

Seniors face serious driving safety and mobility issues.



Associations Between Falls and Driving Outcomes in Older Adults: A Systematic Review and Meta-Analysis

A LongROAD Study

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Title

Associations Between Falls and Driving Outcomes in Older Adults: A Systematic Review and Meta-Analysis: A LongROAD Study. (March 2016)

Authors

Kenneth A. Scott, MPH¹, Eli Rogers,² Marian E. Betz, MD, MPH,² Lilian Hoffecker, MS, PhD, MLS³; Guohua Li, MD, DrPH,⁴ Carolyn DiGuseppi, MD, MPH, PhD¹

¹*Department of Epidemiology, Colorado School of Public Health, University of Colorado Anschutz Medical Campus*

²*Department of Emergency Medicine, School of Medicine, University of Colorado Anschutz Medical Campus*

³*Health Sciences Library, University of Colorado Anschutz Medical Campus*

⁴*Center for Injury Epidemiology and Prevention; Department of Anesthesiology, College of Physicians and Surgeons; and Department of Epidemiology, Mailman School of Public Health; Columbia University*

About the Sponsor

AAA Foundation for Traffic Safety
607 14th Street, NW, Suite 201
Washington, DC 20005
202-638-5944
www.aaafoundation.org

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About LongROAD

Safe mobility is essential to healthy aging. Recognizing that lifestyle changes, along with innovative technologies and medical advancements, will have a significant impact on the driving experiences of the baby boomer generation, the AAA Foundation for Traffic Safety has launched a multi-year research program to more fully understand the driving patterns and trends of older drivers in the United States. This multi-year prospective cohort study is being conducted at 5 sites throughout the country, with 3,000 participants, tracking 5+ years of driving behaviors and medical conditions. The multidisciplinary team assembled to investigate this issue is led by experienced researchers from Columbia University, University of Michigan Transportation Research Institute and the Urban Institute.

The LongROAD (Longitudinal Research On Aging Drivers) Study is designed to generate the largest and most comprehensive data base about senior drivers in existence and will support in-depth studies of senior driving and mobility to better understand risks and develop effective countermeasures. Specific emphasis is being placed on issues related to medications, medical conditions, driving patterns, driving exposure, self-regulation, and crash risk, along with mobility options for older Americans who no longer drive.

Abstract

Objectives

Driving is an important indicator of mobility and well-being for older adults. Prior work suggests falls may increase the risk of subsequent motor vehicle crash (MVC) or other adverse driving outcomes. To inform efforts to enhance older adult health and well-being, we aimed to examine the associations of falls with subsequent MVCs, crash-related injuries, and driving performance and behavior.

Methods

Systematic review and meta-analysis of adult drivers aged 55 and older or with a mean age of at least 65. Two authors independently extracted study and participant characteristics, exposures and outcomes and assessed risk of bias. Pooled risk estimates for MVCs and MVC-related injuries were calculated using random-effects models. Other results were synthesized narratively.

Results

From 3286 potentially eligible records, 15 studies met inclusion criteria; sample size ranged from 27 to 17,349 subjects. A fall history was associated with a significantly increased risk of subsequent MVC (summary risk estimate=1.40; 95%CI 1.20, 1.63; $I^2=28\%$), based on five studies. One cohort study found a significantly increased risk of MVC-related hospitalizations and deaths after a fall (adjusted hazard ratio=3.12; 95%CI: 1.71, 5.69). Falls were associated with a modestly elevated risk of crash-related injuries, but the pooled risk estimate from the two relevant studies was not statistically significant (1.34; 95%CI 0.94, 1.92; $I^2=0\%$). There was inconclusive evidence for an association of falls with driving cessation and no association of falls with conditional driving avoidance, driving difficulty and driving frequency, distance or space.

Conclusions

Falls in older adults are associated with a significantly increased risk of subsequent MVCs. Evidence also suggests that older adults might be at an increased risk of MVC-related injury after a fall. Rigorously designed studies are needed to clarify the relationships between falls, driving behaviors and driving safety among older adults.

Introduction

The ability to travel throughout the community allows people to live independently, access goods and services, preserve social bonds and engage with civic institutions.¹

Transportation in the community is considered an *instrumental activity of daily living* (IADL), along with the ability to, for example, manage money and prepare meals.²

Automobile travel is the only practical transportation option in many areas, especially rural regions.³ Driving is thus an IADL that promotes health and independence.⁴

Among older adults, falls are a common and preventable cause of injury that could potentially adversely affect driving and thereby reduce older adults' ability to travel within a community. A fall is defined as an event in which a person comes to rest inadvertently on the ground or floor or other lower level. Theoretically, falls have the potential to affect driving via three main pathways. First, falls can directly limit functional mobility by causing physical injury and disability.^{5, 6} A wrist fracture resulting from a fall, for example, may reduce a person's ability to shift gears or change a vehicle's direction quickly. Such injury-related functional limitations could either increase MVC risk by diminishing functional abilities while driving or decrease MVC risk by leading to a reduction in driving frequency or duration. Second, a fall may indirectly lead to reduced functional ability by way of physical and cognitive deconditioning. It is common for a fall to increase an individual's fear of falling and for him or her to limit physical activity as a result.^{7, 8} Reductions in physical activity may, in turn, lead to physical and cognitive deconditioning, increased risk of further falls and functional mobility impairment.^{8, 9} Such impairments can reduce driving performance and, as with direct injury-related functional limitations, either increase or decrease overall motor vehicle crash risk.^{10, 11} Third, a fall might precipitate behavior change among an older driver by heightening self-awareness of age-related physiological changes or precipitating a more general fear of injury.¹²⁻¹⁷ Even if functional changes have not developed as a result of the fall, awareness of physical changes or a fear of injury may lead to self-restricting driving behaviors (e.g. reduced mileage, day-driving only, etc.). Self-restricting driving behaviors could reduce overall MVC risk by reducing driving exposure or reducing driving in potentially hazardous conditions. In other words, falls could precipitate self-regulation among older drivers. In addition to the three primary pathways by which a fall might cause a change in driving risk or driving behavior, a fall may also act as an indirect marker of increased driving risk. Falls and motor vehicle crashes share certain risk factors. The use of benzodiazepine medications, for example, is independently associated with both falls¹⁸ and motor vehicle crashes.¹⁹ Identifying risk factors shared by both falls and motor vehicle crashes may lead to interventions that prevent both fall injuries and motor vehicle crash injuries.

Whether falls are associated directly or indirectly with driving outcomes, one way to prolong older adults' independent mobility in their communities may be to prevent falls or reduce fall-related risk factors. Effective fall prevention programs exist²⁰ that can prolong older adults' independent mobility by preserving health, maintaining functional abilities and reducing fear of injury that may impede physical and social activity. Fall prevention programs that have been established as effective at reducing the rate or risk of falls include: multiple-component group exercise programs (e.g. Tai Chi); multifactorial interventions that include individual risk assessment; home safety assessments; pacemakers in people with certain heart conditions; "first cataract surgery" (i.e., when

cataract surgery is performed on the first affected eye); a medical management of certain medications; and certain activities focusing on footwear.²⁰ If falls directly or indirectly contribute to crashes and other adverse outcomes, fall prevention has the potential to interrupt the causal chain. Additionally, considering falls as a marker of declining functional abilities, some fall prevention interventions proven to be effective also target factors relevant to motor vehicle crashes. “First cataract surgery”, for example, has been found to reduce motor vehicle crashes,^{21, 22} in addition to falls. Rehabilitative interventions that improve functional ability and self-efficacy subsequent to a fall may also have beneficial impacts on driving behaviors and safety. Interventions that targeted drivers after a stroke or an acquired brain injury may serve as useful models.²³

To inform efforts to enhance older adult health, mobility and well-being, we sought to systematically review the observational (that is, non-experimental) research literature characterizing relationships between falls in older adults and subsequent driving behaviors and outcomes, and to synthesize data across studies on the associations between falls and subsequent driving activity and performance and motor vehicle crashes (MVCs). We hypothesized that falls would be associated, either positively or negatively, with subsequent changes in occurrence of MVCs as well as changes in driving performance and activity.

Methods

Study Population

Eligible studies examined human subjects aged greater than or equal to 55 years or a subject sample with an average age of at least 65 years to allow for the fact that some studies of older drivers may report only mean ages. While the risk of a fall increases exponentially after age 65, fall risk begins to increase at age 45²⁴ and age-related functional changes that influence fall risk begin at much younger ages.²⁵ We excluded studies that did not report subjects' ages.

Study Exposure

The primary exposure of interest was falls. For the purpose of this review, we included any study that specified the assessment of "falls," regardless of how falls were defined by the original study author. Studies in which the exposure was fall-related injuries (as defined by the original study author) or fractures (the majority of which, in older adults, result from falls²⁶) were also eligible for inclusion, since such injuries may be the means through which falls affect driving outcomes. The occurrence of a fall or fall-related injury is typically measured by asking study participants how many times (or whether) they fell, or had a fall-related injury, over a specified number of weeks, months or years. We also included studies that measured falls using an objective measurement device (e.g. video camera, accelerometer, etc.) and studies that examined health records to identify falls or fall-related injuries. We excluded studies in which the only exposure was a self-reported fear of falling or a measure of fall risk.

Study Outcomes

We examined any outcomes related to driving, including self-reported and objectively measured driving behaviors (e.g., reduced distance traveled, avoidance of night driving, driving cessation), performance on driver assessments (e.g., on-road driving test), legal violations and actions (e.g., speeding, license revocation), motor vehicle crashes and crash-related injuries.

