U.S. Department of Transportation
National Highway Traffic Safety Administration

NHTSA

DOT HS 813 535 March 2024

State of Knowledge on Older Drivers

Page intentionally left blank.

DISCLAIMER

Suggested APA Format Citation:

Freed, S. A., Staplin, L., Sprague, B. N., & Ross, L. A. (2024, March). *State of knowledge on older drivers* (Report No. DOT HS 813 535). National Highway Traffic Safety Administration.

Page intentionally left blank.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 813 535		

4. Title and Subtitle State of Knowledge on Older Drivers	**5. Report Date** March 2024 **6. Performing Organization Code**
7. Authors Sara A. Freed, Ph.D.,[1a] Loren Staplin, Ph.D.,[1] Briana N. Sprague, Ph.D.,[2b] Lesley A. Ross, Ph.D.[3] [1] TransAnalytics, LLC, Quakertown, PA [2] Department of Epidemiology, University of Pittsburgh, Pittsburgh, PA [3] Department of Psychology, Clemson University, Clemson, SC [a] Now at Center for Injury Research and Prevention, Children's Hospital of Philadelphia, Philadelphia, PA [b] Now at Indiana University School of Medicine, Indianapolis, IN	**8. Performing Organization Report No.**
9. Performing Organization Name and Address TransAnalytics, LLC 127 S. 5th St. Suite 100 Quakertown, PA18951	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** 693JJ919F000216
12. Sponsoring Agency Name and Address Office of Behavioral Safety Research (NPD-320) National Highway Traffic Safety Administration 1200 New Jersey Avenue SE Washington, DC 20590	**13. Type of Report and Period Covered** Final Report **14. Sponsoring Agency Code** NPD-320

15. Supplementary Notes
Christine Watson, Ph.D., was the NHTSA COR on this project.

16. Abstract

The research team conducted a systematic literature review to identify the current state of knowledge on older driver safety and performance based on research published from 2000 to 2020. Researchers identified eligible articles through searches in TRID, PsycINFO, and PubMed databases, as well as published literature reviews. In total, 225 eligible articles reporting safety and/or performance outcomes among drivers 65 and older were included in the review. The results indicate that older-driver crash rates in the United States have declined over the past 20 years yet remain comparable to the rates of young drivers. Older-driver crashes are more likely to occur in clear weather, during the daytime, and at intersections than to drivers of other ages. Cognitive, physical, and visual functions are related to driving safety and performance, though the strength of the association depends on the domain and the way it is measured. A quantitative meta-analysis of selected articles indicated that speed of processing/attention measures of cognition have the strongest association with driving performance. Certain medications including benzodiazepines, selective serotonin reuptake inhibitors, and Z-drugs (nonbenzodiazepines) are also associated with crash risk, as are untreated eye disease and Alzheimer's disease. Some interventions designed to change driver behavior appear to be associated with better older driver safety, including certain types of training; others, including licensing restriction programs and the use of advanced driver assistance and automated vehicle technologies, have not been evaluated sufficiently to draw reliable conclusions about their impact.

17. Key Words	18. Distribution Statement
older driver, older adult, driver age, safety, performance, cognition, vision, physical function, medical condition, training, education, assessment	This document is available to the public from the DOT, BTS, National Transportation Library, Repository & Open Science Access Portal, https://rosap.ntl.bts.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	124	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

Page intentionally left blank.

Table of Contents

List of Figures

List of Tables

Acknowledgements

This project could not have been completed without the contributions of each member of the project team. Research assistants Courtney Fine, Jordan Solt, and Michelle Huerbin conducted database searches, abstract and title reviews, and literature review cross-referencing. Graduate students Joanne Tian, Jordan Chamberlain, and Abigail Stephan conducted full-text article reviews and quality control assessments. Joanne Tian also provided valuable insight on the systematic review plan.

List of Acronyms

ABT	age-based testing
AD	Alzheimer's disease
ADAS	advanced driver assistance system
ADReS	Assessment of Driving-Related Skills
ADS	Automated Driving System
AMD	age-related macular degeneration
CDRS	certified driving rehabilitation specialist
CDT	clock drawing test
CRSS	Crash Report Sampling System
CS	contrast sensitivity
DLB	dementia with Lewy bodies
DRS	driving rehabilitation specialist
FARS	Fatality Analysis Reporting System
FRT	Functional Reach test
FVA	far visual acuity
GES	General Estimates System
GPT	Grooved Pegboard test
LMB	low mileage bias
MCI	mild cognitive impairment
MMSE	Mini Mental State Exam
MoCA	Montreal Cognitive Assessment
PD	Parkinson's disease
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RPW	Rapid Pace Walk
SHRP 2 NDS	Second Strategic Highway Research Program Naturalistic Driving Study
SSRI	selective serotonin reuptake inhibitor
TCA	tricyclic antidepressants
TUG	Timed Up and Go
UFOV	useful field of view
VA	visual acuity

Executive Summary

Older adults represent a substantial and increasing proportion of the U.S. licensed driver population and have unique challenges related to driving safety and mobility. Research over the past 20 years has focused on topics related to older driver safety and performance, spanning older drivers' crash risk relative to drivers of other ages to approaches to improving driving safety through various behavior change strategies. This report on older drivers presents a comprehensive review of key research findings.

The research team conducted literature searches to identify peer-reviewed articles and articles from government agencies and nonprofit organizations with internal review procedures published since 2000. Four databases were used: PsycINFO, PubMed, SafetyLit, and TRID. Articles were also identified through other published reviews. After applying inclusion/exclusion criteria for eligibility, the research team selected 225 articles that reported safety and/or performance outcomes for drivers 65 and older published from 2000 to 2020 and related to a series of pre-selected topics.

First, the systematic review identified patterns and trends of older-driver crashes in the United States since 2000. During this period older drivers' fatal crash rates declined, though older-driver crash rates remain elevated compared to drivers in their 30s, 40ss, and 50s. The crash rates of older drivers in their 70s, 80s, and older are similar to the crash rates of young drivers (drivers in their teens and early 20s); however, the exact magnitude and pattern of differences between older drivers and drivers of other ages differs depending on the methods used to calculate crash risk. Older-driver crashes occur most often under ideal conditions (i.e., daytime, clear, and dry).

Next, the systematic review examined diverse techniques and procedures for identifying risk factors and predicting older-driver crash risk in both research settings and real-world practice. Research on older drivers across several countries indicated that measures of cognition, vision, and physical function are related to driving safety and performance. The research team supplemented the systematic review with a quantitative meta-analysis to determine the strength of the relationship between these functional abilities and driving measures. Conservative estimates showed that cognition is the strongest predictor of driving safety and performance in older drivers; vision and physical function also predicted on-road performance in the meta-analysis, although these findings may be viewed with lower confidence based on fewer studies. Other measures, obtained using driving simulators and self-reports of driving difficulties or crash experience, showed less evidence as valid indicators of driving safety, though few such studies met the inclusion criteria for the present review.

Reviewers considered driving assessments that occur in State driver license agencies and in clinical settings. The results suggested safety benefits for an in-person license renewal requirement for older drivers, while support was less clear for other age-based requirements such as vision tests and shorter renewal cycles. Healthcare professionals, including doctors, nurses, and occupational therapists, also conduct driving assessments and interventions for older adults as part of their care. Only one eligible article was identified in the present review examining medical referral and driving safety, though other cited reviews describe the role of medical professionals in driving assessment.

Third, the present review supplements a 2018 literature review on medical conditions and driving with a focus on medical conditions prevalent among drivers 65 and older. The prevalence of medical conditions increases with age, and some medical conditions and the medications used to treat these conditions may affect a person's ability to drive safely. The present review cites evidence that benzodiazepines, selective serotonin reuptake inhibitors and Z-drug (nonbenzodiazepines) medications are related to crash risk among older drivers. Untreated or moderate eye disease and Alzheimer's disease or general dementia were associated with crash risk and driving performance, respectively, while evidence relating to driving outcomes was mixed for arthritis, diabetes, and glaucoma. Several challenges exist for determining the association between medical conditions and medications, on the one hand, and driving safety on the other. Key among these challenges is that medications may be metabolized differently for different people; the difficulty of distinguishing a medical condition from the effects of a medication used to treat the condition; and some people with medical conditions may reduce their driving exposure.

Finally, there have been a variety of approaches to changing driver behavior with the goal of improving older driver safety. While older drivers report avoiding driving situations perceived to be riskier, such as driving at night and on high-speed highways, it remains unclear the extent to which such self-imposed limits on exposure and mobility result in safety benefits among drivers 65 and older. Some States issue restricted driver licenses that restrict older people to driving only in certain situations, such as during the daytime or within a prescribed proximity to home. There is some evidence supporting safety benefits of license restrictions for older drivers, but this is an underused strategy that has not been extensively studied. Research has also examined the effects of skills-training approaches. The research team found some evidence for driving performance benefits of simulator, on-road, and cognitive training, though few eligible studies included safety measures in their assessment of training benefits. The use of active safety systems and automated vehicle technologies is an emerging area of research. Although no eligible articles confirmed safety or performance benefits for older drivers, simulator studies have demonstrated limited benefits of active safety systems (e.g., blind spot and lane departure warnings).

Overall, this report may serve as a reference for a variety of audiences including State Highway Safety Offices, healthcare practitioners, researchers, and officials involved in licensing decisions.

Chapter 1: Preface and Methods

Preface

Drivers 65 and older represent a substantial portion of the total driving population in the United States. In 2020 about 47.7 million licensed drivers, or 21% of all licensed drivers in the United States, were 65 and older (National Center for Statistics and Analysis, 2023). Getting older does not necessarily imply diminishing driving safety, but certain changes associated with the normal aging process can affect older drivers. While declining vision, memory loss, and other normal age-related changes in functional ability, as well as the onset or progression of medical conditions, can place older drivers at greater risk of a crash and increase the severity of injuries they suffer, older drivers appear to modify their driving behavior in the face of these changes—and, by some metrics, may be safer than drivers of other ages. Various stakeholders, including State driver licensing agencies and healthcare providers, apply behavioral countermeasures to promote older driver safety through screening, assessment, and interventions.

Since 2000 a considerable research effort has targeted issues surrounding older driver safety with the goal of maintaining independent mobility by extending safe driving through older adulthood. The present systematic review is focused on a broad cross-section of this body of research. The research is then critically evaluated, and limitations in the current body of research are identified. In some cases, no articles were identified that met a predefined set of inclusion/exclusion criteria for the review; this is noted when relevant.

The aim of Chapter 2 is to provide an overview of older adult driving safety patterns in the United States and Canada. The research team reviewed how the crash involvement of older drivers has changed in approximately 20 years. Research is presented that compares older-driver crash rates to drivers of other ages using different metrics, such as at-fault versus not-at-fault crashes and fatal versus non-fatal crashes. Another aim of Chapter 2 is to describe the conditions surrounding older-driver crashes, including environmental conditions such as time of day and behavioral variables like seat belt use. In some cases like alcohol-impaired driving, older adults may be safer than drivers of other ages. Chapter 2 also considers research comparing differences in crash patterns between older male and older female drivers.

While examining broad patterns of older-driver crashes is informative, variability exists within the older driver population in driving performance and safety. Age alone is not a good indicator of driving ability or safety; rather, functional declines associated with the normal aging process may impact a person’s driving. A primary goal of older driver research is to identify which functional abilities are related to driving safety and the best way to assess these abilities. Older driver research in the last 20 years has focused on how well cognitive, physical, and visual function predicts driving safety and performance. Beyond functional assessments, there is also an interest in assessments of driving performance that are viewed as low-risk yet valid indicators of real-world safety concerns. Some of these approaches, like driving simulators, are used primarily in research labs; others are more commonly used in clinical evaluations by providers like occupational therapists. The overall focus of Chapter 3 is the prediction of older driver performance and safety across research, clinical, and license administration settings. Chapter 3 also includes a supplementary quantitative meta-analysis of research findings on the association between functional measures and driving among older drivers.

