assessed using the article grading guidelines previously described.[21,22] Ten of the coauthors of the dementia knowledge synthesis deliberated at an in-person meeting in April 2016 on the specific ratings to assign to each of the included studies (Class I, II, III, or IV), and arrived at a final decision by consensus (see Supplemental Digital Content 3 for the specific article grading guidelines).

Analysis

A qualitative synthesis was prepared for the results of the papers presented in the primary studies. We conducted a meta-analysis comparing persons with and without dementia and computed the risk ratio (RR) and 95% confidence interval (CI) associated with failing an on-road assessment. The Review Manager (RevMan, Version 5.3)[23] software package was used to perform the meta-analysis, with a DerSimonian and Laird random-effects model.[24] The χ^2 test[25] and I^2 statistic were used to examine heterogeneity and its magnitude, respectively.[25] We assessed the possibility of publication bias (i.e., a tendency for only statistically significant results to be published) by visually inspecting a funnel plot of the RRs for asymmetry.

RESULTS

Study Selection

Among the 12,860 citations identified for all four questions, 9,165 remained for screening after excluding duplicates (Figure 1). Of these, 6,378 were excluded after the title review. Agreement was "almost perfect" (kappa >0.8) within the two pairs of reviewers, with kappa coefficients of 0.96 (95% CI: 0.95–0.97) and 0.98 (95% CI: 0.97–0.98), and 140 disagreements were resolved by consensus. At the abstract screening stage, narrowing down to the topic of this study, 398 of the remaining 2,787 studies were identified as potentially relevant by at least one reviewer within 11 independent reviewer pairs. Kappa coefficients of agreement ranged from 0.36 (95% CI: 0.25–0.46) to 0.86 (95% CI: 0.78–0.95). At that stage, four pairs had a high level of agreement (kappa >0.6), five pairs had moderate agreement (kappa 0.4 to 0.59), and two pairs had only fair agreement (kappa 0.2 to 0.39), with 504 disagreements resolved by a third-party arbiter.

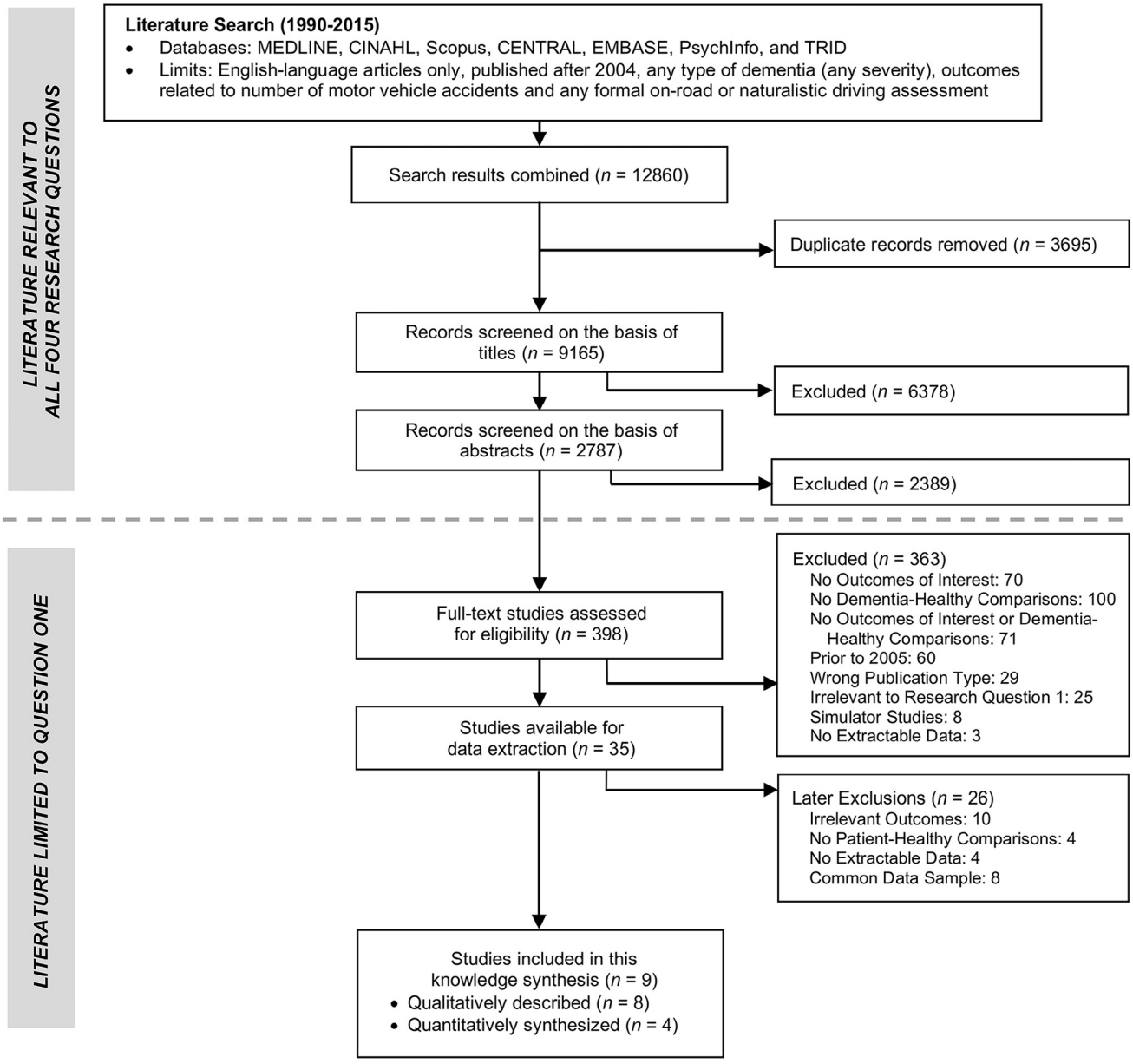
Of the remaining 398 studies, each underwent full-text review by six pairs of independent reviewers, and 363 did not meet inclusion criteria. There were 122 disagreements resolved by a third-party arbiter. The remaining 35 studies proceeded to data extraction by 11 pairs of independent reviewers. At the data extraction stage, an additional 26 were excluded. Among these, eight studies[26–33] were excluded for having common samples of data, keeping only the primary studies.[34,35] The other 18 were excluded for having irrelevant outcomes (N = 10), no patient–healthy control comparisons (N = 4), and no extractable data (N = 4). A total of nine studies were included in the knowledge synthesis. Eight of them were qualitatively described. Four of them presented a failure rate for on-road assessments, and thus were quantitatively pooled in a meta-analysis (Figure 1; also see Supplemental Digital Content 4 for a list of included studies).