Study Designs

Eligible designs include controlled observational studies (cohort, time-series, case-cohort and case-control studies) that examined the association between falls or fall-related injuries and subsequent driving behaviors and outcomes. Controlled observational studies were defined as studies in which researchers assessed statistical associations between one or more exposures and one or more outcomes without intentionally intervening to influence the likelihood of the outcome(s) of interest. We also included cross-sectional studies that examined the relationship between previous falls or fall-related injuries and current driving behaviors, as supporting evidence. We excluded cohort, case-control and cross-sectional studies when it was unclear whether the fall occurrence preceded measurement of the driving outcome. For example, if a cross-sectional study measured self-reported falls in the past year and current driving status, it would be included. If a cross-sectional study

measured self-reported falls in the past year and records of crashes in the past year, it would be excluded.

Search Strategy, Data Sources, and Extraction

Search Strategy & Data Sources

The search strategy was developed and performed with assistance from a medical research librarian. The strategy combined text word terms and appropriate subject headings related to the concepts of accidental falls (e.g., fall, slip, stumble), driving outcomes (e.g., accident, automobile driving, driver behavior), and aging (e.g., geriatric, elderly, aged). Relevant studies were identified through a comprehensive search of electronic bibliographic databases, including: MEDLINE (via Ovid), EMBASE (via Embase.com), PsycINFO (via Ovid), CINAHL (via EBSCO), Web of Science (via Thomson Reuters) and the Transportation Research International Documentation or TRID (via the National Academies of Sciences, Engineering and Medicine). The electronic search strategies are shown in Appendix B. To capture research studies that were not published in peer-reviewed journals, such as technical reports, unpublished manuscripts, or ongoing research (referred to as ‘gray’ literature), we searched TRID, NIH Reporter, ProQuest’s Dissertation and Theses Database, and websites of organizations involved in older adult traffic safety (including AAA Foundation for Traffic Safety, National Institute on Aging, MIT AgeLab, Insurance Institute for Highway Safety, National Highway Traffic Safety Administration, Transportation Research Board, and AARP, Inc.). No language, date or document type restrictions were applied in the search. For each study identified as ‘included,’ we reviewed the reference list and used a lateral search function (cited by) to identify additional relevant studies for this review. The retrieved references were imported into EndNote and duplicate records were removed. The searches were complete through August 2015.

Selection of studies

Two reviewers independently examined titles, abstracts and keywords of retrieved records to exclude ineligible studies. Those that appeared to meet inclusion criteria or that could not definitely be excluded based on this initial screen were retrieved in full-text.

For the initial screen, any potentially eligible record identified by either investigator was retrieved in full text. Hence, if the first investigator who screened records marked a record as potentially eligible, the second investigator did not review that record, since it would be retrieved regardless. For this reason, reliability statistics cannot be accurately calculated for the initial screen. It should be noted that of 3166 records marked as not eligible by the first investigator, only 10 (0.3%) were changed to “potentially eligible” by the second investigator.

After the initial screen of titles, abstracts and keywords had identified potentially eligible records, two reviewers independently determined eligibility of each record based on full-text review. The two reviewers were in agreement with 88.5% of the full-text articles that were reviewed. Disagreements were resolved by discussion.

Data extraction and management

One investigator extracted data from included studies using a structured abstraction form; a second investigator reviewed and confirmed the accuracy of extracted data. The abstraction form included: primary author; publication year; country; study design characteristics; sample characteristics; fall exposure measures; driving outcome measures; covariates; statistical methods; and results. Additional information was sought from corresponding authors when relevant data were not reported.

Risk of Bias Assessment

Risk of bias in each individual study was independently assessed by two investigators using the Newcastle-Ottawa Scale (N-OS)²⁷ for cohort and case-control studies; disagreements were resolved by discussion. The N-OS used for cohort studies was adapted for assessment of the cross-sectional studies by excluding three items deemed not relevant for this design (outcome shown not to be present at start of study, and length and adequacy of follow-up). All cross-sectional studies were considered to have high risk of bias based on inability to assess the temporal relationship between falls and driving outcomes. Although scores cannot be directly compared across study types, for all types of studies a higher N-OS score indicates less risk of bias.

Statistical Analysis and Data Synthesis

Measures of association

We extracted crude and adjusted risk estimates when reported. For continuous data, means and standard deviations were used to estimate standardized mean difference (SMD) values, which were converted to odds ratios (ORs) using the Cox logit formula.²⁸

Assessment of heterogeneity

We analyzed statistical heterogeneity using the Cochran's Q and I² tests.²⁹ As Cochran's Q test has low power to detect heterogeneity with a small number of studies, we used an alpha of P<0.10 for this test.³⁰ We considered statistical heterogeneity to be high if the I² statistic was ≥ 50% with a P value <0.10, moderate if one of these two criteria was met, and low if the I² statistic was ≥25% and <50% with a P value ≥0.10.

Assessment of reporting biases

To reduce reporting bias, we searched for studies without publication, date or language restrictions and asked authors for unreported data. Funnel plot tests to assess publication bias were planned, but data were not sufficient.³¹

Data synthesis

We grouped studies according to outcome type (motor vehicle crashes, crash-related injuries, self-imposed driving restrictions, conditional driving avoidance, conditional driving difficulty and other outcomes). We considered both statistical and clinical heterogeneity

within each outcome category. Where sufficient data were available and visual examination of results and test statistics indicated low or no heterogeneity, results were combined quantitatively using a random effects model. Study-specific adjusted risk estimates (i.e., hazard ratios, rate ratios or odds ratios) were combined using the generic inverse variance method of Dersimonian and Laird.³² All summary risk estimates were calculated using R.³³
³⁴ Forest plots were created to show the distribution of the association of falls with the driving outcome overall and by subgroup where appropriate. All other results were summarized in narrative form.

Figure 1. Flow diagram of identification, review and selection of articles included in the systematic review

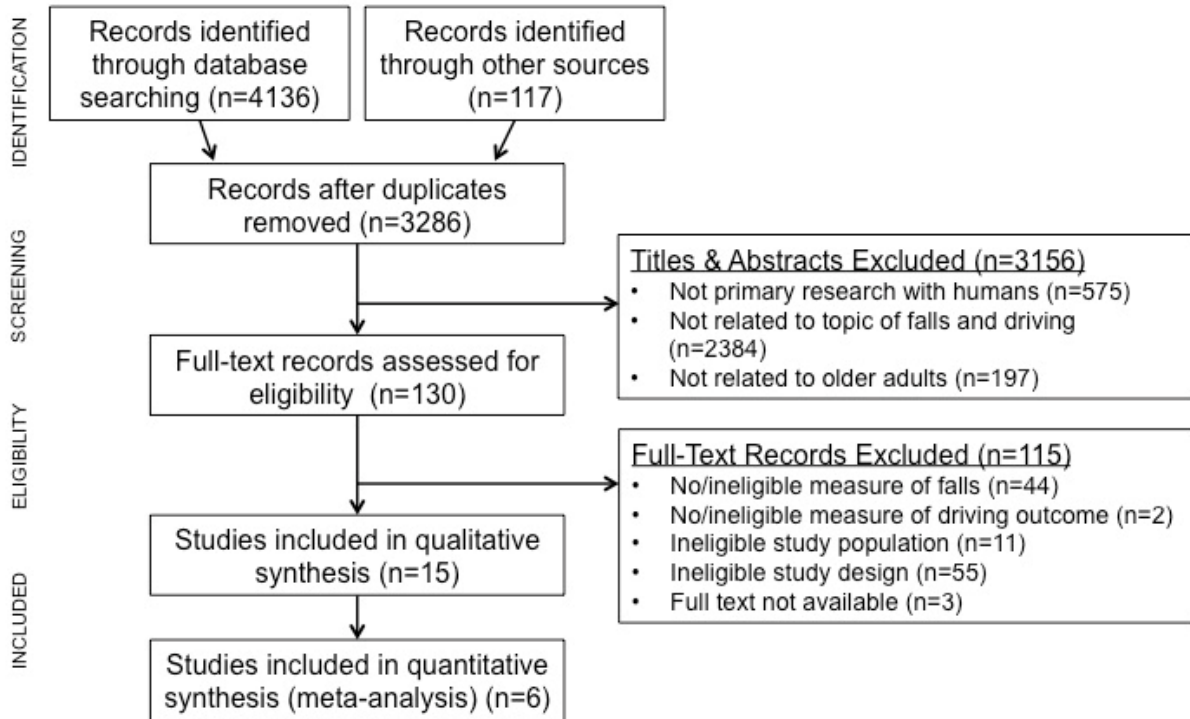


Figure 1 Legend.

Adapted From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-analyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed100009

Results

A total of 3286 unduplicated records were identified and screened for eligibility, of which 3156 were excluded based on title, abstract and keywords. Three-fourths of the excluded records were not related to the topic of falls and driving despite including relevant terms in the title, abstract or keywords (e.g. “the main factors **driving** the **falling** enzyme levels...”).

Full-text articles or reports were sought for 130 records that could not be excluded based on title, abstract or keywords alone, of which three records (2%) could not be retrieved despite attempted author contact. One author no longer had a copy of the requested document, one study was published in a now-defunct newsletter (hence was unlikely to meet study design criteria), and authors of the third article did not respond to our request. The full texts of the remaining 127 records were reviewed, of which 15 met eligibility criteria (see Figure 1).

All 15 eligible studies were published English-language journal articles. There were 10 cohort studies, 2 case-control studies and 3 cross-sectional studies.³⁵⁻⁴⁹ One study was conducted in Canada,³⁶ one in France,⁴⁶ one in 40 countries from around the world,⁴¹ and the rest in the United States. Study participants included older adults recruited from motor vehicle licensing agencies,^{35, 49} clinical settings,^{36, 39, 41, 42} and the community.^{37, 38, 40, 43-48} Two studies examined the same subjects for different outcomes.^{35, 49} All studies that specified the method of exposure assessment measured falls by self-report. Three studies also examined self-reported fall injuries or fractures, although only two analyzed these injuries in relation to driving outcomes.