Beyond the functional declines associated with normal aging, certain medical conditions (and medications used to treat these conditions) become more prevalent with advanced age and may also degrade functional abilities needed to drive safely. For example, eye diseases such as cataracts and age-related macular degeneration affect visual abilities essential to safe driving. Some of these conditions are fairly common: for example, the National Eye Institute estimated that in 2010 about 68% of people 80 and older had cataracts, and 8% of people 80 and older had age-related macular degeneration (National Eye Institute, 2019). Medications (like benzodiazepines, antidepressants, and sleep aids) can affect driving through sedative effects that become more pronounced in older adults, and there is some evidence that these medications may impair driving performance. Combinations of medications (polypharmacy) may result in impairments to driving performance that are not evident for one of the medications taken alone. However, significant limitations exist in this area of research that make it challenging to draw firm conclusions about effects on driving. The emphasis in Chapter 4 is on medical conditions and medications that are either more prevalent among older adults or that have effects shown to have a particular impact on older drivers. For each condition or medication, the chapter includes a description of the condition, its prevalence among older adults, and research findings about how it relates to driving safety or performance among this cohort.

A major goal of research in this area is to inform practices with the potential to extend the safe driving years. A variety of approaches have been developed to improve older driver performance and safety. Some approaches are based on reducing older drivers' exposure to high-risk situations, such as driving at night, while other approaches aim to enhance the skills or knowledge needed to drive safely. It is important to evaluate whether these programs show benefits to real-world driving. A rapidly emerging strategy to improving safety for older drivers is the deployment of advanced driver assistance technologies, including active control systems like automated emergency braking and alerts including blind spot and lane departure warnings. While these technologies show promise, research has just begun to formally evaluate the extent to which they demonstrate benefits for the safe mobility of older drivers. Chapter 5 examines the safety and performance effects of a range of approaches for improving older driver safety.

Appendices A and B outline the criteria used to assess the quality of research included in the systematic review and detail the methodology and results of a quantitative meta-analysis carried out in association with Chapter 3.

Methods

The systematic literature review involved a multi-step protocol to identify eligible articles based on predefined criteria. The first step was conducting online database searches with predetermined search terms and filters. Research assistants conducted searches in four online databases: PsycINFO, PubMed, SafetyLit, and TRID. When available, the following filters were applied to searches: date of publication (January 2000 to December 2020), language (English), population (humans), and age group (65+).

Each chapter had its own set of search terms that were repeated in each of the four databases. All search terms followed a pattern; the third term was changed depending on the topic. The pattern was: older* AND driv* AND (third term) OR elder* AND driv* AND (third term) OR aging AND driv* AND (third term).

The following third terms were added for each chapter.

- Chapter 2: crash*, fatal*, injur*, accident*
- Chapter 3: cognit*, function*, sensorimotor*, vision*, physical*, licens*, occupational therapist, clinic*, physician*, evaluation, fitness, and practitioner
- Chapter 4: fitness, medical*, medication*, health, physical*, polypharm*
- Chapter 5: adapt*, rehab*, educ*, licens*, train*, intervention, practice, program, regulat*, restrict*, limit, technology, automat*, advanced driver assistance system

In total, there were 36 unique sets of search terms repeated across four databases for a total of 144 searches. Research assistants conducted the searches and a title and abstract review of each search result to determine whether an article should be sent to full-text review. Research assistants recorded the total number of search results, number of articles that were duplicates of another search, number of ineligible articles based on title and abstract, and the number sent to full review. Database searches were conducted from March to August 2020.

The second step of the systematic review was a full-text review of each article sent from the title and abstract search. Two research assistants reviewed the full text of each article independently for eligibility. A third reviewer resolved discrepancies between the two research assistants. The following inclusion criteria were used in both the title and abstract review and the full-text review.

- published on or after 2000
- published in English
- included distinct results for drivers 65 or older
- reviewed either through peer-review or State or Federal Government agency review
- included a safety and/or performance outcome

Conference abstracts, dissertations, theses, commentaries, book chapters, and other reports (i.e., gray literature, but excluding State or Federal Government reports) were excluded in both abstract and title review and full-text review. Articles reporting results for special populations were also excluded, such as operators of vehicles with hand controls or who use bioptic telescopes; experimental studies of drug- or alcohol-impairment were excluded. Articles only with results for older passengers or pedestrians were also excluded. Additional chapter-specific criteria are noted in each chapter's review. Eligible articles were also identified from review articles that had been identified in the initial database search.

Figure 1 displays a PRISMA-style diagram (Page et al., 2021) reporting the results of the literature search and screening procedures. After full text review, 225 articles were included in the systematic review.

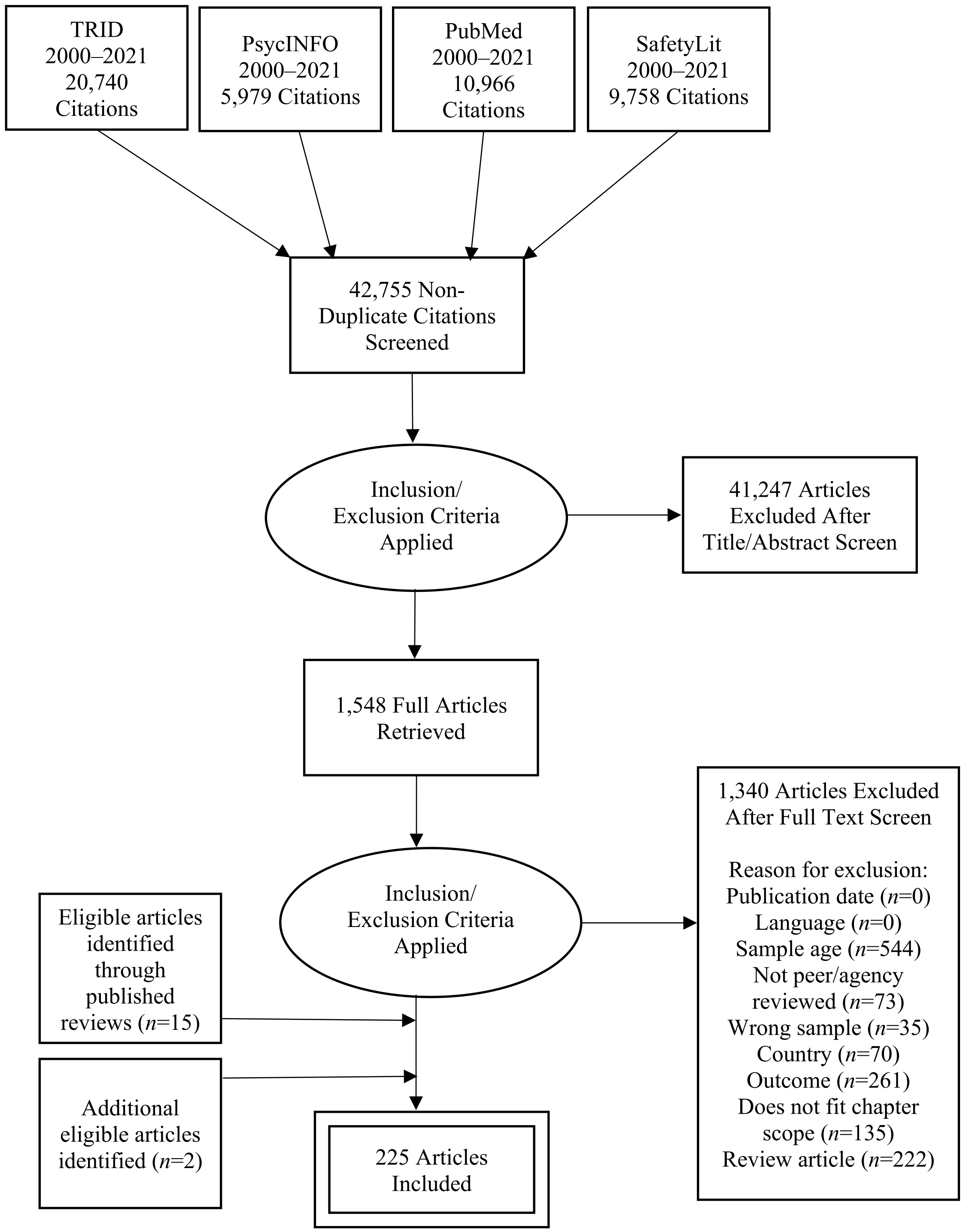

Figure 1. PRISMA Diagram

The third step of the systematic review was to extract information from each eligible article to aid in synthesizing research findings from several articles. For each eligible article, the research team used a qualitative quality control checklist adapted from the RTI Item Bank (Viswanathan & Berkman, 2012), Newcastle Ottawa Scale (Wells et al., n.d.), and Cochrane Risk of Bias Scale (Sterne et al., 2019). The team also extracted information about design, sample, and measures. Two research assistants entered the information for each article, and any discrepancies in information were resolved by a third reviewer. Appendix A details the criteria applied to each article in the third step to assess study quality.

Page intentionally left blank.

Chapter 2: Older Drivers and Crash Involvement

Older drivers' crash involvement compared to drivers of other ages has been a major focus of research in the past 20 years. Though it is generally understood that older drivers are at higher risk for crashes compared to other drivers, the extent to which older drivers' crash involvement differs from crashes among drivers of other ages depends on the way crash risk is calculated. Older drivers are also a heterogeneous group, beginning at age 65 and spanning across 30 or more years. Even within the older driver group, differences exist between drivers of different ages and sexes. While older-driver crashes share some characteristics with drivers of other ages, older-driver crashes also have unique patterns in the circumstances surrounding crashes. This chapter reviews research published since 2000 on older-driver crashes in the United States and Canada, including how older drivers' crash involvement compares to crashes among drivers of other ages, trends over time, and the driving situations in which older-driver crashes are most likely to occur.

All the studies reviewed in Chapter 2 used data from older drivers in the United States and Canada. As this section examined broad trends in older-driver crashes, studies were only included if they used data from State and/or national databases (with one exception of examining the low mileage bias hypothesis). The national crash data in the studies came from two primary sources: the Fatality Analysis Reporting System, and the General Estimates System/Crash Report Sampling System. FARS is a census of fatal crashes on public roads in the 50 States, District of Columbia, and Puerto Rico since 1975. A crash is included in FARS if a driver, passenger, pedestrian, or other road user involved in the crash died within 30 days of the crash. Because the current review focuses on older drivers, the reviewed studies using FARS include data from older drivers *involved* in fatal crashes, both those who survived a crash and those who died within 30 days of the crash. Unlike FARS, CRSS (which began in 2016), and its predecessor, the National Automotive Sampling System GES, contain a nationally representative sample of police-reported crashes of differing severities, from property-damage-only to fatal crashes.

As described in the methods section, the research team conducted a multi-step screening of articles published since 2000 or later extracted through searches of four databases. For Chapter 2, the following search terms were used to identify studies across all topics: older* AND driv* AND either "crash*," "fatal*," "injur*," or "accident*," applied across four databases for a total of 16 search strings. The search returned 12,552 results that were reviewed based on title and abstract. At this step, 11,847 results were deemed ineligible based on title and abstract and 490 results were duplicates of another search. The database search yielded 215 articles to send to full review, and four additional articles were identified from review articles, for a total of 219 articles sent to full review. The most common reason an article was ineligible after a full text review was that the article was not related to the topic (52 articles), the data came from a country other than the United States or Canada (47 articles), or the article did not report distinct results for drivers 65 and older (40 articles). In total, 33 articles were eligible and included in the Chapter 2 review.