Characteristics and Results of Individual Studies

Findings on MVC Risk

The two studies[34,35] that examined MVC risk in persons with dementia used both self/informant-reported and state-recorded data among 143 persons with dementia (specifically, possible or probable AD), who had questionable/very mild and mild dementia by Clinical Dementia Rating (CDR 0.5 and 1), and 88 healthy comparison participants (Table 1). Davis et al.[34] (Class I) did not reveal any differences between the healthy comparison group and the dementia group for either the percentage of persons with MVCs or the number of MVCs per year per 10,000 miles driven

FIGURE 1. **Flow chart of study selection. The study selection process is summarized in this PRISMA flow chart. The dotted line indicates the point at which screening was focused only on addressing study one.**



in the past year (Table 2A). Similarly, Ott et al.[35] (Class I) found no group differences in the percentage of persons with MVCs, MVC rate per driver per year, or total number of MVCs in the 3 years before a baseline assessment, but they did find that the total number of MVCs per 1,000 miles driven per week was 4.72 times higher in the dementia group (8.78 MVCs) than in the healthy comparison group (1.86 MVCs; $p < 0.01$). In the 3 years after the assessment, the percentage of MVCs in the healthy comparison group was 11.0 times higher than that of the dementia group (11% versus 1%) ($p < 0.05$); that difference

