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

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Abstract

Background/Objectives—Driving is an important indicator of mobility and well-being for older adults. Prior work suggests falls are associated with an increased risk of adverse driving outcomes. We examined associations between falls and subsequent motor vehicle crashes (MVCs), crash-related injuries, driving performance and driving behavior.

Design—Systematic review and meta-analysis.

Participants—Observational studies including adult drivers aged 55 and older or with mean age of at least 65.

Measurements—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 (N=27 to 17,349 subjects) met inclusion criteria. Risk of bias was low to moderate, except for cross-sectional studies (n=3) which all had a high potential for bias. A fall history was associated with a significantly increased risk of

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subsequent MVC (summary risk estimate=1.40; 95%CI: 1.20, 1.63; I^2=28%, N=5 studies). One study found a significantly increased risk of MVC-related hospitalizations and deaths after a fall (hazard ratio=3.12; 95%CI: 1.71, 5.69). Evidence was inconclusive regarding an association of falls with driving cessation and showed no association with driving performance or behavior.

Conclusion—Falls in older adults appear to be a risk marker for subsequent MVCs and MVC-related injury. Given the nature of the evidence, which is limited to observational studies, the identified associations may also result at least partly from confounding or bias. Further research is needed to clarify the mechanisms linking falls to increased crash risk and develop effective interventions to ensure driving safety in older adults with a history of falls.

Keywords

older adult; fall; driving; motor vehicle crash; systematic review

INTRODUCTION

The ability to travel throughout the community allows people to live independently, access goods and services and preserve social bonds.[1] Falls are a common and preventable cause of older adult injury that could adversely affect driving, thus reducing older adults' ability to travel within a community.[2]

Theoretically, falls have the potential to affect driving via three direct pathways. First, falls can cause physical injury that limits functional mobility and interferes with driving performance.[3] Second, falls may increase fear of falling, leading to reduced physical activity,[4] consequent deconditioning and reduced fitness to drive.[5] Third, a fall might have adverse psychological consequences that lead to changes in driving behavior.

Falls may also act as indirect markers of increased driving risk. Falls and motor vehicle crashes (MVCs) share risk factors such as untreated cataracts or benzodiazepine use.[6,7] MVC rates are relatively low among older adults and have been declining.[8] Even so, older adults have elevated fatal crash rates, likely due to underlying health status.[8] Identifying shared risk factors may lead to interventions that prevent disability and death associated with both MVCs and falls.

We sought to systematically review and synthesize research literature characterizing relationships between older adult falls and subsequent driving outcomes. We hypothesized that falls are associated with subsequent changes in occurrence of MVCs, crash-related injuries and changes in driving performance and activity.

METHODS

Study Designs

Eligible designs included cohort, case-cohort, case-control and time series studies that tested an association between falls or fall-related injuries and subsequent driving outcomes. Relevant cross-sectional studies were included as supporting evidence if the fall occurrence was reported to precede the driving outcome.

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. We excluded studies that did not report subjects' ages.

Exposure

The primary exposure was a fall or fall-related injury measured by self-report, record linkage or an objective measurement device. We excluded studies examining only fall risk or fear of falling.

Outcomes

We examined any driving-related outcomes, including self-reported and objectively measured driving behaviors, driving performance, legal actions, MVCs and crash-related injuries.

Search Strategy, Data Sources and Extraction

Search Strategy & Data Sources—The search strategy, developed with assistance from a medical research librarian, combined text word terms and subject headings related to the concepts of accidental falls (e.g., fall, slip), driving outcomes (e.g., 'Accidents, Traffic/', automobile driving), and aging (e.g., geriatric, 'Aged/'). We searched six electronic bibliographic databases: 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). To capture 'gray' literature, e.g., technical reports, unpublished manuscripts, and ongoing research, we searched TRID, NIH Reporter, ProQuest's Dissertation and Theses Database, and websites of organizations involved in older adult traffic safety. No language, date or document type restrictions were applied. For each eligible study we used the reference list and a lateral search function to identify additional studies. 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. Any record identified by either reviewer as eligible or possibly eligible on initial screen was retrieved in full-text.