Older-Driver Crash Frequency

Improvements in vehicle safety, roadway design, post-crash medical care, and behavioral countermeasures over time have led to a reduction in crash-related injuries and fatalities for drivers of all ages in the United States. The present review focused on crash trends specific to older drivers and identified studies that reported changes in crash rates over time in FARS and/or GES/CRSS. Older drivers' fatal crash involvement rates declined between 1983 and 1985

(Lyman et al., 2002) and between 1995 and 2012 (Cheung & McCartt, 2011; Cicchino, 2015; Cicchino & McCartt, 2014). Older drivers' involvement in non-fatal crashes also declined during the same time periods, though one study reported stability in non-fatal crashes from 1983 to 1995 (Lyman et al., 2002). From 2010 to 2019 the fatal crash rate slightly declined for older drivers, from 13.65 fatal crashes per 100,000 population in 2010 to 13.34 fatal crashes per 100,000 population in 2019 (National Center for Statistics and Analysis, 2021b). Declines were highest for drivers 85 and older, whose fatal crash rates per population declined by 12% from 2010 to 2019.

While older-driver crashes have declined over time, differences remain in the crash involvement of older drivers relative to drivers of other ages. The degree to which older drivers are overrepresented in crashes differs depending on the method used to calculate crash rates. The reviewed studies used different measures of exposure to calculate crash rate, including the number of licensed drivers and miles driven. Thirteen of the reviewed studies compared the crash rates per driver between older drivers and drivers of other ages. Crashes of all severities per driver nationwide are highest for drivers 16 to 19, decline rapidly after age 19, then slowly decline or remain steady from age 30 onward (Braver & Trempel, 2004; Lyman et al., 2002). A study of crashes in New Jersey found that older drivers had significantly lower rates of crashes of all severities per licensed driver than drivers from 35 to 54 (Palumbo et al., 2019). When only fatal crashes are considered, older drivers beginning at 70 had significantly higher rates per licensed driver compared to drivers 35 to 54. The highest fatal crash rate was among female drivers 85 or older, who had two and a half times the fatal crash rate of drivers 35 to 54. National studies have also found elevated fatal crash rates per licensed driver beginning at 70 (Braver & Trempel, 2004; Lyman et al., 2002; Tefft, 2008; Williams & Shabanova, 2003).

Using the number of licensed older drivers as an exposure measure suggests that older drivers have lower crash rates than drivers from 16 to 19, typically a high-risk group, and similar or even lower crash rates compared to middle-aged drivers. However, using administrative license datasets to measure the number of older drivers on the road may provide biased estimates of crash risk (Braver & Trempel, 2004; Tefft, 2008). Administrative license datasets like the ones maintained by the Federal Highway Administration and State licensing agencies may include people who are licensed but are no longer driving; their inclusion has the potential to underestimate the true crash rate for older drivers. Therefore, the two studies that used license data to calculate crash rates may have underestimated the crash risk for active drivers (Palumbo et al., 2019; Williams & Shabanova, 2003). However, two of the studies estimated the number of active drivers using self-reported driving data from the Nationwide Personal Transportation Survey (Braver & Trempel, 2004) and the National Household Travel Survey (Tefft, 2008), and these studies found similar patterns in older drivers' crash rates to the studies using license data.

Another way of accounting for exposure in calculating crash risk is the quasi-induced exposure method, which produces a relative crash involvement ratio based on the number of at-fault drivers versus not at-fault drivers from the same group. The quasi-induced exposure method for calculating crash risk is often applied when a measure of driving mileage is not available and assumes that crash-involved but not-at-fault drivers are a representative sample of their cohort who happen to be 'at the wrong place at the wrong time.' The outcome metric, relative crash involvement ratio, represents the crash-causing propensity of a particular group. However, the quasi-induced exposure method requires the use of a variable that is not included in all crash datasets, like FARS: the 'at-fault' status of a driver. Instead, studies using FARS to conduct quasi-induced exposure analyses determine whether a driver has any ‘contributing factors’ to a crash, such as making an improper turn or failure to yield the right of way. Additionally, for quasi-induced exposure analyses, all single-vehicle crashes are typically considered at-fault crashes (e.g., Braitman et al., 2014; Geyer & Ragland, 2005; Lombardi et al., 2017).

One study using quasi-induced exposure analyses reported differences in crash involvement across age groups based on the FARS dataset from 2002 to 2006 (Stutts et al., 2009). Drivers under 20 and drivers 70 to 79 had similar crash involvement ratios of approximately two (i.e., two drivers with contributing factors in a crash for every one driver without), which was higher than the ratios for drivers in the middle ranges of age categories. However, drivers 80 years or older had a crash involvement ratio of approximately four. Quasi-induced exposure analyses were also used in other reviewed studies reported later in this section that examined whether older drivers are over- or under-represented in crashes with respect to certain characteristics, such as crashes with passengers in the vehicle (Braitman et al., 2014; Geyer & Ragland, 2005; Hing et al., 2003), intersection crashes (Lombardi et al., 2017), crashes in wet or icy road condition (Robertson & Aultman-Hall, 2001), and other roadway and environmental characteristics (Stutts et al., 2009).

When available, a reliable measure of driving mileage is the preferred metric for calculating exposure-based older-driver crash risk. When crash rate is calculated as the rate of crashes per mile driven, a U-shaped curve emerges in which older drivers and young drivers have higher crash rates, and middle-aged drivers have lower crash rates. Six studies in the current review using FARS and/or GES provide evidence for this pattern, which exists for injury crashes (Dellinger et al., 2004), fatal crashes (Cicchino & McCartt, 2014; Dellinger et al., 2004; Lyman et al., 2002; Rolison & Moutari, 2018; Tefft, 2008), and all crashes regardless of severity (Cicchino & McCartt, 2014; Li et al., 2003; Lyman et al., 2002). However, the uptick in crashes per mile for older drivers is lessened somewhat when the outcome includes crashes of all severity. When the outcome is fatal crashes, older drivers have comparable crash rates per mile driven to drivers 16 to 19 (Cicchino & McCartt, 2014; Dellinger et al., 2004; Lyman et al., 2002; Tefft et al., 2008). Crash rates calculated by driving mileage are similar to rates calculated using the quasi-induced exposure method but are different from rates that calculate crash risk based on the number of drivers, which do not find elevated crash rates for older drivers, except in the case of fatal crashes for drivers 70 or older (Braver & Trempel, 2004; Lyman et al., 2002; Palumbo et al., 2019; Tefft, 2008; Williams & Shabanova, 2003).

Yet the use of mileage to calculate crash risk may also produce biased estimates of the crash risk of older drivers compared to drivers of other ages. Janke (1991) first introduced the idea that age comparisons of crash risk based on crashes per mile driven may not accurately represent the crash risk of all drivers. According to Janke, it is possible that drivers who drive the fewest miles per year have the highest risk of crashes, and those who drive the most miles per year have the lowest risk, not because of differences in driving competence but because of differences in driving environment. Janke (1991) argues that high-mileage drivers tend to drive on highways and similar limited-access roads that pose fewer crash opportunities. On the other hand, low-mileage drivers tend to drive on congested streets that have more crash opportunities. Hakamies-Blomqvist et al. (2002) introduced the term low mileage bias to refer to the hypothesis that mileage-based crash estimates across age are biased by a high number of crashes among low-mileage older drivers. Most articles on the LMB were excluded on this topic because they included studies from countries other than the United States or Canada (e.g., Hakamies-

Blomqvist et al., 2002; Langford et al., 2006), were published prior to 2000 (Janke, 1991), or did not include crashes as an outcome (Staplin et al., 2008). After applying exclusion criteria, two articles were included in the current review that examined the LMB in older drivers (Antin, Guo, Fang, Dingus, Perez, et al., 2017; Rolison & Moutari, 2018).

In response to work showing that self-report mileage data used in studies supporting the LMB can be overestimated by high-mileage drivers and underestimated by low-mileage drivers (Staplin et al., 2008), Antin, Guo, Fang, Dingus, Perez, et al. (2017) aimed to replicate the LMB using objective driving data. The authors used data from 802 older adult participants in the SHRP 2 NDS. Participants in the study drove instrumented vehicles for up to 3 years, during which information on driving mileage and crashes was collected. Antin, Guo, Fang, Dingus, Perez, et al. (2017) found that greater annual mileage was associated with a lower risk of overall crashes and at-fault crashes, lending support to the LMB. Additionally, the percentage of low-mileage drivers increased with age and was higher among female than male drivers.

Rolison and Moutari (2018) explored the hypothesis that low mileage drivers have a higher crash rate because they drive more frequently on urban roads with more opportunities for crashes, such as intersections and environments where there are changes in traffic speed. Using FARS and National Household Travel Survey data, the authors calculated fatal crash risk by four exposure indices: number of trips, mileage, trip duration, and a metric that combines all three to produce a measure of average travel time per trip. This exposure metric, risk-exposure density, has higher values when travel distance per trip is low, but travel time per mile is high. Risk-exposure density was significantly higher in drivers 70 or older compared to drivers 60 to 69. When using mileage as a measure of exposure, drivers 70 or older had a higher crash risk compared to drivers 60 to 69. By contrast, when using risk-exposure density as a measure of exposure, drivers 70 or older had a lesser but still significant increase in crash risk compared to drivers 60 to 69; the authors suggest this slight difference may reflect the fact that older drivers are more susceptible to fatal injury. Results from this study suggest that low-mileage drivers may experience an elevated crash risk at least in part by a tendency to drive in areas with more opportunities for crashes, like urban roads.

While older drivers may have a higher injurious and fatal crash involvement because they are more likely to be involved in a crash in the first place, age-related increases in fragility lead to older drivers being more likely to be injured or to die in a crash. Two studies examined the relative contribution of fragility to older-driver crash outcomes using data from FARS and GES (Cicchino, 2015; Li et al., 2003). Both studies found that older drivers had a higher rate of driver deaths per mile than middle-aged drivers, and this higher risk could be attributed to an increased likelihood of dying rather than to an increase in overall crash risk. For drivers 16 to 19 and 20 to 29, excessive crash involvement contributed more to their death rate per mile driven (Li et al., 2003).

Hanrahan et al. (2009) examined injury and fatality outcomes of drivers in Wisconsin from 2002 to 2004 using linked police crash reports, emergency department and hospital discharge data, and death certificates. Drivers 65 or older were more likely to die as a result of a crash compared to drivers 25 to 44, and, among drivers who survived a crash, drivers 65 and older were more likely to have a moderate or severe injury. Drivers 16 to 19 and 20 to 24 were significantly less likely to be injured compared to drivers 25 to 44. These results suggest that older drivers involved in a crash are at greater risk for injury and fatality compared to middle-aged drivers, possibly due to increased fragility.

Finally, the majority of fatalities in older-driver crashes are among the drivers themselves, and the proportion of driver fatalities is higher for older drivers than drivers of any other age group (Braver & Trempel, 2004; Tefft et al., 2008; Williams & Shabanova, 2003). Further, older drivers are responsible for significantly more deaths to others per mile than middle-aged drivers (Dellinger et al., 2004), though some work suggests that this is driven by deaths of their passengers who may be older adults themselves and share the same risk of fatality due to increased fragility rather than deaths of occupants of other vehicles or other road users (Braver & Trempel, 2004; Tefft, 2008).

Risk Factors and Protective Factors for Older-Driver Crash Involvement

Though general patterns in exposure-based analyses indicate an overinvolvement of older drivers in crashes compared to middle-aged drivers, research has identified a number of risk and protective factors for older-driver crash involvement that provide a more nuanced picture of older driver safety. While older drivers have an elevated crash risk in certain driving situations, their crash risk is comparable to that of drivers of other ages in other situations. Older-driver crash risk varies depending on the driving situation, driver behavior, and sociodemographic differences.