Seven studies examined motor vehicle crashes, based on police (n=5) or self (n=2) reports (see Table 3). Three studies examined injurious crashes or crash-related injuries. The most commonly measured behavioral outcome was driving restriction (e.g., cessation, fewer trips, shorter distance), assessed in twelve studies. Four studies measured driving difficulties, and three examined avoidance of driving in adverse or difficult conditions. Three examined other driving outcomes. Characteristics of the included studies are described in Table 1.

Risk of bias

Table 2 shows the risk of bias assessments for all included studies, categorized by study design and scored using the Newcastle-Ottawa Scale (N-OS), with higher scores indicating less risk of bias. Scores for the 10 cohort studies averaged 6.4 (range 4-9) out of a maximum possible score of 9. Scores for the two case-control studies averaged 7.5 (range 7-8) out of a maximum possible score of 9. Cross-sectional study scores averaged 3.7 (range 3-4) out of a maximum possible score of 6. Points were most commonly taken off for lack of representative samples (4 of 10 cohort studies), lack of adequate follow-up (4 of 10 cohort studies), lack of an independently validated case definition (both case-control studies), measurement of self-reported current driving behaviors at the same time that history of past fall exposure was measured (all three cross-sectional studies), and self-reported or unspecified ascertainment of falls (9 of 10 cohort studies and all three cross-sectional studies). In contrast, all but three studies controlled for multiple potentially confounding variables, thus reducing risk of bias.

Driving outcomes in relation to falls

Table 3 summarizes the relationships between driving-related outcomes and both falls and fractures.

Motor vehicle crashes and crash-related injuries

Six cohort studies (one of which analyzed this outcome as a nested case-control study)³⁵ and one case-control study evaluated police- or self-reported motor vehicle crashes. Results from Sims et al (2000)⁴⁷ are not reported here because this cohort is also analyzed as one of the four cohorts included in Cross et al.³⁷ Another cohort study collected self-reported crashes as primary driver, but did not report these results.⁴⁶ The other five studies all demonstrated increased risk of crashes following self-reported falls, which was statistically significant in four of the studies. Risk of bias for these five studies was low to moderate, with a mean N-OS score of 7.4 (range 6-9). Three cohort studies reported rate or hazard ratios and two case control analyses reported odds ratios. The combined results demonstrated a significantly increased risk of motor vehicle crashes after falls, with low heterogeneity (summary risk estimate=1.40; 95%CI 1.20, 1.63; Q=4.31, p=0.366; I²=28%) (Figure 2). When stratified by survival versus case-control analysis, results in each stratum were similar in magnitude, direction, and statistical significance to the overall results (Figure 2). Exclusion of the cohort study with the lowest N-OS score³⁷ did not materially change results (summary risk estimate=1.38; 95% CI: 1.16, 1.63). There were too few studies included in this meta-analysis to create a funnel plot.

All three studies evaluating crash-related injuries revealed increased risk associated with self-reported falls. Risk of bias was moderate (mean N-OS score 6.7; range 6-7) for the three studies. Results from Joseph et al⁴¹ were not combined quantitatively with the other two studies^{37, 42} because visual examination of results and test statistics (Q=5.69, p=0.058; I²=66%) indicated high heterogeneity for these outcomes across the three studies, which may have been due to the fact that Joseph et al⁴¹ examined only hospitalizations and deaths, while the other two studies^{37, 42} included all recorded injuries, some of which may have been minor injuries (Table 1). Joseph et al⁴¹ reported a significant association between a fall in the prior year and death or hospitalization resulting from a motor vehicle crash in which the subject was driving (adjusted Hazard Ratio=3.12; 95% CI: 1.71, 5.69). Both Cross et al³⁷ and Koepsell et al⁴² reported modestly increased risk of a crash-related injury after a fall, without heterogeneity, that may have been due to chance (summary risk estimate=1.34; 95%CI 0.94, 1.92; Q=0.11, p=0.740; I²=0%) (Figure 3).

Driving restriction

Twelve studies examined various self-imposed driving restrictions. Driving restrictions reported in the studies include driving cessation, driving frequency, driving distance, driving duration and driving space, which were measured in a variety of different ways. Only six studies provided quantitative results, three of which provided data for only a subset of the relevant outcomes measured. Further, three of the six studies that did report data were cross-sectional. A seventh study indicated that the reason for not reporting any quantitative results was that there was no significant association found. Among the seven studies reporting any results, risk of bias was low to moderate (mean N-OS score=6 [range

5-7]) for cohort studies and high (N-OS score=3.7 [3-4] for cross-sectional studies. The remaining five studies that assessed this outcome did not report their findings. Given study limitations and apparent reporting bias, we did not combine data quantitatively for any outcomes within this category.

Driving Status

Six cohort studies measured the association between falls and current driving status or change in driving status, including driving cessation, of which three did not report results. MacLeod⁴⁴ demonstrated a two-fold increased risk of stopping driving within five years among those who had fallen (RR=2.1; 95% CI: 1.3, 3.4). Dugan and Lee³⁸ found a minimally increased odds of no longer driving two years after a self-reported fall (adjusted OR=1.09; 95% CI: 1.0, 1.18; p=0.045); the association was stronger for those with a self-reported hip fracture at baseline (adjusted OR=1.43; 95% CI: 1.08, 1.89, p=0.014). Marie Dit Asse et al⁴⁶ reported no significant association between fall history and subsequent driving cessation, without reporting the data. One cross-sectional study³⁹ also reported no association of fall history with present driving status (without data), while fracture history was significantly associated with current driving status (OR=1.79; 95% CI: 1.11-2.91).

Driving Frequency

Four studies examined driving frequency. The only cohort study³⁶ found no association between having fallen and subsequent number of trips taken per week, measured objectively through a device installed in the vehicle (OR=1.18; 95% CI 0.33, 4.28). All other studies examining driving frequency were cross-sectional. Lyman et al⁴³ found no association between falls and low number of driving days per week (adjusted OR=1.1; 95% CI: 0.6, 2.1) and Forrest et al³⁹ similarly reported no association between either falls or fractures and trip frequency (without reporting quantitative data). Vance et al⁴⁹ administered the Driving Habits Questionnaire (DHQ), which measures trip frequency, but did not report results.

Driving Distance

Three cohort studies and one case-control study, as well as three cross-sectional studies, assessed one or more measures of driving distance in relation to fall history, including average distance traveled per week (n=5) and estimated annual mileage (n=3). Crizzle et al³⁶ found that fallers and non-fallers drove similar (objectively measured) average miles per week (OR=0.97; 95% CI: 0.27, 3.51). A second cohort study⁴⁶ also reported no association between fall history and self-reported weekly driving distance (without providing data). The third cohort study⁴⁵ and a case-control study⁴⁸ measured driving distance but did not report findings. Of the three cross-sectional studies that examined weekly or annual mileage, two^{39, 49} did not report their findings for this outcome, while the third⁴³ found no association between falls and low annual mileage (OR=0.8; 95% CI: 0.4, 1.3), supporting the cohort study findings. However, it is unclear whether the fall exposure preceded the outcome in this study.

Driving Space

Only one cohort study assessed driving ‘space’ (defined as the area in which an individual drives), as did two cross-sectional studies. Crizzle et al³⁶ demonstrated non-significant reductions in objectively measured maximum and average radius traveled per week associated with self-reported falls (OR=0.41; 95% CI: 0.11, 1.50, and OR=0.51; 95% CI: 0.14, 1.87, respectively). One cross-sectional study³⁹ reported “no association” between history of falling and having undertaken a trip of >100 miles in the past year; another⁴⁹ assessed but did not report quantitative results. Another cross-sectional study³⁹ reported a significantly increased odds of avoiding trips >100 miles among those with a history of a fracture (OR=2.61; 95% CI: 1.32, 5.16), although it is unclear if the fracture preceded this driving restriction.

Driving Exposure

As noted above, Vance et al⁴⁹ administered the Driving Habits Questionnaire (DHQ). The measures of driving frequency, distance and space included in this instrument were standardized and summed to form a composite “Driving Exposure” outcome. This cross-sectional study reported no correlation between number of falls and driving exposure ($r=-0.05$, 95% CI: -0.12, 0.02).

In summary, there is conflicting evidence regarding an association between falls and driving status (including cessation), and no evidence of any association between falls and other driving restrictions, including frequency, distance, and space. There was some support for an association between history of fractures and both driving cessation and space (but not trip frequency), but only two studies examined this exposure. Large proportions of the studies assessing the relationships between falls or fractures and driving restrictions did not report their results. Risk of bias among the studies, particularly those of cross-sectional design, further reduces confidence in the findings.

Conditional driving avoidance

Three studies examined avoidance of driving under certain conditions, such as driving at night, on highways, or alone, of which two (mean N-OS score=4.5) reported data. In a cohort study that used objective measurement,³⁶ fallers made significantly more highway trips (OR=3.85; 95% CI: 1.01, 14.64) and appeared to make more freeway trips although confidence intervals included the null value (OR=1.88; 95% CI: 0.51, 6.86). None of four measures of night driving (average numbers of nights driven and of night trips and average time and distance driven at night) in this study differed significantly between fallers and non-fallers. A cross-sectional analysis within the same cohort study, and two cross-sectional studies also assessed this outcome. The cohort study³⁶ administered the Situational Driving Avoidance Scale concurrently with taking a fall history, and found no difference between fallers and non-fallers in mean score (OR=1.10; 95% CI: 0.31, 3.99). One cross-sectional study⁴⁹ combined a range of self-reported measures (e.g., avoidance of driving at night, on the highway, and alone) into a “driving avoidance” composite score, which was positively correlated with number of self-reported falls ($r=0.15$; 95% CI: 0.08, 0.22). Another cross-sectional study³⁹ also examined driving avoidance but did not report results. Thus, there is limited and conflicting evidence regarding an association between

falls and conditional driving avoidance. Further, risk of bias is high and reporting bias is probable.