Two investigators independently reviewed and determined final eligibility of each full-text record. Agreement between investigators was 88% for this full-text review. Disagreements were resolved by additional review and discussion.

Data extraction and management—One investigator extracted characteristics (Supplementary Table S1) and results of included studies, using a structured abstraction form. A second investigator reviewed and confirmed the accuracy of extracted data. Missing data were sought from corresponding authors.

Risk of Bias Assessment

Each study's risk of bias was independently assessed by two investigators using the Newcastle-Ottawa Scale (NOS) for cohort or case-control studies, as appropriate.[9] Disagreements were resolved by discussion. The cohort study NOS was adapted for assessment of cross-sectional studies. All cross-sectional studies were considered to have high risk of bias since falls and driving outcomes were measured concurrently.

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.[10]

Assessment of heterogeneity and reporting biases—We analyzed statistical heterogeneity using the Cochran's Q and I^2 tests.[11] Statistical heterogeneity was considered high if the I^2 statistic was ≥ 50% and p<0.10 on Cochran's Q test,[12] moderate for I^2≥30% or p<0.10, and low if the I^2 statistic was <30%. Funnel plot tests to assess publication bias were planned, but data were not sufficient for this test.[13]

Data synthesis—We categorized studies by outcome. We considered both statistical and clinical heterogeneity within each outcome category. Where sufficient data were available and indicated low or no heterogeneity, results were combined quantitatively using a random effects model. Study-specific risk estimates were combined using the generic inverse variance method.[14] Summary risk estimates were calculated using R.[15, 16] Forest plots were created for each driving outcome, overall and by subgroup, where appropriate. All other results were summarized in narrative form.

RESULTS

Figure 1 shows the numbers of records identified, screened and retrieved in full text, and the number of studies assessed as meeting inclusion criteria. All 15 eligible studies were published English-language journal articles, including 10 cohort studies, 2 case-control studies and 3 cross-sectional studies (Supplementary Table S1).[17–31] Three studies were conducted in Canada,[18] France,[28] and 40 countries,[23] respectively, and the rest in the US. Study participants included older adults recruited from motor vehicle licensing agencies,[17, 31] clinical settings,[18, 21, 23, 24] and the community.[19, 20, 22, 25–30] Two studies examined the same subjects for different outcomes.[17, 31] One study, by Crizzle et al., included only patients with Parkinson's disease.[18] All studies that specified the method of fall or fall injury assessment used self-report.

Seven studies examined MVCs and three examined injurious crashes or crash-related injuries. Twelve studies assessed driving restriction (e.g., cessation, fewer trips, shorter distances), four measured driving difficulties, three examined avoidance of driving in adverse or difficult conditions ("conditional driving avoidance") and three examined other driving outcomes. Results of the risk of bias assessment are summarized in Supplementary Table S2.

Motor vehicle crashes and crash-related injuries

Five cohort studies, and two case-control studies (one of which was nested within a cohort[17]), evaluated police- or self-reported MVCs. We excluded two cohort studies from meta-analysis; the cohort in one study[29] was also analyzed in another included study (Cross et al[19]), and the other study did not report quantitative results.[28] The five remaining studies all demonstrated increased risk of crashes following falls. Risk of bias for these five studies was low to moderate, with a mean NOS score of 7.4 (range 6–9). The combined results demonstrated a significantly increased risk of MVC after falls, with low heterogeneity (summary risk estimate=1.40; 95%CI 1.20, 1.63; Q=4.31, p=0.366; I^2=28%) (Figure 2). Exclusion of the cohort study with the lowest NOS score[19] did not materially change results.

All three studies evaluating crash-related injuries revealed increased risk associated with self-reported falls. Risk of bias was moderate (mean NOS score 6.7; range 6–7) for the three studies. Results from Joseph et al[23] were not combined quantitatively with the other two studies[19, 24] because visual examination of results and test statistics (Q=5.69,p=0.058; I^2=66%) indicated high heterogeneity for these outcomes across the three studies (Supplementary Table S1). Both Cross et al[19] and Koepsell et al[24] reported modestly increased risk of a crash-related injury after a fall that may have been due to chance (summary risk estimate=1.34; 95%CI 0.94, 1.92; Q=0.11, p=0.740; I^2=0%) (Figure 3). Joseph et al[23] reported a significant association between a fall in the prior year and death or hospitalization resulting from a MVC in which the subject was driving (adjusted Hazard Ratio=3.12; 95% CI: 1.71, 5.69).