Driving Situation

Environmental Characteristics

A seminal paper in 2006 reviewed the driving situations in which older-driver crashes are most likely to occur (Mayhew et al., 2006). This review found that the majority of older-driver crashes occur in more ideal weather, road, and lighting conditions, and their proportion of crashes in ideal conditions is significantly higher than that of drivers of other ages. In the current review, articles published since the 2006 review have also found that older drivers have a higher proportion of crashes in clear weather (Davis et al., 2018; Stutts et al., 2009) and in daylight conditions/daytime hours (Davis et al., 2018; Kim et al., 2013; Lombardi et al., 2017; NCSA, 2021b; Stutts et al., 2009), and older drivers are more likely to be at-fault in a crash in dry road conditions (Robertson & Aultman-Hall, 2001), compared to drivers of other ages. Some authors attribute older drivers' higher proportion of crashes in ideal conditions to their propensity to avoid adverse driving conditions, in general. This may be the case for weather conditions: studies that account for exposure using quasi-induced exposure have not found an elevated risk of older drivers being at-fault in crashes based on weather conditions (Lombardi et al., 2017; Stutts et al., 2009). While older-driver crashes may be more likely to occur in ideal conditions than drivers of other ages, their crashes in non-ideal conditions are not necessarily more severe. In the present review, evidence was mixed regarding the association between lighting conditions and crash severity. While one study found that older-driver crashes in dark conditions are more severe (Khattak et al., 2002), other studies did not find an association between lighting condition and crash severity (Finison & Dubrow, 2002; Zhang et al., 2000).

Older-driver crashes also differ from crashes of drivers of other ages with respect to where they are most likely to occur. As reviewed in Mayhew et al. (2006), the majority of older-driver crashes occur at intersections, and the proportion of older-driver crashes occurring at intersections is higher than for drivers of other ages. The latter finding is reinforced in additional articles identified in the current review (Lombardi et al., 2017; Stutts et al., 2009; Ulak et al., 2018). Older drivers' crash risk at intersections is related to the type of traffic controls regulating traffic movement at the site of the crash. While older drivers' fatal intersection crashes are more likely to occur in places with traffic controls than places without traffic controls (Lombardi et al., 2017), crash risk varies by the type of traffic control device. Stutts et al. (2009) found that older drivers' fatal crash relative accident involvement ratio was higher when the traffic control device was a stop sign or a flashing signal but lower when the device was a traffic signal compared to all intersection crashes regardless of traffic control device. Understandably, where intersections are *without* traffic controls, crashes at such locations are more likely to be fatal (Zhang et al., 2000). Researchers have also reported that older driver intersection or driveway crashes are less likely than non-intersection crashes to result in hospitalization or death (Finison et al., 2002; Zhang et al., 2000). This finding may reflect slower travel speeds at intersections–and certainly on driveways–compared to non-intersection roadway segments.

Older drivers also have a higher proportion of crashes in urban areas compared to drivers of all other ages (Finison & Dubrow, 2002; Stutts et al., 2009). This is likely related to older drivers' increased involvement in intersection crashes; urban roads typically have more intersections than rural roads. Consistent with studies showing that crashes on rural roads tend to be more severe than crashes on urban roads (Finison & Dubrow, 2002; Khattak et al., 2002), older driver fatal intersection crashes are more likely to occur on rural roads compared to younger driver fatal intersection crashes, which are more likely to occur on urban roads (Lombardi et al., 2017).

As reviewed by Mayhew et al. (2006), the majority of older-driver crashes occur on roads with low posted speed limits, and older-driver crashes are more likely to occur at lower speed limits than crashes among drivers of other ages. This finding was also confirmed in studies identified in the current review (Khattak et al., 2002; Stutts et al., 2009; Zhang et al., 2000). Rolison and Moutari (2018) also found that older drivers had a higher travel time per trip than drivers of other ages, suggesting more travel in areas with greater traffic density and lower speed limits. However, Ulak et al. (2018) found that Florida roads with higher speed limits (excluding interstates) had significantly higher rates of older-driver crashes compared to roads with lower speed limits, though on weekdays but not weekends. Studies consistently found that older adult crashes on roads with greater speed limits were more likely to be severe than crashes on roads with lower speed limits (Finison & Dubrow, 2002; Khattak et al., 2002; Zhang et al., 2000). The increase in crash severity at higher speeds is not unique to older drivers, though crashes at higher speeds may be especially severe or fatal for older drivers due to age-related increases in fragility.

Overall, the findings of the current review echo the findings of a prior literature review by Mayhew et al. (2006). The majority of older-driver crashes occur in ideal conditions including daylight, and clear weather and road conditions. Compared to drivers of other ages, older drivers have a higher proportion of crashes at intersections, on urban roads, and on roads with lower speed limits. However, the most severe older-driver crashes tend to occur at non-intersections, on rural roads, and on roads with higher speed limits. Older drivers' overinvolvement in crashes in ideal conditions and in urban areas likely reflect a propensity to drive in these conditions, in general, and lend support to the idea that older drivers' crash involvement may be related to their propensity to drive on roads with greater crash risk (e.g., Janke et al., 1991). Chapter 5 reviews research on older drivers' avoidance of specific driving situations.

Vehicle Age

Another factor that contributes to older-driver crash risk is vehicle age. For drivers of all ages, the risk of fatal injury in a crash is higher for older vehicles (NCSA, 2013). Newer vehicles have improvements in design that reduce the likelihood of crashing and the possibility and severity of injury as a result of a crash (Glassbrenner, 2012). The current review confirmed this finding for older drivers in a single study that examined the association between vehicle age and fatal crashes in California crash records. The authors found that older drivers driving vehicles more than 10 years old were more likely to be fatally injured in a crash than older drivers driving vehicles 10 years old or newer (Kim et al., 2013). A higher proportion of older drivers in fatal and all crashes in the United States from 2002 to 2006 were driving vehicles 10 or more years old compared to drivers of other ages (Stutts et al., 2009). A lower proportion of older drivers were driving vehicles 5 or fewer years old compared to drivers of other ages. The effect of older drivers' increased fragility on injury and fatality risk after a crash is magnified in an older vehicle without up-to-date occupant protection features.

Additionally, there are differences in the effects of vehicle age related to drivers' sex. Older female drivers in fatal crashes are more likely to be driving older vehicles compared to (all) male drivers and middle-aged female drivers (Baker, 2003). A study using Indiana State crash records found that older male drivers who drove vehicles less than 5 years old were *more* likely to be fatally injured than those who drove older vehicles (Islam & Mannering, 2006). The association between vehicle age and fatality was not significant for older female drivers, though driving vehicles 6 to 10 years old and more than 10 years old was associated with increased likelihood of injury for female drivers 25 to 64. It is unclear why the fatality risk was elevated for older male drivers, though it is possible that older male drivers are more likely to engage in risky driving in newer model vehicles.

Passenger Presence

The presence of passengers in the vehicle is also related to older-driver crash risk. Four papers examined the presence of passengers as a predictor of older drivers' crashes, three of which used FARS data from different date ranges (Bédard & Meyers, 2004; Braitman et al., 2014; Geyer & Ragland, 2005) and one that used Kentucky State crash data (Hing et al., 2003). Older drivers were transporting at least one passenger in 42% of fatal crashes between 1975 to 1998 (Bédard & Meyers, 2004) and in 37% of fatal crashes from 2002 and 2009 (Braitman et al., 2014). In comparison, drivers 16 to 19 were transporting at least one passenger in over half of fatal crashes during the same time periods. Generally, drivers tended to be driving passengers of similar ages at the time of a fatal crash (Braitman et al., 2014).While young drivers with passengers are more likely to be at-fault in a fatal crash compared to those without passengers (Bedard et al., 2004; Braitman et al., 2014), older drivers with passengers are less likely to be at-fault compared to older drivers without passengers (Braitman et al., 2014; Geyer & Ragland, 2005; Bédard & Meyers, 2004), particularly male older drivers (Braitman et al., 2014). In fact, the association between passenger presence and lower crash risk appears around age 30 to 45 (Bédard & Meyers, 2004; Braitman et al. 2014; Geyer & Ragland, 2005).

One reason why passenger presence might be associated with a lower crash risk for older drivers is that older drivers are less likely to engage in risky behaviors when passengers are in the vehicle, either due to peer pressure from passengers or a sense of responsibility for passenger safety. Geyer and Ragland (2005) found that older drivers with passengers were more likely to be wearing a seat belt at the time of a fatal crash compared to drivers without passengers, especially for male drivers. Older drivers with passengers were also less likely to be under the influence of alcohol at the time of the crash. Bédard and Meyers (2004) found that older drivers with passengers were less likely to be at fault for speeding in a fatal crash. Another possible reason why passengers are associated with lower odds of a crash is that passengers may assist the driver with other tasks like navigation, adjusting the radio, and monitoring traffic during turns. Though none of the reviewed studies directly examined the interactions between passenger and driver, one study found that the decrease in crash risk for older drivers only exists when the passenger is under younger than 75 (Braitman et al., 2014). The authors suggest that passengers at more advanced ages may be less able to assist the driver. Qualitative research has also found that older drivers receive way-finding assistance from their passengers including reading written directions and locating traffic signs (Bryden et al., 2014).

Finally, it is possible that the relationship between passenger presence and driving safety can be explained by the fact that safer drivers are more likely to carry passengers. All the reviewed studies examined historical crash datasets, so they were unable to determine the direction of the association between passengers and crash risk, or the reasons for either a protective or a detrimental effect of passengers. Another limitation of research on passenger presence is that the most recent data used to examine older drivers' crash risk and passenger presence was from 2009. It is possible that advances in technology in vehicles may lessen the role of passengers in crashes because these technologies replace the tasks that passengers would normally complete for drivers, like navigation or blind spot monitoring.

Driver Behavior

Drivers' behavior at the time of a crash is another major topic of interest in the study of older-driver crash risk, particularly because these factors have such a strong relationship with crashes and can be targeted with behavior-based countermeasures. The three major driver behavior factors related to older-driver crashes identified in the current review are distraction, drug/alcohol use, and seat belt use. While the safety risks of these driver behaviors are not unique to older drivers, their prevalence among crash-involved older drivers is different from crash-involved drivers of other ages, and there may be different safety consequences associated with these behaviors for older drivers.

Distraction

In 2019 about 15% of all injury crashes and 9% of all fatal crashes in the United States involved distracted drivers (NCSA, 2021a). Cellphone use was cited as the distraction in 13% of distraction-involved fatal crashes and 7% of distraction-involved injury crashes. Among distracted drivers in fatal crashes, 5% of drivers were 65 to 74, and 6% were 75 or older. The age group with the highest percentage of distracted drivers in fatal crashes was drivers 25 to 34 (23%). Though special focus has been on cellphone use while driving, driver distraction also includes interacting with climate control and music systems, eating and drinking, reaching for an object, grooming, interacting with a passenger, and smoking (Ranney, 2008). The negative effects of distracted driving and especially cellphone use on driving performance and safety for drivers of all ages have been examined in several literature reviews (e.g., Ferdinand & Menachemi, 2014; Ranney, 2008) and meta-analyses (e.g., Caird et al., 2014; Simmons et al., 2016).

The current review identified three eligible articles that examined distracted driving among older crash-involved drivers, two of which used FARS and/or GES (Donmez & Liu, 2015; Stutts et al., 2009) and one of which used crash data from a single State (Finison & Dubrow, 2002). A study using FARS and GES data from 2002 to 2006 reported the most prevalent type of distraction among older drivers involved in police-reported crashes of all severities was inattention/lost in thought, present in 7% of crashes among drivers 70 to 79 and 10% of crashes among drivers 80 or older (Stutts et al., 2009). Less than 1% of drivers 70 to 79 and drivers 80 or older involved in fatal single- and two-vehicle crashes were cited as using cellphones, compared to 1.3% of drivers of all ages.

Two of the reviewed studies found that driver distraction was associated with crash severity. A study of Maine crashes found that any form of distraction was associated with almost two times greater odds of hospitalization or death among drivers 65 or older (Finison & Dubrow, 2002). Donmez and Liu (2015) examined the odds of injury associated with specific types of distraction among 3,704 older drivers in two-vehicle crashes in GES. Distraction from in-vehicle sources, talking on cellphones, and dialing or texting on cellphones were associated with greater odds of injury among older drivers, while inattention was not. However, the study's results were limited by the small number of older drivers distracted by dialing or texting on cellphones (4 drivers) and by talking on cellphones (14 drivers).