Driving difficulty

Included studies measured self-reported “driving difficulty” by asking study subjects whether they had difficulty driving under certain conditions, while performing certain tasks (e.g., left turns), or due to specific health conditions. Only two cohort studies,^{40, 47} along with two cross-sectional studies,^{39, 43} measured driving difficulties, but only one, a cross-sectional study⁴³ (N-OS score = 4) reported results. This study found a significant increased risk of self-reported high driving difficulty associated with a fall history (adjusted OR=1.7; 95% CI: 1.1, 2.8). Evidence regarding this outcome is therefore incomplete, with high risk of bias.

Other driving outcomes

Crizzle et al³⁶ reported objectively measured data for driving speeds in a range of different settings during a two-week period following baseline data collection. The exposure included having experienced one or more falls within one year prior to the baseline visit. With the exception of city driving, fallers drove significantly slower than non-fallers in all settings examined, ranging from a mean of 4.7 kilometers (2.9 miles) per hour slower in residential areas, and about 7 kilometers (4.4 miles) per hour slower in both rural areas and on highways, to 20.9 kilometers (13.1 miles) per hour slower on freeways (all comparisons, $p < 0.05$, Mann-Whitney U test). Two cross-sectional studies^{39, 43} measured self-reported relative driving speed (i.e., driving at a different speed than others on the same road), but neither reported their results. Crizzle et al³⁶ also found that fallers had significantly more objectively measured “hard braking” (≥ 0.35 g force) than non-fallers (OR=8.26; 95% CI: 2.02; 33.73). No other studies assessed this outcome.

Figure 2. Forest plot, individual and summary risk estimates, and 95% confidence intervals for the association between falls and motor vehicle crashes

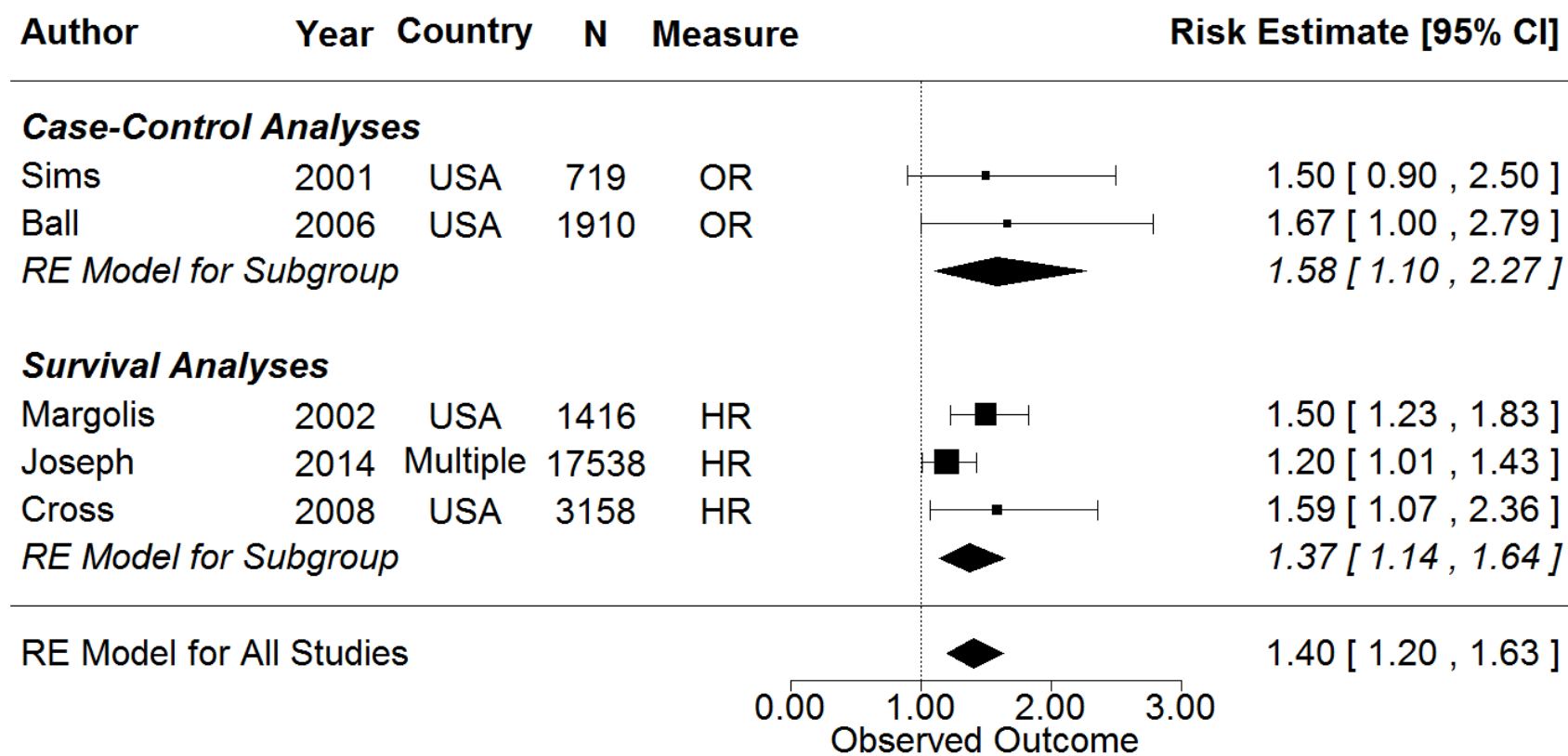


Figure 2 Legend.

The size of each square is proportional to the relative weight that each study contributed to the summary risk estimate. A diamond represents a summary risk estimate. Horizontal bars and diamond spread indicate the 95% confidence interval.

Figure 3. Forest plot, individual and summary risk estimates, and 95% confidence intervals for the association between falls and crash-related injuries

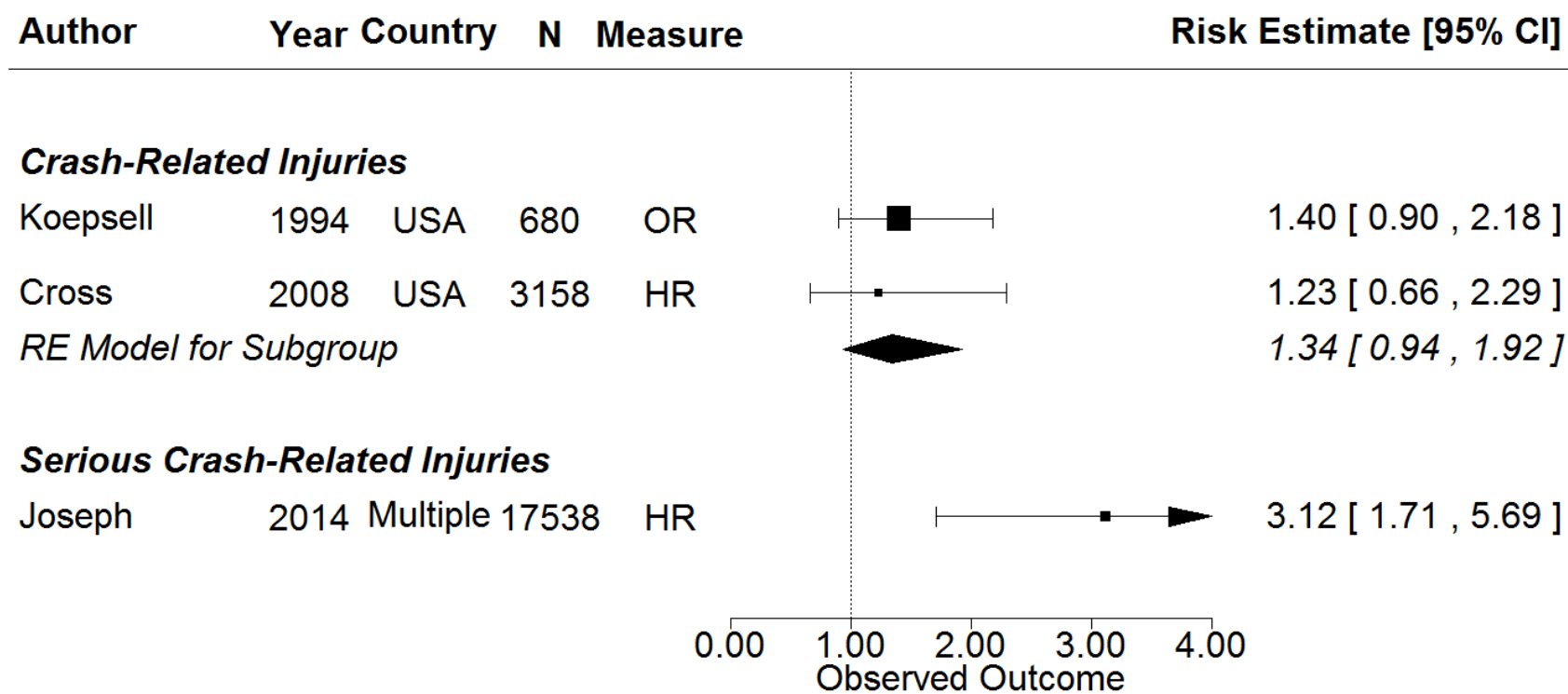


Figure 3. Legend.

The size of each square is proportional to the relative weight that each study contributed to the summary risk estimate. A diamond represents a summary risk estimate. Horizontal bars and diamond spread indicate the 95% confidence interval.