Driving restriction

Twelve studies examined self-imposed driving restrictions including driving cessation or reduced driving frequency, distance, duration or space. Only six studies, three of which were cross-sectional, provided quantitative results, three of which provided data for only a subset of the measured outcomes. A seventh study that reported no quantitative results indicated that no significant association was found. Among the seven studies reporting any results, risk of bias was low to moderate (mean NOS score=6 [range 5–7]) for cohort studies and high (NOS score=3.7 [3–4]) for cross-sectional studies. Given study limitations and apparent reporting bias, we did not combine data quantitatively for any outcomes within this category. Narrative summaries are provided for each outcome.

Driving Cessation—MacLeod[26] 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 Lee[20] 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 al[28] reported no significant association between fall history and subsequent driving cessation, without providing data. A cross-sectional study[21] also reported no association of fall history with driving cessation (without data), while fracture history was significantly associated with driving cessation (OR=1.79; 95% CI: 1.11–2.91).

Driving Frequency—The only cohort study examining driving frequency[18] 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). One cross-sectional study found no association between falls and low number of driving days per week (adjusted OR=1.1; 95% CI: 0.6, 2.1)[25], while another[21] similarly reported no association between either falls or fractures and trip frequency (without quantitative data). Vance et al[31] administered the Driving Habits Questionnaire (DHQ), which measures trip frequency, but did not report results.

Driving Distance—Crizzle et al[18] found, in a cohort of patients with Parkinson's disease, 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 study[28] also reported no association between fall history and self-reported weekly driving distance (without data). Another cohort study[27] and a case-control study[30] measured driving distance but did not report findings. Of three cross-sectional studies that examined this outcome, two[21, 31] did not report their findings. The third[25] found no association between falls and low annual mileage (OR=0.8; 95% CI: 0.4, 1.3), but it is unclear whether the fall exposure preceded this outcome.

Driving Space—Crizzle et al[18] also found 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). Of three cross-sectional studies assessing this outcome, one[21] reported "no association" between history of falling and any trip >100 miles in the past year, another[31] did not report results, and a third[21] 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).

Driving Exposure—Vance et al[31] used the Driving Habits Questionnaire (DHQ) to develop a composite "Driving Exposure" outcome, incorporating measures of driving frequency, distance and space. 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 was conflicting evidence regarding an association between falls and driving cessation and no consistent evidence of any association with other driving restrictions. Limited evidence suggested an association between history of fractures and both driving cessation and space. Many relevant studies did not report quantitative results. Risk of bias among the studies further reduces confidence in the findings.

Conditional driving avoidance

The three studies reporting this outcome had a mean NOS score=4.5. In Crizzle et al's cohort study,[18] fallers made significantly more objectively-measured 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), but measures of night driving did not differ significantly between fallers and non-fallers. Crizzle et al. also administered the Situational Driving Avoidance (SDA) Scale, which measures avoidance of various driving situations, concurrently with taking a fall history, and found no difference between fallers and non-fallers in mean score on the SDA (OR=1.10; 95% CI: 0.31, 3.99). One cross-sectional study[31] 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). A second cross-sectional study[21] did not report its driving avoidance results.

Driving difficulty

Driving difficulty (defined as difficulty driving under certain conditions, such as performing certain tasks (e.g., left turns), or due to specific health conditions). Four studies measured driving difficulties.[22, 29, 21, 25] Only one, a cross-sectional study[25] (NOS score = 4), reported results, finding a significantly increased risk of self-reported 'high' driving difficulty associated with a fall history (adjusted OR=1.7; 95% CI: 1.1, 2.8).

Other driving outcomes

Crizzle et al[18] reported objectively measured data for driving speeds in a range of different settings during a two-week period following baseline reporting of falls within the previous year. Fallers drove significantly slower than non-fallers in all settings examined except in cities (all comparisons, $p<0.05$, Mann-Whitney U test). Two cross-sectional studies[21, 25] measured self-reported relative driving speed (i.e., driving at a different speed than others on the same road), but neither reported results. Crizzle et al[18] 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.