TABLE 1. Methodological and Participant Characteristics of the Included Studies

Author (Year)	Class Rating	Driving Protocol	Outcomes	Group Characteristics	Sample Size (N)	Age (years)	Sex (% M)	Education (years)
Aksan et al. (2015)[36]	**Class II b**	**i.) Naturalistic Assessment:** *A standardized, 18-mile 45-minute on-road driving test in an instrumented vehicle*	**b) On-Road Impairment** *(navigation-related secondary task performance)*	**COMP: Healthy older adults:** [c] *No neurologic disease* **EXPT: AD (probable):** *Severity not specified*	**COMP:** 77 **EXPT:** 32	**COMP:** 75.4 (4.06) **EXPT:** 77.6 (4.28)	**COMP:** N/A[f] **EXPT:** N/A[f]	**COMP:** 15.7 (2.8) **EXPT:** 15.25 (3.4)
Barco et al. (2015)[37]	**Class II b**	**ii.) Road Test:** *mWURT*	**b) On-Road Impairment** *(operational errors, tactical errors, etc.)* **c) On-Road Test Pass/Fail** *(fail vs. pass)*	**COMP: Healthy older adults:** [c] **EXPT: Dementia[d]:** *Severity not specified*	**COMP:** 32 **EXPT:** 60	**COMP:** 70.7 (8.1) **EXPT:** 74.7 (8.5)	**COMP:** 50.0 **EXPT:** 66.7	**COMP:** 14.9 (3.0) **EXPT:** 15.3 (3.4)
Eby et al. (2012)[38]	**Class II b**	**i.) Naturalistic Assessment:** *Normal driving in an instrumented vehicle for up to 2 months*[a]	**b) On-Road Impairment** *(travel patterns, wayfinding, safety belt use, headway, gear errors/pedal errors, etc.)*	**COMP: Healthy older adults:** [c] **EXPT: Dementia[d]:** *Severity not specified, but patients had an "early stage" diagnosis*	**COMP:** 26 **EXPT:** 17	**COMP:** 64.5 (2.8) **EXPT:** 76.2 (10.4)	**COMP:** 50.0 **EXPT:** 76.0	**COMP:** N/A **EXPT:** N/A
Davis et al. (2012)[34]	**Class I**	**i.) Naturalistic Assessment:** *4 hours of consecutive daytime driving collected over 2 weeks* **ii.) Road Test:** *RIRT;*	**a) MVC Rates** *(retrospective only);* **b) On-Road Impairment** *(e.g. RIRT Score, CDAS Score);* **c) On-Road Test Pass/Fail** *(fail vs. pass + marginal)*	**COMP: Healthy older adults:** [c] *Normal cognition* **EXPT: AD (probable):** *Questionable to very mild (CDR = 0.5) and mild dementia (CDR = 1)*	**COMP:** 44 **EXPT:** 59	**COMP:** 71.2 (7.6) **EXPT:** 76.0 (6.0)	**COMP:** 38.6 **EXPT:** 49.2	**COMP:** 16.3 (3.8) **EXPT:** 13.8 (3.4)
Barrash et al. (2010)[39]	**Class II b**	**i.) Naturalistic Assessment:** *A standardized, 45-minute on-road driving test in an instrumented vehicle*[b]	**b) On-Road Impairment** *(e.g., errors with observing traffic signals and signs, control of speed, overtaking another vehicle)*	**COMP: Healthy older adults** (unmatched)**:** *Neurologically normal* **EXPT: AD (probable):** *Very mild dementia ("very mild" AD patients selected for "very mild cognitive decline")*	**COMP:** 24 **EXPT:** 26	**COMP:** 73.1 (5.1) **EXPT:** 75.2 (5.5)	**COMP:** 50.0 **EXPT:** 61.5	**COMP:** 16.2 (2.7) **EXPT:** 16.2 (3.2)
Dawson et al. (2009)[40]	**Class II b**	**i.) Naturalistic Assessment:** *A standardized, 45-minute on-road driving test in an instrumented vehicle*[b]	**b) On-Road Impairment** *(lane observance errors, total safety errors, etc.)*	**COMP: Healthy older adults** (age & sex-matched)**:** *No neurologic diagnosis nor family history of diagnosis* **EXPT: AD (probable):** *Mild AD*	**COMP:** 115 **EXPT:** 40	**COMP:** 69.4 (7.0) **EXPT:** 75.1 (7.7)	**COMP:** 52.2 **EXPT:** 82.5	**COMP:** 15.8 (2.5) **EXPT:** 15.6 (3.1)
Ott et al. (2008)[35]	**Class I**	**ii.) Road Test:** *mWURT*	**a) MVC Rates** *(retrospective + longitudinal);* **c) On-Road Test Pass/Fail** *(unsafe vs. safe + marginal)*	**COMP: Healthy older adults** (age-matched)**:** *Without cognitive impairment* **EXPT: AD (probable and possible):** *Very mild (CDR = 0.5) and mild dementia (CDR = 1)*	**COMP:** 44 **EXPT:** 84	**COMP:** 73.5 (9.1) **EXPT:** 75.7 (7.0)	**COMP:** 43.0 **EXPT:** 61.0	**COMP:** 15.2 (3.0) **EXPT:** 13.9 (3.4)
Lincoln et al. (2006)[41]	**Class II b**	**ii.) Road Test:** *NNDA*	**c) On-Road Test Pass/Fail** *(definitely safe vs. probably unsafe + probably safe + definitely safe)*	**COMP: Healthy older adults:** [c] *No known memory problems* **EXPT: Dementia[d]:** *Severity not specified*	**COMP:** 31 **EXPT:** 37	**COMP:** 68.5 (5.7) **EXPT:** 71 (8.9)	**COMP:** 74.0 **EXPT:** 84.0	**COMP:** 12 (10–16)[g] **EXPT:** 10 (9–13)[g]

(*continued on next page*)

TABLE 1. *(continued)*

Author (Year)	Class Rating	Driving Protocol	Outcomes	Group Characteristics	Sample Size (N)	Age (years)	Sex (% M)	Education (years)
Whelihan et al. (2005)[42]	Class II b	ii.) Road Test: *RIDE*	**b) On-Road Impairment** *(e.g., RIDE Score)*	**COMP: Healthy older adults** (age-matched); *No neurologic disease* **EXPT: Dementia**[e]**:** *Questionable/very mild dementia (CDR = 0.5)*	**COMP:** 23 **EXPT:** 23	**COMP:** 74.3 (7.3) **EXPT:** 78.2 (9.3)	**COMP:** 30.4 **EXPT:** 52.2	**COMP:** 14.3 (2.4) **EXPT:** 12.7 (2.9)

Notes: See Supplemental Digital Content 5 for more information about the way dementia was diagnosed and categorized in each study. AD: Alzheimer disease; AD8: Assessing Dementia-8 Screening Interview; CDAS: Composite Driving Assessment Scale; COMP: comparison group (healthy older adults); DRS: Dementia Rating Scale; EXPT: experimental group (dementia patients); MMSE: Mini-Mental State Examination; mWURT: Modified Washington University Road Test; NNDA: Nottingham Neurological Driving Assessment; RIDE: Rhode Island Driving Examination; RIRT: Rhode Island Road Test; TMT-B: Trail Making Test (Part B).

[a]Using a University of Michigan Transportation Research Institute (UMTRI) instrumented vehicle.

[b]Using the ARGOS instrumented vehicle.

[c]No matching described by authors.

[d]Lincoln et al.[37] and Eby et al.[35] merely reported that persons with "dementia" were recruited for the study by referral from health care professionals (psychiatrists, clinical psychologists, etc.).