Discussion

In this systematic review, we found that fall occurrences in older adults were associated with subsequent motor vehicle crashes. Older adults who had fallen were approximately 40% more likely to experience a subsequent motor vehicle crash than older adults who had not fallen. Evidence also suggests an association between fall history and subsequent motor vehicle crash injuries though this finding is not statistically conclusive.

The exact mechanisms underlying these relationships remain unclear. It is possible that there are underlying factors that adversely affect functional abilities, leading to both falls and MVCs. Some, but not all, of the included studies adjusted for health conditions or functional limitations that might explain an association between falls and driving risk. The fact that falls maintained a statistically significant association with crashes in studies that adjusted for neuromuscular function,⁴⁵ vision^{37, 41, 45} and cognitive ability,³⁷ as well as other chronic health conditions,^{37, 41, 45, 48} suggests that falls may instead act independently to adversely affect drivers' functional abilities, thereby increasing crash risk. Given the nature of the evidence identified in this review, it is also possible that the identified association results at least in part from confounding or bias.

If the relationship between falls and MVCs is causal, then targeting functional changes common to both falls and MVCs might be one way to reduce the occurrence of both of these adverse events, regardless of whether falls directly increase risk of MVCs or are indirectly associated with MVC risk through a common causal pathway. For example, 'first cataract surgery' has been found to prevent both falls²⁰ and motor vehicle crashes,^{21, 22} and to reduce driving difficulty.⁵⁰ Researchers have initiated trials to improve driver performance⁵¹ and to prevent falls⁵² by improving cognitive ability, which has been linked to both of these outcomes in previous studies.^{53, 54} Improving overall physical and cognitive function through exercise may be another possible intervention strategy. In a comprehensive systematic review, physical activity interventions such as tai chi and other balance-enhancing exercises were proven to prevent falls.²⁰ Evidence also exists that tailored physical activity interventions can improve older drivers' performance. Ostrow et al found that a fitness regimen aimed at improving older drivers' joint range of motion improved driving test scores.⁵⁵ In two trials, Marmeleira and colleagues in Portugal developed and tested an intervention in which older adults executed challenging cognitive tasks while they were also engaged in physical activity.^{56, 57} Using a driving simulator, both trials improved drivers' reaction time. Marottoli, et al found that an intervention designed to address three categories of functional abilities associated with driving difficulty -- axial/extremity conditioning, upper extremity coordination/dexterity and hand strength, and gait and foot abnormalities -- improved driving performance⁵⁸. It is therefore plausible that exercise aimed at improving leg strength, balance, reaction time, joint range of motion, gait abnormalities and cognition (to name a few possible shared risk factors) could both reduce fall risk and improve driving safety. Interventions that reduce both fall risk and motor vehicle crash risk at the same time would be especially valuable as the population ages.

If fall injuries themselves have a direct effect on subsequent driving ability and behavior, rehabilitation programs that improve functional ability and self-efficacy subsequent to a fall could be developed that might improve subsequent driving outcomes. Models of condition-specific driving rehabilitation programs have been described in the literature.²³

Clinicians are well-suited to direct injured patients to prevention and rehabilitation services. Older drivers consider health care providers to be trusted sources of information. While conversations about driving can be difficult, research has shown that older drivers do want to engage with health care providers in conversations about driving safety as long as their opinions are respected and the importance of driving to them is recognized.⁵⁹

While the association between fall history and MVCs was consistently positive and statistically significant for the five studies included in this analysis, it should be noted that a sixth study that collected data on these variables failed to report their relationship.⁴⁶ Investigators may fail to report findings if the association was not tested (e.g., because the association was not of primary interest to the investigator) or because the relationship was tested and was not statistically significant. Under-reporting of statistically non-significant results has been previously documented in the literature.⁶⁰ If Marie Dit Asse⁴⁶ failed to report her results because she found no association, then the true estimate of MVC risk after falls may be smaller than that obtained in our meta-analysis.

The scientific literature identified in this review demonstrated inconsistent evidence regarding an association of falls with driving cessation, and no association of falls with driving frequency, distance and space; conditional driving avoidance; or difficulty with driving. The lack of consistent associations between falls and the reported driving outcomes could be explained by several factors. It is possible that there are no consistent associations – that neither falls nor fall risk factors have any meaningful relationships with older adult driving behaviors or driving difficulty. It is also possible that relationships do exist but that, to date, the heterogeneity of the measures that have been used is masking one or more latent relationships. Finally, considering that one or both of the primary variables of interest were self-reported, it is possible that misclassification is biasing one or more true effects toward the null. Regardless, based on the relatively low quantity and quality of the overall body of evidence identified relevant to these outcomes, additional prospective research using cutting-edge research methodologies is very likely to change these conclusions. Further, within each type of outcome, the measures used were diverse (e.g., objectively measured weekly mileage versus self-reported annual mileage) which makes synthesis of results problematic. Nevertheless, it is plausible that fall occurrence may be associated with changes in driving behaviors. Falls increase individuals' fear of falling, which can make them reluctant to participate in physical activity and subsequently decondition their muscles and coordination.¹⁵ It is possible that falls may decrease older adults' risk tolerance more generally, thus affecting their average driving speed, the number of hard brakes they make, the overall distance they travel and other measures of cautious driving. A study of older adults with Parkinson's disease included in this review provides evidence supporting this hypothesis: participants who had fallen were less confident about their balance and more likely to exhibit hard braking and drive at slower speeds on most roadways; these differences in driving behavior were not explained by differences in disease severity between fallers and non-fallers.³⁶ Alternatively, it is plausible that fallers may drive more, on average, in order to avoid the possibility of falling while walking. Lachman et al found that fear of falling was strongly associated with a lower likelihood that participants would walk several blocks outside.⁶¹ Whether and how falls might change transportation behavior may relate to how, on average, older adult fallers perceive the respective risks of falling and driving. Prospectively-collected data on falls, fear of falling and driving behavior as well as more consistent reporting are needed to empirically evaluate these relationships.

Driving can help older adults maintain independence, mobility and community involvement, thus promoting physical and mental health and longevity.^{11, 62, 63} Some older drivers, however, are at increased risk of crashes^{62, 64, 65} because of medical conditions, medications or age-related deterioration.^{10, 11, 66} “Driving retirement” – the transition from driving to other forms of transportation – is inevitable for most older adults, given data showing that both men and women outlive their safe driving by 7 to 10 years.⁶⁷ However, many older drivers have strong emotional attachments to driving.^{59, 68} Driving retirement has been linked to a number of negative health outcomes,^{69, 70} including depression,^{70, 71} earlier institutionalization,⁶⁶ and even early death.⁷² Our findings showing that falls are associated with subsequent motor vehicle crashes indicate that it may be possible to prolong mobility in the community and prevent falls by developing interventions that target falls themselves or common pathways for falls and MVCs. As suggested by Dugan and Lee, “viewing falls prevention as a potential pathway to continued independence and driving may provide extra motivation” for older adults to participate in preventive interventions.³⁸

The mechanisms underlying the association between falls and motor vehicle crashes, and the relationships between falls and other driving outcomes, warrant further investigation through prospective studies.

Strengths and limitations of the review

We comprehensively searched nine databases, including three databases that capture gray literature materials, using structured searches with guidance from a medical librarian, as well as seeking relevant studies from other sources, and did not limit our search by language, publication status, or year. However, all 15 included studies were published articles and only two studies involved countries in which English is not an official language, raising the possibility of publication and language biases. We may also have missed studies that did not have key search terms in the title, abstract, keywords or subject headings. Due to the wide variety of ways in which the words “fall” and “driving” are used in research studies (e.g., ‘sociodemographic factors may be driving these results’), a free text search for the key concepts in this review would have been impractical. One of the included articles⁴⁴ was not captured by our search of bibliographic databases because falls were not mentioned in the title, abstract or keywords, suggesting that there may be other eligible articles missed by the search.

We used meta-analytic techniques to quantitatively assess the variability and the combined effects of falls on motor vehicle crashes and on crash-related injuries, increasing the precision of these effect estimates. We carefully considered which outcomes to group together for comparison and analysis, resulting in minimal heterogeneity within the meta-analyses. Nevertheless, differences in how the authors measured the exposure (i.e. falls) as well as the various driving outcomes could potentially have biased the findings. The populations included in the systematic review were also diverse, including clinical populations that may not generalize to the general adult population. There could be factors specific to, for example, adults with Parkinson’s Disease, that influence the relationships between falls and driving outcomes. While most of the studies in the meta-analysis assessed crashes through police reports, crash reporting mechanisms may vary by country, state and municipality. Combining studies from different legal jurisdictions is a potential

limitation. A narrative synthesis was chosen for the non-crash driving outcomes due to the variability in reported measures and to the fact that a large proportion of relevant studies did not report all of the associations that were collected and were or could have been tested. While we considered these outcomes too heterogeneous and too incomplete to combine quantitatively, other researchers may have chosen a different approach.

What the LongROAD Study Will Add to the Literature on Falls and Driving

The LongROAD study will be the first of its kind to prospectively explore the relationships between functional abilities, driver attitudes, health conditions and driving outcomes in a large cohort of older US drivers. The quality of the data collected by LongROAD is expected to be particularly high compared to many of the studies included in the current review. Driving behaviors measured by GPS device in addition to self-report will be a significant improvement over studies using only self-reported data. Functional abilities are being measured objectively using validated instruments to assess not only how existing functional abilities affect driving, but how declines in these abilities with age affect driving. Linkages with electronic medical records and administrative driving records will add other measures of health, medical interventions and driving outcomes that avoid reporting bias.

With regard to the specific relationships between falls and driving outcomes, the LongROAD study will enable researchers to:

1. Assess the degree to which objectively-measured functional abilities such as vision or balance explain the relationship between falls and motor vehicle crashes;
2. Test whether demographic, clinical or other individual characteristics modify the relationship between falls and motor vehicle crashes;
3. Characterize the independent effects of fall injuries on long-term functional abilities and motor vehicle crashes;
4. Describe the effects of falls and fear of falling on objectively measured driving behaviors and subsequent motor vehicle crashes;
5. Assess the effects of medical and surgical interventions on motor vehicle crashes and falls;
6. Explore the effects of self-reported physical activity on both falls and motor vehicle crashes.