There are important limitations to distraction estimates from FARS, GES/CRSS, and other police-reported crash databases. The presence of distraction at the time of a crash may be underreported for several reasons. First, the presence of distraction is often determined by asking crash-involved drivers if they were distracted, and drivers may not be willing to admit that they were distracted. Second, police may rely on witness accounts to determine driver distraction in cases of driver fatalities; these accounts may either be unavailable or unreliable. Overall, studies in the present review found that older drivers engage in distractions while driving at similar rates to drivers of other ages, and distraction is associated with greater odds of injury and death. However, the research shares the limitations associated with FARS, GES, and other police crash reports.

Alcohol/drug Impairment

The effects of alcohol consumption on the driving performance of drivers of all ages are well-established (Yadav & Velaga et al., 2021). The present review identified studies on the prevalence of alcohol impairment specifically among older drivers involved in crashes. In 2019 about 8% of older drivers involved in fatal crashes in the United States were alcohol-impaired based on blood alcohol concentrations of .08 grams per deciliter or higher (NCSA, 2021b). Among older drivers, the percentage of alcohol-impaired older drivers in fatal crashes decreased with age, from 12% of drivers 65 to 69 to 5% of drivers 85 or older. A study of Oregon trauma center patients from 2000 to 2010 found a similar percentage (10%) of trauma patients 65 or older testing positive for alcohol who were drivers in crashes (Blomberg et al., 2014). Compared to drivers of other ages, a lower percentage of older drivers test positive for alcohol in fatal crashes (NCSA, 2021b) and crashes with injuries (Blomberg et al., 2014). A study of fatally injured drivers in 14 States from 2008 to 2012 found that older drivers also had a significantly lower rate of BACs of .01 g/dL or higher compared to drivers of other ages (Rudisill, Zhu, Abate, et al., 2016). Some studies have found that crashes in which alcohol is involved are more likely to be more severe for drivers 65 or older (Khattak et al., 2002) and more likely to be fatal for drivers 65 to 69 but not drivers 70 or older (Zhang et al., 2000). However, other studies using State crash data found no association between driver alcohol use and hospitalization or death after a crash (Finison & Dubrow, 2002) nor single-vehicle fatalities (Islam & Mannering, 2006) among older drivers. While alcohol use may increase the risk of a crash, research has not identified an association between alcohol use and crash severity among older drivers.

Two studies in the present review examined drug use and older-driver crashes. From 2011 to 2012 older drivers in Iowa were reported as being under the influence of drugs in less than 1% of police-reported crashes, compared to 2% of drivers 50 to 64 (Davis et al., 2018). Rudisill, Zhu, Abate, and colleagues (2016) examined 2008 to 2012 FARS data from 14 States with reportable drug results for at least 80% of fatally injured drivers. Out of the total number of older drivers with drug test results, 20% had drug-positive results (i.e., positive for at least one over-the-counter, prescription, or illegal drug). The prevalence of drug-positive tests decreased with age, and male and female older drivers had similar drug-positive test rates. Older drivers' drug-positive test rate was significantly lower than that of middle-aged drivers. Compared to drivers 30 to 50, drivers 65 or older were more likely to test positive for other drugs (which included over-the-counter drugs), narcotics, and benzodiazepines, and less likely to test positive for cannabinoids, stimulants, hydrocodone/oxycodone, cocaine, and methadone. However, the difference in proportions for hydrocodone and oxycodone were less than 0.5%. Older drivers who tested positive for drugs were less likely to be wearing seat belts than fatally injured older drivers who tested negative for drugs.

Results of Rudisill, Zhu, Abate et al. (2016) and other studies using FARS and State drug-testing data should be interpreted with caution. Serious limitations exist in the drug data collected by States and compiled in FARS (Berning & Smither, 2014). First, a drug test provides information on the presence of a drug in the body, not the level of impairment a person experienced. FARS does not have information on the amount of a drug that was detected, and some drugs remain detectable long after consumption. Additionally, just because a drug was detected does not mean that it impaired a person's driving, only that it was in the person's body prior to a fatal crash. Second, there are inconsistencies between and within States on drug testing and reporting procedures. States differ in who they test, how they test, and what they test. For example, in 2012 only 52% of all drivers in fatal crashes in the United States were tested for drugs (Berning & Smither, 2014). During the period in which this review took place, the FARS database also only allowed for three drugs to be recorded in the database, even if more were detected in the body, and some States will not test for other drugs if alcohol is present. FARS also does not provide information on whether a medication was prescribed by a doctor and taken as prescribed, so some of the drugs for which older drivers test positive may have been prescribed by their physician.

Overall, the reviewed studies indicate that alcohol and drug use among older drivers involved in fatal crashes and crashes with injuries are rare. The effects of alcohol on driving performance are well-established, while the effects of drugs are less understood. Serious limitations exist in State and FARS databases on drug testing in fatal crashes, so results of drug presence and older drivers' fatal crashes should be interpreted with caution. It was also not possible to determine whether the drugs present in older drivers' drug tests were prescribed by a doctor. The effects of prescription medications on driving performance and safety are reviewed in more detail in Chapter 4. In Chapter 4, several reviewed studies use data other than FARS to obtain information on prescription medication use and dosage.

Seat Belt Use

Seat belt use is another behavioral variable not unique to older adults in its importance to traffic safety. It is estimated that three-point seat belts reduce 45% of overall fatalities in passenger cars, and 48% of driver fatalities (Kahane, 2000). Data from FARS and CRSS indicate that in 2019, a higher proportion of drivers 65 or older involved in a fatal crash were wearing a seat belt compared to drivers under 65 (NCSA, 2021b). In the nationally representative 2020 National Occupant Protection Use Survey, 92% of passenger vehicle front seat occupants 70 or older were wearing seat belts (Enriquez, 2021). This percentage is higher than the percentage for occupants 16 to 24 (88%) but similar to that of occupants 25 to 69 (91%).

In the current review, six eligible studies were identified that specifically examined seat belt use in older drivers. Three studies used data from State crash databases (Finison & Dubrow, 2002; Islam & Mannering, 2006; Kim et al., 2013), two used FARS (Geyer & Ragland, 2005; Rudisill, Zhu, Abate, et al., 2016) and one used administrative crash data from Ontario (Zhang et al., 2000). Studies consistently found that crashes of older drivers who did not wear seat belts at the time of collision were more likely to be more severe (Finison & Dubrow, 2002; Islam & Mannering, 2006; Zhang et al., 2000) and fatal (Zhang et al., 2000). Several crash characteristics associated with seat belt use were identified. Passenger presence was associated with increased odds of seat belt use in fatal crashes among older drivers, especially male drivers (Geyer & Ragland, 2005). On the other hand, fatally injured drivers who tested positive for drugs were less likely to be wearing seat belts in fatal crashes (Rudisill, Zhu, Abate, et al., 2016). Overall, the current review confirms the safety benefits of seat belt use in crashes involving older drivers.

Driver Sociodemographic Predictors

The review identified several articles that included sociodemographic predictors of driving safety and performance including race, education, and income. However, these studies included sociodemographic predictors as adjustment variables, not as a main focus of analysis (Emerson et al., 2012; Keay et al., 2009, 2013; Sims, 2001). Additionally, these studies examined the variables in small samples of participants that were not nationally representative. The results of these studies may not be generalizable to the larger population of older drivers because they only sample from a single geographic region (e.g., Wicomico County, Maryland; Keay et al., 2009) rather than from the entire United States as in FARS and GES. The studies' generalizability is also limited by small sample sizes (e.g., 100 participants in Emerson et al., 2012) or a small number of participants in the sample with a certain sociodemographic characteristic (e.g., 122 out of 1,115 participants identifying as African American; Keay et al., 2009). Though FARS and GES include race and ethnicity data, no studies in the present review examined crash differences by race or ethnicity. Education and income are not collected in FARS or GES.

Regarding the sex of drivers, important differences exist between the driving experiences of older males and females. Studies in the present review found that, overall, there are more older male drivers involved in crashes than older female drivers (Finison & Dubrow, 2002; Kim et al., 2013; Lombardi et al., 2017; Stutts et al., 2009). Crash differences by sex persist after taking driving exposure into account. Though older female drivers have lower driving exposure than male drivers based on license rate (Palumbo et al., 2019), driving mileage (Antin, Guo, Fang, Dingus, Perez, et al., 2017; Rolison & Moutari, 2018), and driving trip duration (Rolison & Moutari, 2018), older male drivers' overinvolvement in crashes persists after taking exposure into account. Older male drivers have a higher fatal crash rate per licensed driver (NCSA, 2021b; Palumbo et al., 2019; Williams & Shabanova, 2003) and higher crash rate regardless of severity per licensed driver (Palumbo et al., 2019) than older female drivers. Older male drivers also have higher fatal crash rates per trip, distance traveled, and driving time (Rolison & Moutari, 2018). Two studies, however, found some evidence of higher crash rates for older female drivers compared to older male drivers (Antin, Guo, Fang, Dingus, Perez, et al., 2017; Stutts et al., 2009). It may be noted that the Stutts et al. (2009) analyses found only small differences in crash involvement ratios between males (1.60) and females (2.07) for 70 to 79 that disappeared at age 80+.

Antin, Guo, Fang, Dingus, Perez et al. (2017) found higher crash rates for older female drivers compared to older male drivers in a sample of 802 older drivers, but unlike studies using national crash data that only include police-reported crashes, this study included minor crashes involving a collision with another object. This research suggests that it is possible that female drivers are overrepresented in minor crashes but not in more severe, police-reported crashes; however, this study did not compare sex differences in crash type.

Crash patterns of older female and male drivers also differ by severity. Young and middle-aged female drivers are more physically fragile than male drivers of the same age, as evidenced by higher fatality risk given similar physical insults (Kahane, 2013). This pattern is reversed among older drivers, in which older females have lower fatality risk given similar physical insults compared to older males. Studies in the present review also found evidence of greater crash severity for older male drivers. Studies found that male older-driver crashes are more likely to be severe (Khattak et al., 2002) and fatal (Zhang et al., 2000) than female older-driver crashes. Older male drivers also had a higher death rate per crash than older female drivers, especially at age 80 and older (Li et al., 2013).

One possible reason why older female drivers' crashes are less fatal than older male crashes is that older female drivers are less likely to drive in risky environments or engage in risky behavior. Compared to male drivers and middle-aged female drivers, older female drivers were underrepresented in crashes at higher speed limits (more than 45 mph; Baker et al., 2003). Given studies showing that older-driver crashes at higher speed limits are more likely to be fatal (Finison & Dubrow, 2002; Khattak et al., 2002; Zhang et al., 2000), it is possible that older females' crashes are less likely to be severe because they tend to drive in places with lower speed limits. A higher proportion of older females in fatal crashes in 2019 were restrained compared to older males (National Center for Statistics and Analysis, 2021b). Given known reductions in fatalities associated with restraint use, higher prevalence of restraint use may also contribute to lower fatality risk for older female drivers compared to older male drivers. Although one study found that female drivers have 62% greater odds of hospitalization or death from a crash than male drivers, it is not clear why this study did not find patterns in the expected direction (Finison & Dubrow, 2002). Overall, research using national and State databases have found that older male drivers have higher crash rates than older female drivers, and older male drivers' crashes are more likely to be more severe or fatal.