[e]Whelihan et al.[38] incorporated dementia patients with primary cerebrovascular etiologies, possible dementia of the Alzheimer type (DAT), a mixed etiology of cerebrovascular disorder and possible DAT, or other cognitive risk factors (e.g., histories of alcohol abuse or head trauma).

[f]Sex differences cannot be extractable from the entire sample, which includes Parkinson disease patients.

[g]Median and interquartile range (mean and standard deviation were not provided by the authors).

was eliminated after correcting for the distance driven per week, however.

Findings on On-Road Performance

All nine of the included studies reported measures of on-road performance.[34–39,41,42] Seven of the studies presented driving impairment outcomes[34,36–40,42] and four presented on-road assessment failure rates,[34,35,37,41] with two of them presenting both outcome types (Table 1).[34,37] Two types of driving assessment methodologies were used in these studies to evaluate driving performance: 1) on-road assessment protocols, which utilized a driving instructor to examine drivers as they performed a specified set of driving tasks in a real-world environment (gold-standard);[34,35,37,41,42] and 2) naturalistic driving protocols, which utilized an instrumented vehicle to unobtrusively record the driver, the vehicle, and/or the proximal environment throughout the assessment.[34,36,38–40] Altogether, a total of 378 participants were examined in the experimental groups along with 416 healthy comparisons.[34–39,41,42] Dementia severity was unspecified among the experimental group participants,[36–38,41] or was described as questionable[42]/very mild (CDR = 0.5),[34,35,39] or mild (CDR = 1).[34,35]

On-Road Driving Impairment

For the seven studies that examined driving impairment, one rated Class I for quality[34] and the other six rated Class IIb for quality.[36–39,42] Six of the seven studies[34,36–38,40,42] presented significant group differences that were indicative of decreased performance in at least one measure of driving behavior for the persons with dementia, relative to healthy comparisons. We calculated the effect sizes for the significant differences and found that they ranged in absolute value between 0.26 to 3.61, and were large for 19 of the outcomes (landmark/sign identification, number of lost trips, etc.) and medium for 10 of the outcomes (total safety errors, lane observance errors, etc.) (Table 2B).

On-Road Assessment Failure Rate

We found that, in a meta-analysis of the four studies that reported on on-road failure rate (two rated Class I for quality[34,35] and two rated Class IIb[37,41]), persons

TABLE 2. Individual Results of Included Studies: MVC Risk and Driving Performance

a) MVC Risk Outcomes

Author (Year)	MVC Risk Variable	Comparison Group: Baseline Result	Dementia Group: Baseline Result	Comparison Group: Longitudinal Result	Dementia Group: Longitudinal Result
Davis et al.[34] (2012)	Percentage of persons with MVCs	13.6 *(past 1 year)*	8.5 *(past 1 year)*	*Not assessed*	*Not assessed*
	Number of MVCs per year/10,000 miles driven	0.2 (0.4) *(unclear: past 1–3 years)*	1.4 (7.5) *(unclear: past 1–3 years)*	*Not assessed*	*Not assessed*
Ott et al.[35] (2008)	Percentage of persons with MVCs	11 *(past 3 years)*	18 *(past 3 years)*	**11** *(next 1.5 years)*	**1**[*a] *(next 1.5 years)*
	Number MVCs per 1000 miles driven per week	**1.86** *(past 3 years)*	**8.78** ** *(past 3 years)*	5.63 *(next 1.5 years)*	1.85[a] *(next 1.5 years)*
	MVC rate per driver per year	0.04 *(past 3 years)*	0.06 *(past 3 years)*	0.06 *(past 3 years)*	0.01[a] *(past 3 years)*
	Total number of MVCs	5 *(past 3 years)*	17 *(past 3 years)*	5 *(past 3 years)*	2[a] *(past 3 years)*