Conclusion

This systematic review and meta-analysis identified 15 studies that examined the relationship between falls and a subsequent motor vehicle crash or other driving outcome. Studies examining the relationship between falls and non-crash outcomes, including driving cessation, driving restriction, conditional driving avoidance, and driving difficulty found little or no evidence of an association. Bias based on study design, conduct and reporting is likely and precludes any generalizable conclusions about the relationships between falls and driving behaviors. In contrast, a history of falls was consistently positively associated with the occurrence of motor vehicle crashes, although only five studies reported data for this outcome. A few studies also provided some support for an association between falls and subsequent crash-related injuries. The observed association between falls and motor vehicle crashes suggests a relationship between falls and driving risk. While the underlying mechanisms for this relationship have not been fully delineated, it is possible that interventions to prevent falls could also reduce crash risk, and that interventions that address risk factors or causal mechanisms common to both could similarly prevent both types of injury, potentially simultaneously preventing large numbers of fall and MVC injuries worldwide. Before public health interventions are tested and disseminated, more rigorous research can help confirm and clarify the relationships between falls, driving outcomes and common risk factors.

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Appendices

Appendix A. Tables

Table 1. Characteristics of Included Studies (n=15)

Author, Country, Year	Design	Participants	Fall and Fall-Related Injury Measure(s)	Driving Outcome Measure(s)	Covariate(s)
Ball USA 2006 ³⁵	Prospective cohort with nested case-control analysis	1,910 adults aged ≥ 55 (mean age 69; 54% male; 93% white) who had just renewed their licenses at 1 of 3 Motor Vehicle Administration (MVA) field offices in Maryland	Self-reported falls in previous 3 years (Fallers: 14%)	At-fault or fault-unknown MVC reported to the MVA during 4.2-5.1 year follow-up	Self-reported annual miles driven (categorized)
Crizzle Canada 2015 ³⁶	Prospective cohort; cross-sectional analysis for outcome #2	27 drivers with Parkinson's Disease aged 57-82 (mean age 72; 78% male)	Self-reported falls and resulting fall injuries in previous year (Fallers: 41%)	1) Objective driving restriction, conditional avoidance and other driving behaviors (CarChip Pro; Otto Driving Companion) during 2 week follow-up 2) Self-reported driving avoidance at baseline (Situational Driving Avoidance Scale)	None
Cross USA 2009 ³⁷	Prospective cohort	Four distinct cohorts, totaling 3158 licensed drivers, from Alabama (2), Kentucky and Maryland, living independently in the community (mean age 72; 48% male, 82% white, mean 12 years education)	Self-reported frequent falling or tripping: Yes/No (Fallers: 23%)	Police-reported MVC, at-fault MVC, and injurious MVC during 2-6 year follow-up	Unspecified demographic, medical and visual function characteristics
Dugan USA 2013 ³⁸	Prospective cohort	17,349 participants aged ≥ 65 surveyed from 1998-2008 who had complete data (mean age 75; 44% male; 79% non-Hispanic white; 59% married)	Self-reported falls in previous 2 years (Fallers:-- 31%) Self-reported hip fracture (ever) (Hip fractures: 1%)	Self-reported driving status (yes/no) at baseline ('current') and 2 years later ('future')	Unspecified demographic characteristics
Forrest USA 1997 ³⁹	Cross-sectional	1,769 women aged ≥ 71 participating in Study of Osteoporotic Fractures (Pittsburgh Center); non-Black, community-dwelling, capable of walking w/o assistance, ≤ 1 hip replacement. Pittsburgh Center located in rural non-farm area	Self-reported falls and self-reported fractures in previous 2 years	Self-reported driving restriction: driving status, trip frequency, longest trip in previous year, decrease in amount of driving within previous 5 years	Age, education, living arrangement and residence type

Gaspar USA 2013 ⁴⁰	Prospective cohort	36 independent-living older adults recruited from Urbana-Champaign community; normal or corrected-to-normal visual acuity; normal color vision; cognitively intact; valid drivers' license	Self-reported falls in previous 6 months (Fallers: 8.3%)	Objective performance following a lead vehicle and ability to respond to road hazards, using driving simulator immediately after baseline data collection	None; Results stratified by performance measure and presence of distraction
Joseph, 40 countries 2014 ⁴¹	Prospective cohort	17,538 frequent drivers (\geq once per week) who had completed a baseline MMSE as part of a clinical trial of adults aged ≥ 55 with cardiovascular disease or diabetes (mean age 66)	Self-reported falls in previous year (Fallers: 11%; fallers with MVC [1%]; fallers without MVC [10%])	1) Self-reported MVCs (as driver) in 2 years since fall history taken 2) Hospitalizations and fatalities from MVCs in which participant was determined to have been driving based on record review, during 4.5 +/-1 years follow-up	Age, sex, education level, region of habitation, employment status, English-speaking (y/n), multiple health variables
Koepsell USA 1994 ⁴²	Case- control	234 MVC cases and 446 No-MVC controls aged ≥ 65 , licensed drivers in one of 5 counties and belonged to Group Health Cooperative (GHC); Cases received medical care within 7 days for injuries sustained in an MVC in which they were driving, in 1987 or 1988. Age-, gender- and county of residence-matched controls with no MVC injury	Self-reported falls in previous year (Fallers: Cases 12.4%; Controls 9.2%)	Police reported MVCs in 1987 and 1988; case eligibility confirmed by medical record review, or if treated in a facility outside of GHC, a review of charges billed to GHC	Controls matched to cases by age (within one year), gender and county of residence
Lyman USA 2001 ⁴³	Cross- sectional	875 residents of Mobile County, Alabama, aged ≥ 65 who possessed driver's license in 1996	Self-reported falls (time period not specified) (Fallers: 10.9%)	1) Self-reported driving restriction: low annual mileage (<3000 miles in 1996; yes/no), low number of days per week driven (≤ 3 days per week) 2) Self-reported driving difficulty (high difficulty driving under various conditions)	Age, sex, race
MacLeod USA 2014 ⁴⁴	Prospective cohort	1,279 adults aged ≥ 55 years living in/near Sonoma, California, who were driving at baseline	Self-reported "experience with falling" (Fallers: 19.7%)	Self-reported driving restriction at 5 year follow-up: status (current vs. former); driving trips in previous 30 days	Age, gender, presence of a problem in function limitation, health, vision or cognition
Margolis	Prospective	1,416 women aged ≥ 65 (mean	Self-reported number of	1) Police-reported MVC from the	Age, education,

USA 2002 ⁴⁵	cohort	age 71.3) participating in Study of Osteoporotic Fractures (Portland Center); recruited from population-based lists from 1986-1988, non-Black, community-dwelling, capable of walking w/o assistance, ≤1 hip replacement, had driver's license	falls in previous year (Fallers: 46%)	Driver and Motor Vehicle Services Division of Oregon State Department of Transportation during 10 year follow-up 2) Self-reported driving exposure (miles/week in previous year) at 10-year follow-up visit	alcohol use, walking, physical activity, miles driven, systolic blood pressure, foot reaction, ADLs, depression, chronic conditions, sleep aid medication, neuromuscular function, vision, cognition
Marie Dit Asse France 2014 ⁴⁶	Prospective cohort	523 retired drivers in France (mean age 76) selected from 2,104 subjects living in Bordeaux and participating in the Three-City Study; only those who provided complete driving (or driving cessation) data included	Self-reported falls in previous 2 years (Fallers: 29.3%)	1) Self-reported MVC (as driver) during 2.5 year preceding follow-up. 2) Self-reported driving restriction: cessation; reduction in driving distance 3) Other: self-rating of driving skills out of 10; self-report of being asked to stop driving Follow-up: 6 years	Age, sex, education level, monthly income, living arrangement, former profession, km driven per week, mobility deficits, fear of falling, depressive symptoms, central nervous system pathology, IADL deficit, visual retention, slow trail-making part A, severe decline in MMSE
Sims USA 2000 ⁴⁷	Prospective cohort	174 drivers (mean age 71) selected from all licensed drivers aged ≥55 who lived independently in community in Jefferson County, Alabama; stratified sampling on age and crash frequency during previous 5-year period (same cohort included in Cross 2009)	Self-reported frequent falling or slipping (Yes/No) (Frequent falling or tripping: 15.4%)	Police-reported MVC during 5-6 year follow-up	Age, race, gender, days driven per week
Sims USA	Case-control	244 cases (at-fault MVC) and 475 controls (no MVC),	Self-reported falls in 1995 (asked by trained	Reports on police-investigated crashes (to determine	Age, race, gender, miles driven

2001 ⁴⁸		residents of Mobile County, Alabama, aged ≥ 65 with valid driver's license in 1996. Cases had ≥ 1 at-fault MVC in 1996 as recorded by the Alabama Department of Public Safety (DPS); MVC-free controls randomly selected from DPS files and frequency-matched to cases on age and gender	telephone interviewers masked to case status) (Fallers: Cases 13.9%; Controls 9.5%)	participant's involvement as driver and level of fault)	annually, previous vehicle crash, number of diagnoses and medications
Vance USA 2006 ⁴⁹	Cross-sectional	697 adults aged ≥ 55 (mean age 72; 48% male, 91% white) who had just renewed their licenses and agreed to participate in a follow-up phone call 6 months later (same source population as Ball 2006)	Self-reported number of falls (time period not specified) Mean number: 0.18 (sd 0.56), range 0-6	Self-reported driving frequency, space and avoidance (Driving Habits Questionnaire) standardized and combined into composite driving restriction and conditional driving avoidance measures	Age, gender, number of medical conditions, number of medications, lower extremity function, MVPT, Trails A, Trails B, UFOV substest 2

Table 1 Legend.