DISCUSSION

This systematic review found that older adults who had fallen were approximately 40% more likely to experience a subsequent MVC than older adults who had not fallen. Based on annual estimates of older driver MVCs (1,140,340)[32] and older adults falls (28.7%)[33] this translates to a population attributable risk of approximately 10.7%, or 117,430 excess MVCs each year. Evidence also suggested an association between fall history and subsequent crash injuries.

The mechanisms underlying these relationships remain unclear. There may be underlying factors that adversely affect functional abilities, causing both falls and MVCs. However, falls were significantly associated with crashes even in included studies that adjusted for neuromuscular function,[27] vision,[19, 23, 27] cognitive ability,[19] and other chronic health conditions,[19, 23, 27, 30] suggesting that falls may instead act independently to impair drivers' functioning, thereby increasing crash risk. Given the nature of the evidence identified, the associations may also result at least partly from confounding or bias.

Interventions to improve functional limitations common to both fall and MVC risk might reduce the occurrence of both of these adverse events, regardless of the nature of the relationship. Such interventions might include, e.g., cataract surgery,[34,35, 36,37] efforts to improve cognitive ability,[38, 39, 40, 41] or exercise to improve overall physical and cognitive function.[34,42,43, 44,45] If fall injuries directly affect subsequent driving ability and behavior, post-fall rehabilitation that addresses functional ability and self-efficacy might improve driving outcomes. Models of condition-specific driving rehabilitation programs have been described.[46]

While the association between fall history and MVCs was consistently positive and statistically significant for the five studies analyzed, a sixth study (Marie Dit Asse et al) that collected data on these outcomes failed to report their relationship.[28] Under-reporting of statistically non-significant results has been previously documented in the literature.[47] If Marie Dit Asse et al[28] failed to report results because they found no association, the true estimate may be smaller than the estimate reported here.

Joseph et al[23] reported a strong association between a fall and crash-related death or hospitalization, providing supportive evidence that fallers have underlying health issues, such as frailty, that make them different from non-fallers.[8]

We found inconsistent evidence regarding an association of falls with driving cessation and no clear association with any other driving outcomes. It is possible that neither falls nor fall risk factors have any meaningful relationship with older adult driving behaviors or driving difficulty. However, bias due to under-reporting of outcomes may also account for these findings. It is also possible that misclassification is biasing one or more true effects toward the null. Objective measurement of driving behavior might address this potential bias. In the study of older adults with Parkinson's disease,[18] 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. Based on the relatively low quantity and quality of the overall body of evidence, additional prospective research using cutting-edge research methodologies might change our conclusions about the relationship between falls and driving behaviors.

Strengths and limitations of the review

While our comprehensive search included multiple strategies to capture gray literature and had no language limitations, all included studies were published and only three studies involved languages other than English, raising the possibility of publication and language biases. One included article[26] was not captured by our search of bibliographic databases, raising the possibility that other eligible articles may have been missed by the search.

We quantitatively combined results from studies examining effects of falls on MVCs and crash-related injuries. Differences in how the authors measured falls as well as driving outcomes could potentially have biased the findings. The study populations included were diverse. Clinic populations used in some studies may not generalize to the healthy adult population. Combining studies from different legal jurisdictions, where crash reporting mechanisms may vary, is a potential limitation. Some driving outcomes were measured by a small number of studies or studies with small sample sizes (e.g., driving space).