b) Driving Performance Outcomes

Author (Year)	Driving Performance Variable	Comparison Group: Mean (SD)	Dementia Group: Mean (SD)	Effect Size Interpretation	Effect Size (Cohen's d)[g]
Aksan et al.[36] (2015)	Secondary driving task performance	**0.43 (0.73)**	**−0.53 (0.71)**[?b]	Large effect	1.33
	Secondary Driving Tasks				
	Landmark/sign identification	**0.27 (0.76)**	**−0.50 (0.69)**[?b]	Large effect	1.04
	Route-following behavior	**0.04 (0.07)**	**0.13 (0.13)**[?b]	Large effect	−0.98
	Safety Errors				
	Total safety errors	**2.03 (.71)**	**2.21 (0.64)**[?b]	Medium effect	−0.26
	Total safety errors with secondary task	**3.63 (1.57)**	**4.30 (1.95)**[?b]	Medium effect	−0.40
	Lane observance	**0.69 (0.50)**	**0.96 (0.58)**[?b]	Medium effect	−0.51
	Lane observance with secondary task	**0.71 (0.78)**	**1.22 (1.28)**[?b]	Medium effect	−0.54
	Turns with secondary task	**0.84 (0.64)**	**1.12 (0.76)**[?b]	Medium effect	−0.41
Barco et al.[37] (2015)	Driving situation errors	**6.0 (4.9)**	**12.0 (7.5)*****	Large effect	−0.89
	Errors when driving straight	**1.16 (1.51)**	**2.06 (2.42)***	Medium effect	−0.42
	Errors when turning right	**0.38 (0.83)**	**1.04 (1.54)***	Medium effect	−0.49
Davis et al.[34] (2012)	RIRT error score	**0.04 (0.03)**	**0.08 (0.06)*****	Large effect	−0.81
	CDAS error score	**0.10 (0.08)**	**0.19 (0.13)*****	Large effect	−0.81
	Miles driven per week (informant history)	**200.8 (114.9)**	**98.8 (90.5)*****	Large effect	1.00
	Naturalistic Driving Errors				
	Checks blind spots	0.41[?c]	1.03[*?c]	Not enough information to compute	
	Right turns	0.14[?c]	0.54[*?c]	Not enough information to compute	
	RIRT Items				
	Checks blind spots	0.62[?c]	1.06[*?c,f]	Not enough information to compute	
	Uses mirrors for lane change	0.13[?c]	0.34[*?c,f]	Not enough information to compute	
	Uses mirrors	0.08[?c]	0.27[*?c,f]	Not enough information to compute	
	Traffic awareness	0.10[?c]	0.26[*?c,f]	Not enough information to compute	
	Proceeds timely	0.09[?c]	0.23[*?c,f]	Not enough information to compute	
	Lane keeping	0.07[?c]	0.20[*?c,f]	Not enough information to compute	
Eby et al.[38] (2012)	Number of likely lost trips	**0.0 (0.0)**	**0.4 (0.4)****	Large effect	−1.41
	Miles belted (%)	**98.8 (2.3)**	**88.3 (11.6)****	Large effect	1.41
	Miles driven with short headway (%)	**6.1 (3.4)**	**2.9 (1.6)***	Large effect	1.13
	Miles driven 10 mph or more slower than surrounding traffic (%)	**1.8 (0.5)**	**3.9 (1.2)****	Large effect	−2.48
	Miles per day	**35.7 (6.1)**	**14.9 (5.2)****	Large effect	3.61
	Number of unique destinations per week	**12.8 (2.2)**	**6.1 (1.8)****	Large effect	3.26
	Freeway miles (%)	**32.9 (6.8)**	**15.0 (9.2)****	Large effect	2.29
	Miles driven within 5 miles of home (%)	**43.0 (6.5)**	**70.2 (10.4)****	Large effect	−3.30
	Miles driven within 10 miles of home (%)	**60.3 (8.3)**	**84.2 (9.5)****	Large effect	−2.72
	Miles driven during daylight hours (%)	**86.2 (6.1)**	**93.2 (5.1)***	Large effect	−1.22
Dawson et al.[40] (2009)	Lane observance errors	**10.84 (7.77)**	**17.03 (11.00)*****	Medium effect	−0.71
	Total safety errors	**33.18 (12.22)**	**42.00 (12.84)*****	Medium effect	−0.71
	Total more serious errors	**1.90 (1.59)**	**4.35 (2.97)*****	Large effect	−1.21
	Total less serious errors	**31.26 (11.49)**	**37.65 (11.66)*****	Medium effect	−0.55

(*continued on next page*)

TABLE 2. (*continued*)

b) Driving Performance Outcomes

Author (Year)	Driving Performance Variable	Comparison Group: Mean (SD)	Dementia Group: Mean (SD)	Effect Size Interpretation	Effect Size (Cohen's d) [g]
Barrash et al.[39] (2010)	Total number of driving errors[c,d]	37.3 (13.8)	40.0 (16.8)	NS	NS
Whelihan et al.[42] (2005)	RIDE error score	**46.1 (34.5)**	**130.4 (84.1)*****	Large effect	−1.31

Notes: AD: Alzheimer disease; CDAS: Composite Driving Assessment Scale; MVC: Motor vehicle collision; NS: Non-significant; RIDE: Rhode Island Driving Examination; RIRT: Rhode Island Road Test.

Patients differ from comparison participants at: ***p < 0.001, **p < 0.01, *p < 0.05. [?]Incomplete results presented.

[a]The number of persons with dementia still driving in the longitudinal outcome was small and the outcomes are assumed to reflect the performance of the best drivers, as worse drivers no longer drove by that time point.

[b]Statistical significance was not determined for differences between the healthy comparison and AD groups; the outcomes presented were statistically significant for differences between the healthy comparison group and a heterogeneous patient group, including persons with AD and Parkinson disease.

[c]Driving errors are as defined by the Iowa Department of Transportation for assessment of driving performance.

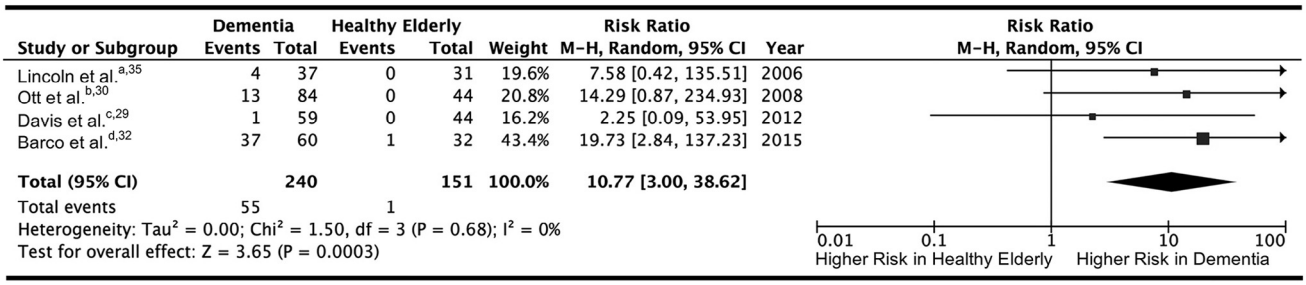
[d]Background differences between groups were not adjusted for as the purpose of the study was not to compare the groups.