Summary

The crash data from the United States and Canada include a number of key findings related to older-driver crash frequency and crash rates, plus risk and protective factors for this group. First, there is broad agreement within the literature that older drivers' fatal crash involvement has declined over the period covered by this review (i.e., since 2000). This decline may be attributed to improvements in vehicle safety, roadway design, post-crash medical care, or behavioral countermeasures that led to a reduction in crash-related injuries and fatalities for drivers of all ages. However, differences remain in the crash involvement of older drivers relative to drivers of other ages. Crash rates based on reliable measures of exposure and those using quasi-induced exposure methods consistently indicate rates for drivers in their 70s, and especially for those 80 and older, that compare to rates for young drivers. Population-based analyses using administrative license datasets do not always demonstrate the same trends, but researchers note that these sources may underestimate older drivers' crash rates because they include people who are licensed but are no longer driving. However, several studies showing a higher rate of deaths per mile for older versus middle-aged drivers attribute this higher rate to an increased likelihood of dying rather than to an increase in overall crash risk, underscoring the impact of increased fragility on age differences in fatal and injurious motor vehicle crash outcomes. Finally, there is evidence that the interpretation of older-driver crash rates—both in absolute terms and in relation to other age groups—depends upon crash location (e.g., intersection versus non-intersection crashes) and a person's annual miles driven, such that low-mileage drivers may appear to have an elevated crash risk at least in part because they drive in areas with more opportunities for crashes, like urban roadways.

Investigations of risk and protective factors provide a more nuanced picture of older driver safety. For example, older-driver crashes occur most often under ideal conditions—i.e., in the daytime, on dry pavement, with good visibility; this pattern may be attributed to an avoidance of adverse conditions by older drivers through self-regulation. Older drivers also have a higher proportion of crashes at intersections, on urban roads, and on roads with lower speed limits, compared to young and middle-aged drivers. Researchers have documented that older drivers are more likely to drive older vehicles; this is a risk factor because newer vehicles include design features that may disproportionately benefit older drivers like crash avoidance technology and superior occupant protection. Finally, studies focused on distraction suggest that older drivers are distracted while driving at similar rates overall as drivers of other ages, but driver distraction increases crash severity more for older drivers.

While researchers have found that alcohol and drug use among crash-involved older drivers is rare, when drug use is indicated, prescription medications with sedating effects such as benzodiazepines are more common among older crash-involved drivers in contrast to, for example, cannabinoids. The literature reviewed here examined crash data prior to the legalization of medical/recreational cannabis use in many States, so these differences may not persist. Additionally, national observational data show a slightly higher percentage of belted vehicle (front seat) occupants 70 and older (92%) than occupants 25 to 69 (91%) and 16 to 24 (88%). Last, researchers have documented differences in crash involvement and crash severity associated with the sex of older drivers, but confounding factors exist including differences by sex in exposure, operating speed, fragility, and vehicle type.

Page intentionally left blank.

Chapter 3: Screening and Assessment of the Ability to Drive Safely

Based on the crash risk of older drivers, as reviewed in Chapter 2, identifying risk factors of older-driver crashes has become a public health priority. The screening and assessment of older drivers takes place in research settings and in real-world settings. In research studies, researchers attempt to identify associations between measures obtained from older drivers and crash risk, including functional measures like visual acuity and performance measures like driving simulator assessment. In real-world practice, older drivers are evaluated by State driver licensing authorities and clinicians, including physicians, occupational therapists, and certified driver rehabilitation specialists. This chapter reviews the body of studies published in the past 20 years that have examined screening and assessment of older drivers in both research and real-world settings to identify which methods are most strongly related to driving safety and performance.

Identifying At-Risk Older Drivers as a Public Health Priority

Epidemiological Research on Predictors of Crash Risk for the Older-Driver Population

In the past 20 years research studies have explored a variety of assessments as potential indicators of crash risk among older drivers, including functional assessments and performance assessments. Prominent models of functional abilities associated with older driver safety focus on three main functional domains: cognitive, physical, and visual function (Anstey et al., 2005). Driving is a complex task that requires the integration of these functional abilities. For example, safe driving relies on cognitive abilities, including reaction time to safety threats and hazards; physical abilities, including the ability to rotate the head to check blind spots and intersection approaches; and visual abilities, including the ability to read road signs and detect path-following cues. A priority of driver safety research is to identify which abilities most strongly relate to older driver safety so these abilities can be targeted in screening efforts and intervention strategies.

Unlike Chapter 2, articles in this topic were not restricted to the United States and Canada; articles with data from all countries were considered. The search terms for this topic were "older*" AND "driv*" AND either "cognit*," "function*," "sensorimotor*," "vision*," or "physical*," applied across four databases for a total of 20 search strings for this topic. There were 8,853 search results, 6,671 of which were deemed ineligible based on title and abstract, 1,645 of which were duplicates, leaving 537 to be fully reviewed. Fifty-four articles were review articles. The most common reason why an article was excluded at this stage was that it did not publish distinct results for people 65 or older (60% of excluded articles). Seventy-eight eligible articles were identified from the search strings, plus an additional four articles identified from cross-referencing literature reviews, for a total of 82 eligible articles for this topic.

Physical Function

Physical function is a broad term that refers to a person's capacity to perform activities in daily life (Painter et al., 1999). In the current review, physical function refers to objective assessments of physical performance measures. A variety of physical function assessments have been examined as potential predictors of driving safety and performance, ranging from specific measures of upper-limb mobility and strength like neck range of motion and grip strength to measures of lower-limb function like walking speed. In total, the current review included 28 articles that examined the association between physical function and driving safety and/or performance. Sample sizes for physical function articles ranged from 45 to 1,230, with most sample sizes between 100 and 200 participants. Seven articles reported longitudinal results, and the longest study included outcomes at 9 years after baseline (Margolis et al., 2002). The remaining studies were cross-sectional, and four were retrospective with an outcome of prior crash involvement. The majority of studies assessed on-road performance as an outcome, either in an on-road assessment by a trained assessor or naturalistic driving observation. Five studies reported crashes as an outcome; two of these studies examined prospective crash involvement.

One of the most common assessments in the reviewed studies was the Rapid Pace Walk test. RPW is a measure of lower limb strength, also depending upon balance and proprioception, in which participants are scored based on the time it takes them to walk from one point to another (typically to a point 10 feet distant and back to the starting point). Eleven articles examined RPW as a predictor of driving safety or performance in older adults. In general, there was little support for associations between RPW performance and either crashes or on-road performance among healthy samples. However, there was support for an association between slower RPW time and on-road performance among samples that included certain populations of older adults, including people referred for a driving evaluation or people seeking driving rehabilitation services (McCarthy & Mann, 2006; McCarthy et al., 2009; Stav et al., 2008) and people with Parkinson's disease (Classen et al., 2011). Two exceptions are a study by Antin, Guo, Fang, Dingus, Hankey et al. (2017) that found that slower RPW performance was associated with a higher crash rate ratio in a naturalistic driving study among 723 healthy participants, and a study by Classen et al. (2013a) in which slower RPW performance predicted failing an on-road test among a sample of 294 healthy older adults.

Timed Up and Go is similar to the RPW, except it adds a component in which the participant must rise from a chair before walking to the designated point. Ten articles examined the association between TUG performance and driving performance or driving safety among older drivers. None of the three studies that included crashes as an outcome found a significant association between TUG performance and crash involvement. Similar to findings regarding RPW and on-road performance, there was little support for an association between TUG and on-road or simulator performance among healthy older adults. However, one study (Urlings et al., 2018) found that slower TUG performance was correlated with failing an on-road test in a sample of older adults specifically recruited if they presented with cognitive complaints or were suspected of cognitive impairment by a caregiver. Kandasamy et al. (2019) stratified participants by their score on the Montreal Cognitive Assessment, a measure of cognitive impairment, and found that TUG was associated with on-road performance among participants with a score of 26 or higher (i.e., suggesting no cognitive impairment.) TUG was not significantly associated with on-road performance for participants with a MoCA of 26 or lower. However, TUG was no longer significant after controlling for age. Other studies controlling for age, education, sex, and other covariates have failed to find an association between TUG performance and crashes (Emerson et al., 2012) and on-road performance (Dawson et al., 2010). In general, there is little support for TUG or RPW as a predictor of driving safety or performance among healthy older adults.

The Functional Reach Test is a measure of dynamic balance in which the person reaches forward as far as they can while sitting or standing. The distance between start and end position is measured in inches; typically, the average of the last two trials is recorded. In the reviewed studies, this test is associated with on-road performance in people presenting with cognitive complaints (Urlings et al., 2018) and with simulator performance in healthy samples (Thompson et al., 2012); other studies, however, have found no association with on-road performance (Dawson et al., 2010) or crashes (Emerson et al., 2012) in healthy samples. The evidence for FRT is inconclusive, particularly given that only four studies have examined its association with driving performance and safety among older adults, and the studies had limited sample sizes, ranging from 86 to 116.

While TUG, RPW, and FRT assess gross motor abilities and balance, other assessments of physical function assess more specific functional abilities. For example, neck range of motion has strong face validity as a predictor of driving safety because it enables a driver to scan the environment before turning at an intersection. Five articles measured neck range of motion as a predictor of driving ability. On-road studies supported an association between worse neck range of motion and worse on-road driving performance, both in healthy samples (Lacherez et al., 2014; Wood et al., 2008) and in a sample of people referred for a driving evaluation (Stav et al., 2008). The two studies reporting significant associations between on-road performance and neck range of motion were from the same study and sample. Two of the studies that did not find an association between neck range of motion and driving safety compared the neck range of motion performance between people who had been previously involved in a crash and those who were not (Molnar et al., 2007; Woolnough et al., 2013). Retrospective studies are limited in that the outcome occurs before the predictor, so it is not possible to determine whether the limited neck range of motion directly led to higher crash risk. The evidence for neck range of motion performance and driving safety and performance is inconclusive.

Grip strength is a marker of not only upper limb function but has been identified as a biomarker of a number of outcomes including cognition, falls, and mortality (Bohannon, 2019). Given its association with these outcomes, it is not surprising that studies have found worse grip strength to be associated with worse on-road performance among healthy older adults (Antin, Guo, Fang, Dingus, Perez, et al., 2017; Lacherez et al., 2014) and older adults referred for driving evaluation (Stav et al., 2008). Woolnough et al. (2013) did not find an association between grip strength and crash involvement in the 2 years prior to study enrollment, though this study was limited by its retrospective design. There were also few participants in the study with impaired grip strength (5% of the study sample) and few participants who crashed (5%), so the study may not have been powered sufficiently to detect differences in crash risk by grip strength impairment. Margolis et al. (2002) also did not find an association between grip strength and crash involvement; however, the sample for this study was all women so results cannot generalize to men. Additionally, the outcome was State-reported crashes, so other crashes not reported to the police were not included.

The Grooved Pegboard Test is a test of motor speed and manual dexterity in which participants must manipulate small key-shaped pegs into holes on a board. Unlike other physical function tests, GPT requires psychomotor speed and eye-hand coordination, so performance on the test is thought to also reflect some cognitive function. One study found slower performance on the GPT to be associated with worse on-road performance (Dawson et al., 2010), while another did not (Thompson et al., 2012). A study did not find the GPT to be associated with State-reported crashes across 3 to 7 years (Emerson et al., 2012). The evidence of GPT and driving safety and performance among older drivers remains inconclusive, as only three studies have examined the association, and the studies had small sample sizes (ranging from 86 to 111 older adults).

Overall, there is some support for an association between physical function and driving performance among older adults, though evidence is mixed. Some tests, such as the RPW and TUG, may be more predictive of driving performance among older adults who have some impairment. Studies of healthy older adults may not capture enough range in physical function to see differences in driving performance. In terms of safety, there is not strong evidence that a relationship exists between physical function and crashes. Importantly, there was only one study supporting an association between a measure of physical function (RPW) and crashes (Antin, Guo, Fang, Dingus, Hankey, et al., 2017). Crashes are rare outcomes, so the included crash studies may not have been able to detect differences in crashes by physical function.

RPW and TUG were the most common measures of physical function in the reviewed studies, followed by neck range of motion, grip strength, grooved pegboard, and the functional reach test. There are a number of other physical function assessments included in the reviewed studies in which evidence is inconclusive, as there are only one or two studies that have examined their association with driving safety and performance, such as knee extension, arm curl, and timed toe tap test. Though some measures of physical function have clear face validity to abilities required in the driving task, such as neck range of motion and ankle strength, other assessments measure components of physical capacity without a clear implication for driving performance and safety. For example, there is not a clear link between balance and driving performance. Measures such as balance and walking speed may be indirectly related to driving performance through some other indicator of functioning or are partially explained by age alone. Further, models of physical function are predicated on a number of factors including cognitive function, visual function, and exercise (Painter et al., 1999). It is also possible that, in sum, measures of physical function are simply weak predictors of driving safety and performance.