MVC: motor vehicle crash. MMSE: Mini Mental Status Exam. IADL: instrumented activity of daily living.

Table 2. Risk of Bias Tables for Cohort Studies (n=10), Case Control Studies (n=2) and Cross-Sectional Studies (n=3) Using Newcastle-Ottawa Scale

Cohort Studies	Selection				Comparability	Outcome			Total
	1. Exposed cohort representative	2. Selection of non-exposed cohort	3. Ascertainment of exposure	4. Outcome not present at start	5. Comparability of exposed and unexposed (0-2)	6. Assessment of outcome	7. Long enough follow up	8. Adequacy of cohort follow up	
Ball 2006	1	1	0	1	1	1	1	1	7
Crizzle 2014	0	1	0	1	0	1	1	1	5
Cross 2009	0	1	0	1	2	1	1	0	6
Dugan 2013	1	1	0	1	2	0	1	1	7
Gaspar 2013	0	1	0	0	0	1	1	1	4
Joseph 2014	0	1	0	1	2	1	1	1	7
MacLeod 2015	1	1	0	1	2	0	1	0	6
Margolis 2014	1	1	1	1	2	1	1	1	9
Marie Dit Asse 2014	1	1	0	1	2	0	1	0	6
Sims 2000	1	1	0	1	2	1	1	0	7
Case Control Studies	Selection				Comparability	Exposure			Total
	1. Adequate case definition	2. Cases representative	3. Selection of controls	4. Definition of controls	5. Comparability of cases and controls (0-2)	6. Ascertainment of exposure	7. Same methods for cases, controls	8. Non-response rate	
Koepsell 1994	0	1	1	1	2	0	1	1	7
Sims 2001	0	1	1	1	2	1	1	1	8

Cross-Sectional Studies	Selection				Comparability	Exposure			Total
	1. Exposed cohort representative	2. Selection of non-exposed cohort	3. Ascertainment of exposure	4. Outcome not present at start	5. Comparability of cases and controls (0-2)	6. Assessment of outcome	7. Long enough follow up	8. Adequacy of cohort follow up	
Forrest 1997	1	0	0	N/A	2	0	N/A	N/A	3
Lyman 2001	1	1	0	N/A	2	0	N/A	N/A	4
Vance 2006	1	1	0	N/A	2	0	N/A	N/A	4

Table 2 Legend.

Newcastle-Ottawa scale adapted for cross-sectional studies

Table 3. Driving Outcomes by Study

	Motor Vehicle Crashes (MVC)	MVC-related injuries	Driving Restriction	Conditional Driving Avoidance	Driving Difficulty	Other
Ball 2006	+		?			
Crizzle 2014			-, ?	-		+ / -
Cross 2009	+	-	?			
Dugan 2013			+			
Forrest 1997			+ / -, ?	?	?	?
Gaspar 2013					?	
Joseph 2014	+	+				
Koepsell 1994		-				
Lyman 2001			-		+, ?	?
MacLeod 2014			+			
Margolis 2002	+		?			
Marie Dit Asse 2014	?		-			
Sims 2000	-		?			
Sims 2001	-		?		?	
Vance 2006			-, ?	+, ?		
Total Studies Measuring Outcome	7	3	12	3	4	3

Table 3 Legend.

‘+’ = significant association of outcome with fall history; ‘—’ = no significant association of outcome with fall history; ‘+ / —’ = associations vary with specific outcome; ‘?’ = outcome measured but result not reported

Appendix B. Electronic search strategy

Medline (Ovid)	1. ((Automobile* or traffic or vehic* or car* or driv*) adj2 (accident* or crash* or collision*)).ab,kf,ti.
1946-Present	<p>2. (driv* adj1 (avoid* or cessation or ceasing or cease* or stop* or reduc* or behavior or test* or assessment* or simulator)).ab,kf,ti.</p> <p>3. (drunk* adj driv*).ab,kf,ti.</p> <p>4. "under the influence".ab,kf,ti.</p> <p>5. dui.ab,kf,ti.</p> <p>6. (moving adj1 violation*).ab,kf,ti.</p> <p>7. (traffic adj1 violation*).ab,kf,ti.</p> <p>8. Accidents, Traffic/</p> <p>9. motor vehicles/</p> <p>10. exp Automobile Driving/</p> <p>11. or/1-10</p> <p>12. Falling.ab,kf,ti.</p> <p>13. (accidental adj fall*).ab,kf,ti.</p> <p>14. (frequent adj fall*).ab,kf,ti.</p> <p>15. (frequent adj fall*).ab,kf,ti.</p> <p>16. (frequent adj fall*).ab,kf,ti.</p> <p>17. fall-related.ab,kf,ti.</p> <p>18. near-fall.ab,kf,ti.</p> <p>19. slip*.ab,kf,ti.</p> <p>20. trip.ab,kf,ti.</p>

	<p>21. tripped.ab,kf,ti.</p> <p>22. tripping.ab,kf,ti.</p> <p>23. stumbl*.ab,kf,ti.</p> <p>24. tumbl*.ab,kf,ti.</p> <p>25. Accidental Falls/</p> <p>26. or/12-25</p> <p>27. geriatric.ab,kf,ti.</p> <p>28. (older adj driver*).ab,kf,ti.</p> <p>29. (older adj adult*).ab,kf,ti.</p> <p>30. (older adj wom#n).ab,kf,ti.</p> <p>31. (older adj men).ab,kf,ti.</p> <p>32. (older adj men).ab,kf,ti.</p> <p>33. (senior adj citizen*).ab,kf,ti.</p> <p>34. elderly.ab,kf,ti.</p> <p>35. (aging adj3 adult*).ab,kf,ti.</p> <p>36. (aged and older).ab,kf,ti.</p> <p>37. Aging/</p> <p>38. exp Aged/</p> <p>39. "Aged, 80 and over"/</p> <p>40. or/27-39</p> <p>41. 11 and 26 and 40</p>
<p>EMBASE (Embase.com)</p> <p>1966-Present</p>	<p>#1. ((automobile* OR traffic OR vehic* OR car* OR driv*) NEAR/2 (accident* OR crash* OR collision*)):ab,ti</p> <p>#2. (driv* NEAR/1 (avoid* OR cessation OR ceasing OR cease* OR stop* OR reduc* OR behavior OR test* OR assessment* OR simulator)):ab,ti</p> <p>#3. (drunk* NEAR/1 driv*):ab,ti</p> <p>#4. 'under the influence':ab,ti</p>

- #5. dui:ab,ti
- #6. (moving NEAR/1 violation*):ab,ti
- #7. (traffic NEAR/1 violation*):ab,ti
- #8. 'traffic accident'/exp
- #9. 'motor vehicle'/exp
- #10. 'car driving'/exp
- #11. #1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10
- #12. (accidental NEAR/1 fall*):ab,ti
- #13. (frequent NEAR/1 fall*):ab,ti
- #14. (fall* NEAR/2 risk*):ab,ti
- #15. 'fall related':ab,ti
- #16. 'near fall':ab,ti
- #17. slip*:ab,ti
- #18. trip:ab,ti
- #19. tripped:ab,ti
- #20. tripping:ab,ti
- #21. stumble*:ab,ti
- #22. tumb*:ab,ti
- #23. 'falling'/exp
- #24. #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20 OR
#21 OR #22 OR #23
- #25. (older NEAR/1 driver*):ab,ti
- #26. (older NEAR/1 adult*):ab,ti
- #27. (older NEAR/1 women):ab,ti
- #28. (older NEAR/1 men):ab,ti
- #29. (senior NEAR/1 citizen*):ab,ti
- #30. elderly:ab,ti

	<p>#31. (aging NEAR/3 adult*):ab,ti</p> <p>#32. aged:ab,ti AND older:ab,ti</p> <p>#33. 'aged hospital patient'/exp</p> <p>#34. 'aged hospital patient'</p> <p>#35. 'frail elderly'/exp</p> <p>#36. 'frail elderly'</p> <p>#37. 'very elderly'/exp</p> <p>#38. 'very elderly'</p> <p>#39. #25 OR #26 OR #27 OR #28 OR #29 OR #30 OR #31 OR #32 OR #33 OR #34 OR #35 OR #36 OR #37 OR #38</p> <p>#40. #11 AND #24 AND #39</p>
<p>Web of Science</p> <p>1974-Present</p>	<p>#1. TS="Automobile accident"</p> <p>#2. TS="traffic accident"</p> <p>#3. TS="vehicle accident"</p> <p>#4. TS="car accident"</p> <p>#5. TS="automobile crash"</p> <p>#6. TS="car crash"</p> <p>#7. TS="car crash"</p> <p>#8. TS="car collision"</p> <p>#9. TS="vehicle collision"</p> <p>#10. TS="driving avoidance"</p> <p>#11. TS="driving cessation"</p> <p>#12. TS="driving behavior"</p> <p>#13. TS=(driving Near/3 reduction)</p> <p>#14. TS="driving test"</p> <p>#15. TS="driving assessment"</p>

- #16. TS="drunk driving"
- #17. TS="drunk driver"
- #18. TS="drunk drivers"
- #19. TS="driving under the influence"
- #20. TS=dui
- #21. TS="moving violation"
- #22. TS="moving violations"
- #23. TS="traffic violation"
- #24. TS="traffic violations"
- #25. #24 OR #23 OR #22 OR #21 OR #20 OR #19 OR #18 OR #17 OR #16 OR
#15 OR #14 OR #13 OR #12 OR #11 OR #10 OR #9 OR #8 OR #7 OR #6 OR #5
OR #4 OR #3 OR #2 OR #1
- #26. TS=Falling
- #27. TS=falls
- #28. TS="accidental falls"
- #29. TS="accidental fall"
- #30. TS="frequent falling"
- #31. TS="frequent falls"
- #32. TS="fall risk"
- #33. TS=fall-related
- #34. TS=near-fall
- #35. TS=slip*
- #36. TS=trip
- #37. TS=tripped
- #38. TS=tripping
- #39. TS=stumbl*
- #40. TS=tumbl*