CONCLUSION

This systematic review and meta-analysis examined the relationship between falls and subsequent MVC or other driving outcome. Studies examining relationships between falls and driving behaviors found little or no evidence of an association. Bias based on study design, conduct and reporting is likely and precludes any generalizable conclusions about these relationships. In contrast, a history of falls was consistently associated with increased occurrence of MVCs in the small number of studies reporting this outcome. This observed association suggests a relationship between falls and driving risk. While the underlying mechanisms for this relationship have not been fully delineated, prevention may nevertheless be possible. Interventions to prevent falls might also reduce crash risk, and interventions that address common risk factors or causal mechanisms might similarly prevent both types of injury. Mechanisms underlying the association between falls and MVCs, and the relationships among falls, driving outcomes and risk factors common to both, warrant further investigation.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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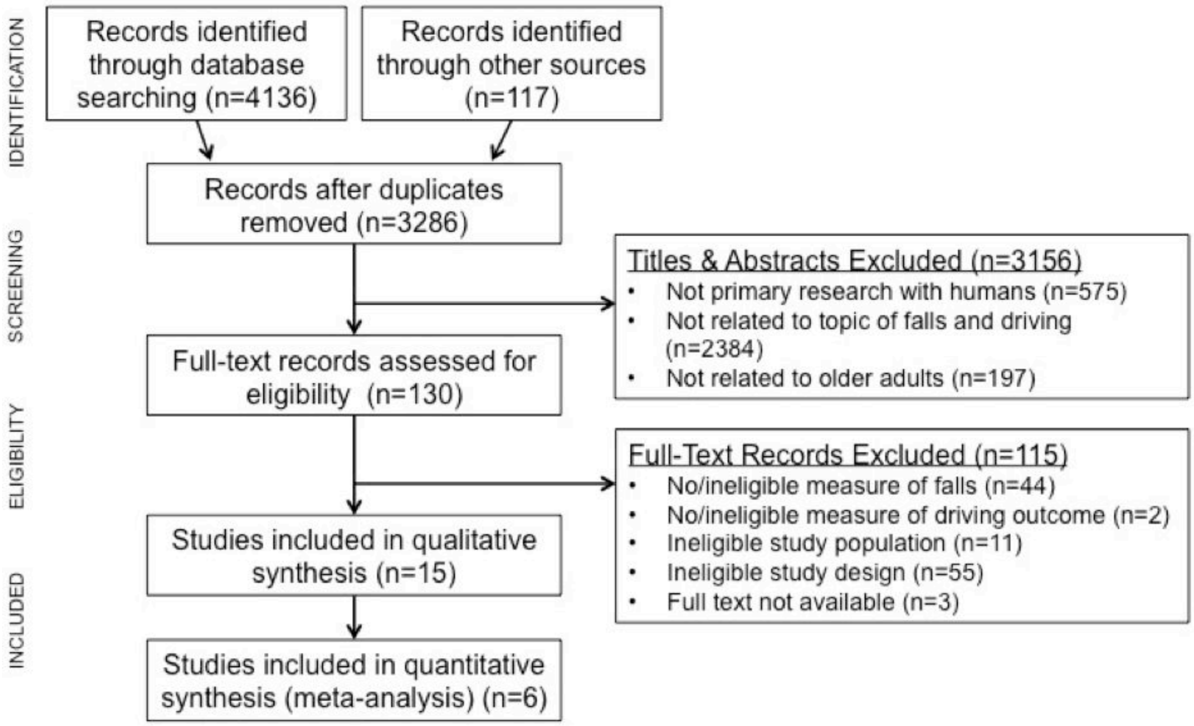

Figure 1.

Flow diagram of identification, review and selection of articles included in the systematic review. Note: 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