Vision

Several indicators of vision have been examined as possible predictors of driving performance/safety. The most common measures of vision across the reviewed studies were VA, contrast sensitivity, and visual field. VA refers to the ability to distinguish fine detail and includes far visual acuity and near visual acuity. FVA was the most common measure of vision in the reviewed studies of older driver safety and performance. There is little evidence to suggest that FVA is related to driving performance and safety among older adults: 20 out of 23 articles in the review did not find an association between FVA and driving safety or performance. FVA was not predictive of prior crashes (Green et al., 2013; Woolnough et al., 2013) or future crashes (Antin, Guo, Fang, Dingus, Hankey, et al., 2017; Margolis et al., 2002; Rubin et al., 2007) among large samples of older adults, ranging from 723 to 2,000 participants. While three studies did report significant associations between worse FVA and worse driving performance (Classen et al., 2011; Thompson et al., 2012; Urlings et al., 2018), these studies were cross-sectional studies with small samples of older adults (ranging from 82 to 116 participants). In the study by Classen et al. (2011), scoring below the threshold for licensing in Florida on FVA was correlated with failing an on-road test but not total score of an on-road test among 41 drivers. However, only one participant scored below the threshold for FVA.

The lack of support for an association between VA and driving safety/performance among older adults has been reported in other reviews of vision and driving among older adults (Anstey et al., 2016; Gruber et al., 2013; Owsley & McGwin, 2010). As discussed by these authors, there may be several reasons for a lack of association between VA and driving safety/performance. First, people with VA impairments may drive less because of an awareness of their impairments.

However, studies have not found an association between VA and crashes before and after controlling for mileage (Margolis et al., 2002; Rubin et al., 2007), suggesting that driving less does not explain why VA is not associated with driving safety.

A related reason for studies not finding an association between VA and driving safety or performance is that older adults with impaired vision may simply not be drivers. It is possible that older adults with poor VA are not legally licensed to drive because State license renewal requirements require drivers to score above certain cut-points for VA. As of 2019 about 40 U.S. States have VA requirements of 20/40 for driving without restrictions (Graham et al., 2020). Older drivers with impaired VA below 20/40 may be removed from the road by State restrictions on VA and are therefore not included in studies of VA and driving safety/performance. Such restriction of range is shown in the study by Margolis et al. (2002), where less than 5% of the sample had a VA of 20/40 or worse. In Rubin et al. (2007), only 3% of drivers had VA worse than 20/40. In the study by McCarthy and Mann (2006), 6% of the sample had VA of less than 20/40. And in a study by Koppel et al. (2016), only 1% of the sample scored below VA impairment criteria for licensing in Australia. Some studies also exclude older drivers from participating who have VA below a certain threshold (Aksan et al., 2013; Emerson et al., 2012; Merickel et al., 2019; Stav et al., 2008, Wood et al., 2013). Decrements in VA that remain above a certain threshold may matter less for driving safety compared to severe impairments in VA.

Finally, tests of VA are conducted in standardized, well-lit, static conditions that do not reflect all conditions of real-world driving. Gruber et al. (2013) suggest that tests of VA in twilight conditions, or that require mesopic (dusk/twilight) VA, may better reflect the older adults' ability to drive at night. Similarly, on-road assessments of driving scored by an occupational therapist or other rater are conducted during the daytime in optimal weather conditions. Participants with poor mesopic VA but acceptable daytime VA may not experience any driving difficulties during optimal conditions in on-road tests.

Visual fields have been proposed as a better predictor of driving safety and performance than VA. Visual field-testing measures how much a person can see when they focus their vision on a central point and can include central vision and peripheral visual fields (Spector, 1990). One way to measure visual field loss is a confrontation visual field test administered by an examiner in which the participant looks directly at an object in front of them, such as counting the number of fingers the examiner is holding up, while the other eye is covered. The test can also be performed using a machine in which the participants must identify the location of flashing lights. While confrontation visual field testing is quick and inexpensive, machines may be more sensitive at detecting visual field impairments.

The research on visual field and older adults' driving performance and safety is mixed. Twelve articles included some measure of visual fields. In terms of safety, four articles examined visual fields as related to crashes. Two of these articles used data from older adults in the SHRP2 naturalistic driving study, a large naturalistic driving study across 1 to 2 years (Antin, Guo, Fang, Dingus, Hankey, et al., 2017; Huisingh et al., 2017). These studies found that total binocular peripheral vision (Antin, Guo, Fang, Dingus, Hankey, et al., 2017) and peripheral vision impairment in either eye or both eyes (Huisingh et al., 2017) as assessed by a machine were associated with crashes. Another crash study found that binocular central and peripheral vision as assessed by a machine was associated with State-reported crashes across 6 years in the Salisbury Eye Evaluation study (Rubin et al., 2007). These three studies were longitudinal and used large samples of participants (659 to 1,801 participants). In contrast, another large study of 1,230 older adults found no significant difference between people involved in a State-reported crash prior to the study on a manual confrontational visual field test, though the study was retrospective (Woolnough et al., 2013). In terms of performance, several papers from the Salisbury Eye Evaluation study examined binocular visual fields assessed by a machine as potential predictors of naturalistic driving performance. Keay et al. (2013) found that visual field score was associated with rapid deceleration events, while Munro et al. (2010) found no association with lane change failures and West et al. (2010) found no association with red light failures. Three on-road studies used a manual confrontational visual field test (Betz et al., 2018; McCarthy & Mann, 2006; McCarthy et al., 2009), and none of these studies found a significant association with on-road pass/fail.

One reason for conflicting evidence on visual fields and driving may be variations in testing protocols. Some work suggests that machine-assessed visual fields are more sensitive than manual confrontational field testing (Johnson & Baloh, 1991). The study by Woolnough et al. (2013) was the only crash study to find no association between visual fields and driving safety, and it used manual visual fields by confrontation tests. Three on-road studies that used manual confrontational visual fields also found no association between visual fields and driving performance (Betz et al., 2018; McCarthy & Mann, 2006; McCarthy et al., 2009). However, other studies using a machine to assess visual fields found no association between visual fields and driving performance (Classen et al., 2011; Wood et al., 2013). Even within studies that used a machine to assess visual fields, testing protocols varied. For example, Wood et al. (2013) measured right and left monocular fields in central vision and scored the mean deviation of the best and worst eye. Classen et al. (2011) defined visual fields as impaired on the basis of legal criteria to drive in Florida at the time of the study but did not specify this value. Also, only four out of the 82 participants had a peripheral visual field impairment, which is unsurprising as the study required participants to be legally licensed to drive in Florida.

Similar arguments to VA have been made to explain why visual field testing does not predict driving safety and performances: namely, that visual field tests do not reflect real-world driving (Gruber et al., 2013; Owsley & McGwin, 2010). Visual field tests require the head and eyes to be stationary and focused on one point, whereas in the real-world drivers move their head to actively scan the environment when driving. Owsley and McGwin (2010) note that drivers with impaired visual field may compensate by moving their head and eyes more. However, machine-assessed visual field testing may still be more predictive of real-world driving than manual tests of visual fields by confrontation, though variations in testing protocols make it difficult to make comparisons across studies.

Another measure of vision, contrast sensitivity refers to the ability to distinguish objects from their background at varying levels of contrast and at varying spatial frequencies. High spatial frequency targets encountered while driving have sharp edges, for example, letters on highway signing. Low spatial frequency objects have blurred or indistinct edges, such as faded pavement markings at the edge of a road. It is also important to note that the human visual system is more sensitive to differences in contrast (between an object and its background) when adapted to a high level of ambient illumination, as occurs in daytime driving.

CS is often measured via the Pelli-Robson chart, which includes a series of black letters on a white background that fade to gray as the test progresses. Research findings on CS's association with driving safety among older adults are mixed. Out of the 27 reviewed articles that examine

CS and driving safety among older adults, 16 found no association with any measure of driving safety, while 11 found some significant associations.

Most of the articles that reported significant findings with CS and driving safety used cross-sectional methods. In contrast, there are several large longitudinal studies that have found no association between CS and driving safety, including naturalistic driving performance (Chevalier et al., 2017) and State-reported crashes (Emerson et al., 2012; Margolis et al., 2002; Rubin et al., 2007). However, a naturalistic driving study spanning up to 2 years in a sample of 723 older adults found that lower CS was significantly associated with a greater likelihood of crashes (Antin, Guo, Fang, Dingus, Hankey, et al., 2017). This study used a machine to measure CS, which tests CS in several spatial frequencies and conditions (day, night, and night glare). This test may be more sensitive to real-world challenges associated with CS because not all driving occurs in well-lit, daytime conditions, and CS challenges may be more relevant to night driving. Guo et al. (2015) also tested CS at different spatial frequencies and found significant associations with naturalistic crashes and near-crashes. Other tests, such as the Pelli-Robson test, are tested in good lighting conditions and in one spatial frequency.

A related challenge in assessing the relationship between CS and driving performance is that on-road tests are typically conducted in good weather and daytime conditions. Drivers with poor CS may be particularly affected by nighttime driving or in other conditions with poor light, and these challenges may not appear in daytime driving tests. However, some on-road studies have found significant associations between CS and on-road performance. These studies may have also found significant results because they had a high prevalence of participants with CS impairment. For example, in the study by Classen et al. (2011), 36% of people without Parkinson's disease and 51% of people with Parkinson's disease were classified as CS impaired. In the study by Huisingh et al. (2017), 10% of people were classified as CS impaired in the better eye and 37% of people were classified as CS impaired in the worse eye. Though Urlings et al. (2018) do not report the number of people with impaired CS, they found elevated numbers with such deficits in a sample of people referred for a driving evaluation; studies drawing on this population may include a higher prevalence of impairment compared to other sampling methods. In contrast, the study by Rubin et al. (2007) had 3% of the sample with a CS impairment, and a study by Koppel et al. (2017) had only one out of 199 people with a CS impairment; neither of these studies found significant results.

In summary, while driving may be strongly dependent on visual information processing, there is not strong evidence for an association between measures of sensory visual function and driving safety in older adults. In particular, studies have consistently failed to find significant associations between VA measures and driving safety or performance. Findings regarding CS and visual fields are mixed, with some work showing that impaired CS and/or visual fields is associated with decrements in driving performance and increased crash risk. There are several possible explanations for mixed findings regarding vision and driving. Some authors have argued that older adults with visual impairments may self-regulate. Older adults with visual impairments may drive less because they are aware of their impairments. If this were the case, studies adjusting for driving exposure would not find an association between vision and driving. However, crash analyses adjusting for driving exposure have found that visual field (Antin, Guo, Fang, Dingus, Hankey, et al., 2017; Huisingh et al., 2017; Rubin et al., 2007) and CS (Antin, Guo, Fang, Dingus, Hankey, et al., 2017; Green et al., 2013; Huisingh et al., 2017) are associated with crash risk among older adults. Another possible reason why some studies have not found associations between vision and driving is that visual impairments are not common in studies. Particularly for visual fields and VA, which are tested as part of licensing renewal requirement in some States, older adults with severe vision impairments may be excluded from driving. Studies with small numbers of people with visual impairments simply may not be adequately powered to detect differences in driving safety or performance.

Finally, tests of vision and tests of driving performance are not typically reflective of real-world driving conditions. Tests of VA, visual field, and CS are conducted under standardized, well-lit conditions. Difficulties in vision may not appear in static, well-lit conditions but may present difficulties for driving in poor visibility. On-road driving tests are also conducted during well-lit conditions in good weather as part of standardization efforts. One unique study that was excluded from the current review because it included people in their early sixties tested older adults at nighttime on a closed-road circuit including glare conditions (Kimlin et al., 2017). The authors found that CS tested under photopic (i.e., daytime) conditions was not associated with driving performance, but CS assessed under mesopic (dusk/twilight) conditions was associated with worse driving performance. VA tested under mesopic and photopic conditions was associated with worse driving performance in the nighttime driving test. The difficulties that arise from poor VA and CS may appear during nighttime driving where the visual system is less well adapted to distinguish between lower differences in contrast between objects and their background.