[e]Standard deviation not provided in study.

[f]Significant group differences found, p value not provided in study.

[g]The effect sizes (Cohen's d) were computed, but not provided by the individual studies.

FIGURE 2. Forest plot for road-test failure. The risk ratio of road-test failure is presented in this forest plot. [a] Definitely Unsafe versus Probably Unsafe, Probably Safe, and Definitely Safe. [b] Unsafe versus Safe and Marginal. [c] Fail versus Pass and Marginal. [d] Fail versus Pass.



with dementia were much more likely to fail a road assessment than healthy comparison group participants (RR: 10.77, 95% CI: 3.00–38.62, z = 3.65, p < 0.001) (Figure 2). There was no significant heterogeneity in this finding ($\chi^2 = 1.50$, p = 0.68, $I^2 = 0\%$). We examined a funnel plot of the results and did not detect asymmetries indicative of publication bias, although the small number of studies limits this conclusion. The study by Barco et al.[37] differed from the other three studies as it did not conceptualize marginal or probably safe/unsafe cases separately than passing or failing cases. To determine if that alternative approach influenced the effect, we performed a sensitivity analysis without including the Barco et al. study.[37] The resulting RR was similar at 6.77 (95% CI: 1.24–36.96, z = 2.21, p < 0.03), again with no significant heterogeneity ($\chi^2 = 0.80$, p = 0.67, $I^2 = 0\%$). Only two of those studies presented failure rates separately for the CDR 0.5, CDR 1, and control participants.[34,35] The failure rates were 11% and 12% for the CDR 0.5 group, 18% and 22% for the CDR 1 group, and 2% and 0% for the control groups (CDR 0) in Davis et al.[34] and Ott et al.,[35] respectively (see Supplemental Digital Content 5 for a summary of the definitions and severities of dementia

examined in the included studies). Hence, the absolute increase in risk for CDR 0.5 ranged from 11% to 12%, corresponding with a relative risk of 5% to 11%. The absolute increase in risk for CDR 1 ranged from 18% to 22%, corresponding with a relative risk of 8% to 20%.

DISCUSSION

In this systematic review of studies published over the last 10 years, we found only two studies that relied on both proxy report and state-recorded data comparing MVCs in patients with dementia with a healthy comparison group. One study showed more than a fourfold increase in risk of collisions per 1,000 miles driven per week retrospectively in the 3 years prior to the study,[35] whereas the other study showed no statistically significant increase in MVCs over the same time span.[34] It is possible that the inclusion of patients with very mild dementia (CDR 0.5) may have diluted between-group differences in both of those papers, particularly because both studies excluded persons with dementia who experienced at-fault MVCs in the past year. A prior systematic review[18] incorporating studies published from 1996 to 2006 found that all three identified retrospective studies that used informant-reported MVC risk[43–45] consistently found greater MVC risks among patients with dementia than in controls, but studies were much more variable with state-recorded MVCs, where only one[46] of three studies[46–48] was positive. Hence, the evidence of an increase in MVC risk remains inconclusive, with conflicting studies and a small body of literature based largely on proxy reports.

In contrast, we found medium to large effects of dementia on driving performance in six of the seven recent studies examined on on-road impairment. We found more than a tenfold increase in on-road test failure in our pooled analysis of four recent studies. This concurs with another synthesis incorporating studies of driving impairment in persons with MCI and dementia, which reported a greater likelihood of on-road assessment failure among persons with very mild dementia (CDR 0.5) and mild dementia (CDR 1) compared with healthy control drivers (CDR 0) with respective failure rates of 13.6%, 33.3%, and 1.6%.[49] Those rates are similar to those found in our synthesis for the CDR 0.5 group, but higher than our rate of 22% for the CDR 1 group. Together, these findings are notable because a large proportion of participants in the studies involving on-road driving tests had CDRs of 0.5, compared with earlier literature, which often incorporated participants with higher levels of severity, by which time many have ceased driving.[50] One study included participants with very mild dementia (e.g., CDR scores of 0.5),[42] and two studies combined individuals with very mild and mild dementia into one experimental group (CDR scores of 0.5 and 1).[34,35] Two studies included persons with either "very mild" dementia[39] or "mild" dementia (with probable AD diagnoses in particular),[40] according to the authors and supported by Mini-Mental State Exam (MMSE) and Trail-Making Test B (TMT-B) scores; however, the clinical scores of the latter study were indicative of a very mild severity as opposed to mild.[40] One study included participants with "early stage" dementia,[38] according to the authors, but did not present MMSE or other clinical scores to facilitate comparisons. The remaining three studies did not specify dementia severity at all, but offered clinical scores (e.g. AD8, MMSE, TMT-B) that were indicative of persons with very mild,[36] mild,[41] or potentially higher severities.[37] It is interesting that, in two studies, a large proportion of persons with mild dementia (CDR 1) still initially achieved safe or marginal (i.e., passing) global rating scores on an on-road assessment. Nevertheless, longitudinal data suggest that driving performance in such individuals is likely to deteriorate over time.[51] It is conceivable that the experimental group participants in these studies represent a biased sample of drivers with mild dementia (CDR 1), because many individuals at that stage of the illness would have ceased driving.[50] A closer examination of the dementia diagnostic approaches in the studies and the clinical characteristics of their participants also reveals that conflation of persons with very mild dementia with persons who have MCI was likely in the studies incorporating CDR 0.5 and questionable ratings (see Supplemental Digital Content 5). Altogether, it seems that the time to raise concerns over driving safety might be earlier on in the disease process, such as when individuals have diagnoses of MCI, preclinical dementia, or even very mild dementia. At these earlier stages, drivers may be less familiar with their personal limitations and may opt to take more risks. Intervening or initiating the assessment of driving ability earlier on would thus have the potential to improve driving safety