	<p>#41. #40 OR #39 OR #38 OR #37 OR #36 OR #35 OR #34 OR #33 OR #32 OR #31 OR #30 OR #29 OR #28 OR #27 OR #26</p> <p>#42. TS=geriatric</p> <p>#43. TS="older driver"</p> <p>#44. TS="older drivers"</p> <p>#45. TS="older adult"</p> <p>#46. TS="older adults"</p> <p>#47. TS="older women"</p> <p>#48. TS="older men"</p> <p>#49. TS="senior citizen"</p> <p>#50. TS="senior citizens"</p> <p>#51. TS=elderly</p> <p>#52. TS="aging adult"</p> <p>#53. TS="aging adults"</p> <p>#54. #53 OR #52 OR #51 OR #50 OR #49 OR #48 OR #47 OR #46 OR #45 OR #44 OR #43 OR #42</p> <p>#55. #54 AND #41 AND #25</p>
<p>PsycInfo (OVID) 1806- Present</p>	<ol style="list-style-type: none"> 1. ((Automobile* or traffic or vehic* or car* or driv*) adj2 (accident* or crash* or collision*)).ab,id,ti. 2. "root (driv* adj1 (avoid* or cessation or ceasing or cease* or stop* or reduc* or behavior or test* or assessment* or simulator))".ab,id,ti. 3. (drunk* adj driv*).ab,id,ti. 4. "under the influence".ab,id,ti. 5. dui.ab,id,ti. 6. (moving adj violation*).ab,id,ti. 7. (traffic adj violation*).ab,id,ti. 8. exp driving behavior/

- | | |
|-----|----------------------------------|
| 9. | exp Motor Traffic Accidents/ |
| 10. | or/1-9 |
| 11. | Falling.ab,id,ti. |
| 12. | (accidental adj fall*).ab,id,ti. |
| 13. | (frequent adj fall*).ab,id,ti. |
| 14. | (fall* adj2 risk*).ab,id,ti. |
| 15. | fall-related.ab,id,ti. |
| 16. | near-fall.ab,id,ti. |
| 17. | trip.ab,id,ti. |
| 18. | tripped.ab,id,ti. |
| 19. | tripping.ab,id,ti. |
| 20. | slip*.ab,ti,id. |
| 21. | stumbl*.ab,ti,id. |
| 22. | tumbl*.ab,id,ti. |
| 23. | falls/ |
| 24. | or/11-23 |
| 25. | geriatric.ab,id,ti. |
| 26. | (older adj driver*).ab,id,ti. |
| 27. | (older adj adult*).ab,id,ti. |
| 28. | (older adj women).ab,id,ti. |
| 29. | (older adj men).ab,id,ti. |
| 30. | (senior adj citizen*).ab,id,ti. |
| 31. | elderly.ab,id,ti. |
| 32. | (aging adj3 adult*).ab,id,ti. |
| 33. | (aged and older).ab,id,ti. |
| 34. | exp Geriatric Patients/ |
| 35. | exp Aging/ |

	<p>36. or/25-35</p> <p>37. 10 and 24 and 36</p>
<p>CINAHL (EBSCO)</p> <p>1976-Present</p>	<p>S1. (Automobile* or traffic or vehic* or car* or driv*) N2 (accident* or crash* or collision*)</p> <p>S2. (driv*) N1 (avoid* or cessation or ceasing or cease* or stop* or reduc* or behavior or test* or assessment* or simulator)</p> <p>S3. (drunk* N1 driv*)</p> <p>S4. ("under the influence")</p> <p>S5. (dui)</p> <p>S6. (moving N1 violation*)</p> <p>S7. (traffic N1 violation*)</p> <p>S8. (MH "Accidents, Traffic")</p> <p>S9. (MH "Motor Vehicles")</p> <p>S10. (MH "Automobile Driving+")</p> <p>S11. S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10</p> <p>S12. Falling</p> <p>S13. (accidental N1 fall*)</p> <p>S14. (frequent N1 fall*)</p> <p>S15. (fall* N2 risk*)</p> <p>S16. fall-related</p> <p>S17. near-fall</p> <p>S18. slip*</p> <p>S19. trip</p> <p>S20. tripped</p> <p>S21. tripping</p> <p>S22. stumble*</p>

	<p>S23. tumbl*</p> <p>S24. MH "Accidental Falls"</p> <p>S25. MH "Fall Risk Assessment Tool"</p> <p>S26. MH "Fall Risk (Saba CCC)"</p> <p>S27. MH "Fall Prevention (Iowa NIC)"</p> <p>S28. S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S23 OR S24 OR S25 OR S26 OR S27</p> <p>S29. geriatric</p> <p>S30. (older N1 driver*)</p> <p>S31. (older N1 adult*)</p> <p>S32. (older N1 women)</p> <p>S33. (older N1 men)</p> <p>S34. (senior N1 citizen*)</p> <p>S35. elderly</p> <p>S36. (aging N3 adult*)</p> <p>S37. (aged AND older)</p> <p>S38. (MH "Aged+")</p> <p>S39. S29 OR S30 OR S31 OR S32 OR S33 OR S34 OR S35 OR S36 OR S37 OR S38</p> <p>S11 AND S28 AND S39</p>
<p>Cochrane Library 1948-Present</p>	<p>#1. ((Automobile* or traffic or vehic* or car* or driv*) near/2 (accident* or crash* or collision*)):ti,ab,kw</p> <p>#2. ((driv*) near/1 (avoid* or cessation or ceasing or cease* or stop* or reduc* or behavior or test* or assessment* or simulator)):ti,ab,kw</p> <p>#3. ((driv*) near/1 (avoid* or cessation or ceasing or cease* or stop* or reduc* or behavior or test* or assessment* or simulator)):ti,ab,kw</p> <p>#4. ("under the influence"):ti,ab,kw</p>

- #5. dui:ti,ab,kw
- #6. (moving near/1 violation*):ti,ab,kw
- #7. (traffic near/1 violation*):ti,ab,kw
- #8. #1 or #2 or #3 or #4 or #5 or #6 or #7
- #9. (accidental near/1 fall*):ti,ab,kw
- #10. (frequent near/1 fall*):ti,ab,kw
- #11. (fall* near/2 risk*):ti,ab,kw
- #12. fall-related:ti,ab,kw
- #13. near-fall:ti,ab,kw
- #14. slip*:ti,ab,kw
- #15. trip:ti,ab,kw
- #16. tripped:ti,ab,kw
- #17. tripping:ti,ab,kw
- #18. stumbl*:ti,ab,kw
- #19. tumbl*:ti,ab,kw
- #20. #9 or #10 or #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19
- #21. (older near/1 driver*):ti,ab,kw
- #22. (older near/1 adult*):ti,ab,kw
- #23. (older near/1 women):ti,ab,kw
- #24. (older near/1 men):ti,ab,kw
- #25. (senior near/1 citizen*):ti,ab,kw
- #26. elderly:ti,ab,kw
- #27. (aging near/3 adult*):ti,ab,kw
- #28. (aged and older):ti,ab,kw
- #29. #21 or #22 or #23 or #24 or #25 or #26 or #27 or #28
- #30. #8 and #20 and #29

<p>NIH RePORTER</p>	<p>("Accidental Falls" OR falls OR faller OR fallers OR fallen OR falling OR "fall-related" OR "near-fall" OR slip OR slips OR slipped OR slipping OR trip OR trips OR tripping OR stumble OR tumble) AND ("Accidents, Traffic" OR "Automobile Driving" OR Automobiles OR "moving violation" OR "traffic ticket" OR "driving cessation" OR "road safety" OR "driver behavior" OR "drunk driving" OR "impaired driving" "driver assessment" OR "driver test" OR "driving simulator" OR "driving violation" OR "automobile driving") AND (Aged OR "Aged, 80 and over" OR Geriatrics OR Aging OR "Age Factors" OR elderly OR geriatric OR "older adult" OR "older driver" OR aging)</p>
<p>TRID</p>	<p>("accidental fall*" or "fall" or "fell" or "falls" or "falle*" or "falling" or "near-fall" or "fall injury" or "near-fall" or "fall injury" or "fall-related") AND (Aged OR "Aged, 80 and over" OR "Age Factors" OR "Older driver*" OR Geriatric* OR Aging OR elderly OR "older adult")</p>
<p>ProQuest</p>	<p>("Accidental fall*" OR "older adult fall*" OR "geriatric fall*" OR "elderly fall*" OR "fall* in elderly" OR "fall* in older adults" OR "fall* injur*" OR "near-fall*" OR "injur* fall*" OR "fall* in geriatric*" OR "fall* in the geriatric*" OR "fall* in the elderly" OR "slip*, trip* and fall*" OR "fall* in aging" OR "fall* in aged" OR "fall* in the aged") AND ("Accidents, Traffic" OR "Automobile driv*" OR "Automobile" OR "Motor vehicle injuries" OR Crashes OR "Motor vehicle collision" OR "Driver assessment" OR "traffic ticket" OR "moving violation" OR "crash data" OR "highway safety" OR "drunk driving" or "impaired driving" or "driver assessment" or "driver test" or "driving simulator" "driving violation" or "driving retirement") AND (Aged OR "Aged, 80 and over" OR "Age Factors" OR "Older driver*" OR Geriatric* OR Aging OR elderly OR "older adult")</p>