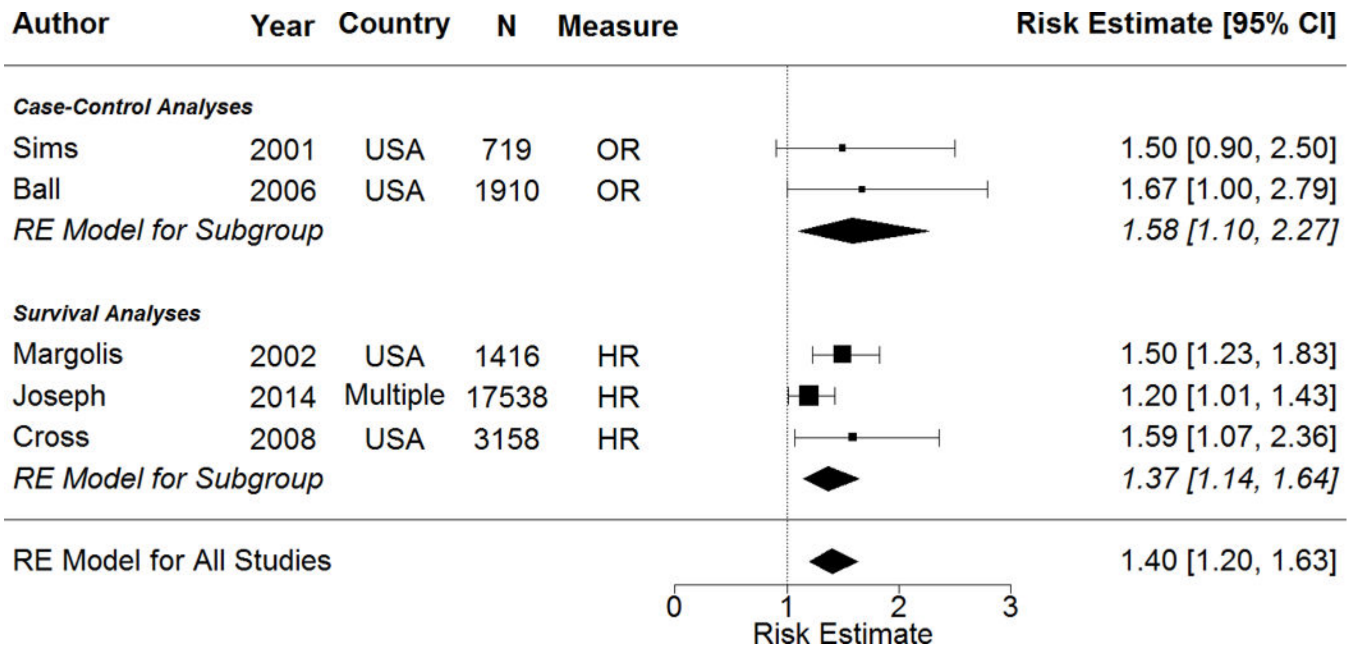

Figure 2.

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

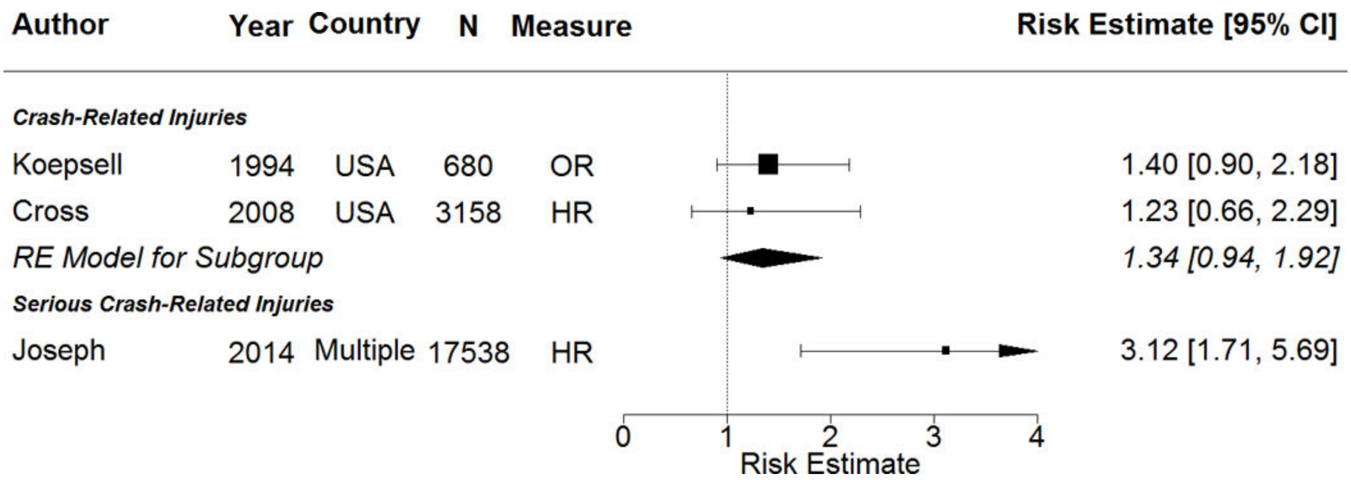

Figure 3.

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