more effectively, or, alternately, offer guidance on driving cessation.

Although composite measures of attention, visuospatial skills, global cognition, and especially executive dysfunction are able to predict such safety issues in part among patients with dementia,[49,52,53] misclassification rates are high and cutoffs are not available, limiting their clinical utility.[52,53] Hence, a clinically useful evidence-based algorithm for predicting safe driving among patients with mild stages of dementia remains elusive.

There are several alternative explanations to our findings of increased road test failures and on-road performance problems in the absence of increased MVCs in patients with dementia compared with controls. First, a mismatch in age and sex between groups may be a confound. In all of the studies, the experimental groups were older than the comparison groups; and in all but one[34] the experimental groups had a greater proportion of men than the comparison groups. Second, patients with dementia often restrict driving, with studies identified in this paper showing fewer than half the miles driven per day[38] or per week.[34] Many patients also stop driving independently or are taken off the road prior to a MVC. Third, there may be a reluctance by proxies to report MVCs because of the implications for a family member with dementia, with data suggesting that the nature of the relationship to the proxy is pertinent: Adult children may also be better predictors of driving ability than spouses.[54] Fourth, as found with earlier syntheses,[18,19,49,52] sample sizes of these studies are small, creating a significant risk of Type II error. None of the included studies presented sample size calculations for the outcomes of interest, and six of them explicitly described their samples as small. It is also important to note that MVCs are, in general, low-probability events; thus, one would need very large sample sizes for these types of analyses. Such large sample sizes are unlikely in these types of studies; thus MVCs might not be the most insightful measure with which to inform guideline revisions for driving and dementia.

We have identified important gaps in the literature. Very little data are available on drivers with moderate dementia, as measured by the CDR scale. This is likely because of the observation that few are able to operate a motor vehicle at this level of dementia severity and what little data we have indicates that the majority of these drivers fail a basic road test.[55] Only one study was longitudinal.[35] The lack of careful screening of controls for cognitive impairment in some of the studies[38,41] may have diluted between-group differences. In addition, some authors included questionable dementia cases, indicating that some of the "dementia" samples may have included cases with MCI or other etiologies that may not have been related to a neurodegenerative brain disease. The higher age and greater proportion of men in the dementia groups may have conversely exaggerated between-group differences and limited generalization. Varying on-road assessments (Table 1) and definitions of dementia (see Supplemental Digital Content 5) make comparisons difficult. On-road assessment studies in drivers with dementia are often difficult to administer because of time needed, reluctance of participation, safety issues, and legal and human study requirements. Selection bias may have also partially influenced the results, as patients who are agreeable to participating in research can differ from nonparticipants on several characteristics (lack of interest, fear of license withdrawal after the assessment, discomfort with driving on an unfamiliar route, etc.).[37]

A limitation of this review is that we were only able to incorporate literature up though October 30, 2015, as that was when we conducted the study, and we relied on earlier high-quality seminal systematic reviews for literature published before 2005. We are aware of a study that was published in 2016, after the process of the present systematic review—that study had similar findings to the paper by Ott et al.,[35] reporting an almost twofold higher MVC risk in the dementia group compared with healthy controls in the 3 years prior to their diagnosis, and a 93% lower MVC risk than the controls in the subsequent 3 years.[56] In addressing our research question, it was also not feasible for us to search for studies that: appeared in the gray literature (conference presentations and proceedings, dissertations and unpublished manuscripts, technical reports, etc.) or were not published in English. Although the topic of MCI and driving is important, we excluded this a priori from the scope of our time-limited review. We anticipated that the plethora of different diagnostic criteria for MCI would significantly complicate the interpretation of our focus on dementia and driving risks.[57] Nonetheless, some patients with CDR 0.5 may have had mild dementia, but it is possible that they had MCI instead, as there is considerable potential for overlap.

Unfortunately, there were very few studies that specifically addressed our primary research topic. It was therefore not possible to draw conclusions on the influence of different types of dementia on MVC risk or driving impairment as intended, because experimental group participants were often treated as one group for statistical analyses within studies despite clinical differences (e.g., CDR 0.5 and 1). Different types of dementia (AD versus other common non-AD neurodegenerative dementias) are likely to have different implications for driving safety and MVC risk based on stage of disease and should be explored in future research.

CONCLUSIONS

We conclude that dementia, even in the very mild or mild stages, places an older adult at a higher risk to fail a performance-based on-road assessment, although a substantial proportion of those at a mild level of dementia (CDR 1) may pass an on-road assessment. Dementia is progressive, however, and longitudinal studies have shown that over time CDR 1 participants (with a diagnosis of AD) are increasingly likely to fail repeat assessments.[51] This is a challenging area to research because, as shown in one epidemiological study, 78% of drivers with dementia at a CDR of 1 had already stopped driving.[50] Thus, those individuals with mild dementia who continue to drive may be a select group that have not yet lost specific cognitive skills (e.g., executive function) that may be key for driving.

Our review has highlighted consistent findings of on-road driving impairment, driving errors, and failure on on-road tests among patients with dementia compared with controls, and is the first to synthesize the findings about on-road test failure in a meta-analysis and to calculate effect sizes for the areas of driving impairment. Interestingly, miles driven was significantly lower, with a large effect size in two of the studies.[36,38] This may be considered a particular red flag when assessing driving safety. We have also highlighted how findings relating to MVCs, in contrast, are quite variable in the literature. These findings are particularly important because most of the participants have had mild dementia, and even these individuals may represent a particularly mild subgroup of patients with mild dementia who have not yet stopped driving. Other driving behaviors were found to differ with large effect sizes as well, and these, too, may be considered red flags in clinical discussions with family members—including problems identifying landmarks or signs, lost trips, not wearing a seatbelt, and also less freeway driving and more close-to-home and daylight-only driving. Our review has also highlighted methodological problems with the literature to-date.

Because driving with dementia is anticipated to become an even larger issue with the aging of the population, new directions for research in this area may be needed in the future. This may incorporate multidimensional assessment of function, such as including patients at the milder end of the spectrum of dementia (including narrowly defined MCI), measures of driving exposure, and the use of naturalistic monitoring with technology (a trend that can be seen emerging in this literature). Given the limitations of adopting the CDR in clinical practice (lengthy time to administer, need for a trained observer/rater with suitable clinical experience, etc.),[58] other methodologies for rating dementia severity may need to be considered. Current reviews of the ability of cognitive testing to predict driving performance have not been encouraging,[18,19,49,52] and it is noteworthy that none of the studies or reviews seek to relate their palette of tests to modern theories of driver behavior:[59] Similar gaps in our knowledge relate to matching models of driving behavior to the International Classification of Functioning, Disability, and Health.[60] This review should prompt future researchers to expand their perspective to embrace assessments that map onto models of driver behavior and function. Functional capacity should also play a crucial role in driving performance;[61] not all dementias impact function in the same way. For example, performance on activities of daily living (ADLs) can be used to distinguish between persons with mild cognitive impairment, dementia, and healthy comparisons.[62] Considering that driving is one of the most challenging instrumental ADLs (IADLs), assessing an individual's level of functional capacity may offer additional insight into their ability to drive, although admittedly this will be incomplete without an on-road driving assessment. More on-road assessment studies in older adults with dementia are needed to enhance confidence in on-road assessment prediction, as is more discussion among clinicians, to find common ground to define dementia severity (e.g., only two of the included studies report

CDR scores and eight of them provide other indicators of severity; see Supplemental Digital Content 5). Research on MVC data and older adults with dementia is necessary but challenging because of a reduction in driving exposure. Research linking lack of insight into loss of IADLs with driving performance are also recommended. Although not covered in the present review, MVC data may play a more important role in MCI and preclinical dementia as these diagnoses become more commonplace. Technology (e.g., instrumented vehicles, GPS tracking, and other data sensors) may offer interesting solutions to carefully studying the longitudinal deterioration in driving ability of patients with dementia.[38,40,63]

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Several of the authors have publications on the topic that were included as part of the review. To mitigate the associated risk, the authors were not involved in the screening or data extraction of their own publications (MJR, DBC, SC, NH, JD, JC, SM, JPT, JD, KO). Several coauthors disclosed research grants/funding for their work (MJR, DBC, SC, NH, JD, JC, KL, SM, FM). Potential conflicts of interest were declared by MJR (Canadian Academy of Geriatric Psychiatry board president; consultancy at the Canadian Medical Association), DBC (board membership for Memory Care Home Solutions, Dementia Organization, and the Advocacy Committee for the Alzheimer's Association; consultancies at ADEPT, MEDSCAPE, Traffic Injury Research Foundation, and AAA Foundation for Traffic Safety; legal cases on medical conditions and driving), SC (honoraria from National Institutes of Health and Canadian Association of Occupational Therapy), NH (research support from Lundbeck and Roche; consultancies at AbbVie, Astellas, and Merck; honoraria from Pfizer, Lundbeck, and Novartis), JC (board membership for BrainLink; consultancies at the Royal College of Physicians of Ireland, and National Transportation Commission), SM (consultancies at the Canadian Medical Association, the Ministry of Transportation of Ontario, and from physicians; expert testimony on traumatic brain injury; honoraria for peer-reviewed speaking activities), and FM (consultancy at the Canadian Medical Association). All other authors have no disclosures.

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APPENDIX: SUPPLEMENTARY MATERIAL

Supplementary data to this article can be found online at doi:10.1016/j.jagp.2017.05.007.

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