Cognitive Function

Cognitive function refers to performance on tests of cognitive ability that span two or more domains. The cognitive domains examined in the reviewed studies as possible predictors of driving performance and safety include executive function, speed of processing, attention, memory, and dementia status. The most common tests or test batteries examined in studies of older driver safety and performance were the Trail-Making Test B (TMT-B, 41 studies), useful field of view (UFOV, 26 studies), Mini Mental State Exam (MMSE, 23 studies), the Trail-Making Test A (TMT-A, 19 studies), and the clock drawing test (10 studies).

By far, the TMT was the most common test used to predict older driver safety and/or performance. TMT is a timed test in which a person must connect circles with a line drawn either on paper or on a computer. In TMT-A, each circle contains a number (the integers 1 through 25) that a person must connect in sequential order, as fast as possible, beginning at 1. TMT-A is thought to measure processing speed and often has a ceiling effect because healthy people tend to complete this task quickly. In TMT-B, the circles contain an alternating sequence of numbers and letters; a person must connect the circles in the alternating sequential order 1, A, 2, B, etc. TMT-B is thought to measure visual search with divided attention or executive function and has face validity to the task of driving that requires divided attention in navigating a complex environment. A variety of scores can be obtained with TMT, including TMT-A completion time, TMT-B completion time, TMT-A and TMT-B errors, and TMT-B completion time minus TMT-A completion time.

Out of the 19 articles that examined TMT-A, only about a quarter (26%) found a significant association between worse performance (longer test completion time) and driving safety or performance. Three out of the five studies that found a significant association with TMT-A included a sample with either self-reported cognitive complaints (Urlings et al., 2018) or MMSE scores indicating cognitive impairment (Duncanson et al., 2018; Szlyk et al., 2002). Because their samples were more likely to contain drivers with cognitive impairments, these studies may not have had ceiling effects with TMT-A, increasing the probability of a significant association between TMT-A and driving performance.

There were 41 articles identified in the review that assessed the association with TMT-B and driving safety and/or performance in older adults, nine of which examined a safety outcome and 31 of which examined a performance outcome. In terms of safety, slower TMT-B performance was associated with greater likelihood of prior self-reported crash involvement (Lafont et al., 2008; Rozzini et al., 2013) and future State-reported crash involvement (Emerson et al., 2012; Friedman et al., 2013; Staplin et al., 2014). Sample sizes for crash studies were large, ranging from 100 to 2,000 participants, including two studies of people completing their driver license renewal, which may be more representative of the general population than studies recruited through community advertisements. However, other studies have found no association between TMT-B and future State-reported crashes (Margolis et al., 2002) or naturalistic (Antin, Guo, Fang, Dingus, Hankey, et al., 2017), or prior State-reported crash involvement (Bieri et al., 2014; Woolnough et al., 2013). These studies also had large sample sizes with the exception of the study by Bieri et al. (2014), which had 55 participants.

In terms of performance, there is substantial evidence that slower TMT-B is associated with worse driving performance in older adults. The majority of studies with performance outcomes found significant associations with poorer on-road, naturalistic, or simulator performance, including large naturalistic driving studies like the Salisbury Eye Evaluation study of 1,242 people (Keay et al., 2013; Munro et al., 2010; West et al., 2010), the LongROAD study of 2,774 people (Eby et al., 2019), and the SHRP2 study of 659 people (Huisingh et al., 2017). Interestingly, another examination of the SHRP2 NDS study found no association between TMT-B and crash involvement (Antin, Guo, Fang, Dingus, Hankey, et al., 2017). This study included participants 65 and older, while Huisingh et al. (2017) included only participants 70 and older. It is possible that TMT-B is more predictive of crashes in older people. This is supported by the fact that the reviewed studies that found an association between TMT-B and driving performance tended to restrict sample age to older participants, many of which only included people 70 and older, whereas studies finding no association often recruited people 65 and older.

Three studies identified in the review attempted to create cut-points for TMT and/or calculate the specificity of the test for predicting driving safety/performance. In a study of older adults referred for a driving evaluation, TMT-A speed was more predictive of failing an on-road test in older adults with cognitive impairment, defined by an MMSE score of less than 25, compared to TMT-B speed (Duncanson et al., 2018). Errors on TMT-B, but not on TMT-A, were predictive of on-road performance in the cognitive impairment group. Though sensitivity was high, the identified cut-score of 24 items completed had a high false positive rate. In drivers with no cognitive impairment, defined by an MMSE score of 25 or higher, TMT-B speed was more predictive of on-road performance than TMT-A speed. Errors on TMT-B, but not on TMT-A, were associated with on-road driving, though the cut-point of 24 items completed for TMT-B had inadequate sensitivity and specificity.

In another sample of 404 older adults, including people with suspected cognitive impairment based on their MoCA score, TMT-A and TMT-B completion time significantly classified older adults with poor on-road driving performance based on area under the curve analysis (Vaucher, Herzig, et al., 2014). Finally, a study examined TMT-A and TMT-B as predictors of State-reported crashes across 18 months in a sample of 692 older adults recruited from licensing centers (Staplin et al., 2014). In this study, TMT-A and TMT-B error-compensated completion time had better sensitivity and specificity for predicting future crashes than completion time alone, suggesting that accounting for errors in TMT may provide better predictive power for driving safety than completion time alone.

Of all the cognitive measures included in reviewed studies, the UFOV test—with a particular emphasis on subtest 2—has the strongest evidence for prediction of older adults' driving safety and/or performance, with 22 of 26 articles finding a significant association between better UFOV performance and better driving safety or performance. The UFOV test consists of four subtests completed on a touch-screen computer, which increase in difficulty using a staircase methodology. In each subtest, participants are asked to respond to object(s) displayed on a screen with and without distractors for a brief amount of time. Display duration adjusts depending on participant performance, and a participant's score is the duration in milliseconds in which the participant can perform the subtest at 75% accuracy. UFOV-1 assesses processing speed, UFOV-2 assesses divided attention, UFOV-3 assesses selective attention, and UFOV-4 is a more difficult assessment of selective attention.

Some work suggests that UFOV as a continuous measure is not related to driving performance and safety, but instead, there is a threshold for UFOV below which older adults are at greater risk for crashes (Huisingh et al., 2017). A threshold of less than 350ms to complete UFOV-2 is sometimes used as a cut-point for impairment and is associated with decreased driving safety (Friedman et al., 2013). One study compared TMT-B and UFOV and found UFOV-2 risk cut-points to be significantly better predictors of passing versus failing an on-road driving test compared to TMT-B cut-points (Classen et al., 2013b). Studies have found that the UFOV-2 subtest is predictive of prior self-reported crash involvement (Edwards et al., 2008; Friedman et al., 2013; Horswill et al., 2010) and future crash involvement in a naturalistic study (Antin, Guo, Fang, Dingus, Hankey, et al., 2017). Studies have also found associations between lower scores on a composite of UFOV-1, UFOV-2, and UFOV-3, and prior (De Raedt & Ponjaert-Kristoffersen, 2001) and future (Kosuge et al., 2017; Rubin et al., 2007) crash involvement. Studies have consistently found that the UFOV-2 and UFOV-3 subtests are predictive of driving performance (Bélanger et al., 2010, 2015; Classen et al., 2013a, 2013b; Cuenen et al., 2016; Dukic Willstrand et al., 2017; Huisingh et al., 2017; Urlings et al., 2018). Overall, the review found strong evidence for an association between the UFOV test and driving performance and safety.

The exploration of biomarkers of preclinical Alzheimer's disease as predictors of driving performance and safety is an emerging area of research. Four papers from three separate studies identified in the review examined how biomarkers predict safety and/or performance (Babulal et al., 2017, 2018; Gorrie et al., 2007; Roe et al., 2017). Biomarkers obtained from brain imaging and cerebrospinal fluid can indicate the presence of changes in the brain, which may indicate Alzheimer's disease. A small study from 2007 found that fatally injured older drivers were more likely to have neuritic plaques, a marker of possible Alzheimer's disease in the brain, than controls who died from other causes (Gorrie et al., 2007). In the last few years researchers have begun examining the prospective association between biomarkers and driving performance in healthy older adults. Three papers from two studies found that worse on-road driving performance was associated with positivity for Alzheimer's disease biomarkers among healthy older adults without cognitive impairment (Babulal et al., 2017, 2018; Roe et al., 2017).

Meta-Analysis: Effects of Cognitive, Physical, and Sensory Function on Driving Safety/performance

After reviewing the literature describing individual studies examining physical, visual, and cognitive predictors of driving safety/performance, the research team considered a broader question: *Across this body of literature, which driver characteristic has the largest effect size (strongest relationship) with driving safety/performance: cognition, physical functioning, or sensory (visual) functioning?*

The research team carried out a meta-analysis exploring this research question. Given prior work, the research team hypothesized that cognition, vision, and physical functioning would each be related to both self-reported and objective measures of driving. The team hypothesized that cognition would have the strongest relationships, physical functioning the second strongest relationships, and vision significant, but weaker, relationships with the outcomes. The team also anticipated that performance-based measures of driving would have the strongest relationships with the predictors. Finally, given the prior literature, the team predicted that age and sex would be significant moderators for performance-based and self-report driving outcomes.

For additional detail about meta-analysis procedures and results, please see Appendix B. Articles were eligible for the meta-analysis if they met the inclusion/exclusion criteria for the systematic review, and if the article reported sufficient statistics to conduct a meta-analysis. Sixty-two articles examining the association between cognition and driving safety or performance met eligibility criteria, 35 examining vision, and 23 examining physical function. Two levels of analysis were carried out, yielding results at higher and lower levels of confidence. A first set of analyses that examined associations of predictor and outcome variables, as well as possible moderator effects on such relationships, followed conservative guidelines requiring a sample size of at least 10 articles (van Wely, 2014); relationships indicated by the results of these analyses could be interpreted with higher confidence. A second set of exploratory analyses supported by evidence from five-to-nine articles focused on main effects only (i.e., no moderator effects examined); the results of these analyses could be interpreted with a lower but still acceptable level of confidence (Valentine et al., 2010).

The Comprehensive Meta-Analysis software program (Biostat, Englewood, NJ) was used to carry out the meta-analyses. Predictor variables were categorized into cognitive, sensory, and physical domains. The cognitive domain was then further divided, with the goal to assess the strength of relationships between specific constructs (e.g., speed of processing/attention, executive function, and dementia status) and our outcomes. For the sensory and physical domains, there were too few studies to further divide into subdomains. Outcomes were categorized into *crashes, on-road performance,* and *simulated driving performance*. The first category included studies with self-reported or State-reported crashes. The second category included studies using instrumented vehicles, naturalistic driving studies, and studies including an on-road assessment scored by an occupational therapist, driving specialist, or other observer. The final category included studies using a driving simulator, with a particular focus on metrics clearly related to driving safety such as crashes, lane exceedance, and gap acceptance (i.e., not, for example, standard deviation of steering inputs). Where permitted, moderator analyses considered variables including the percentage of the sample that were women, the average age of the sample, and whether the sample was intended to generalize to a larger population.

In the analyses based on 10 or more articles, there was a significant association such that better cognitive function was positively associated with better on-road driving performance (correlation = .261, $p < .001$). Moderator analysis for this effect revealed that studies with a smaller percentage of women ($b = -.005$, $p < .001$) and those with samples with poor generalizability had significantly larger effect sizes ($b = .145$, $p < .001$). The average sample age ($b = -.012$, $p = .20$) did not significantly moderate the cognition/on-road driving performance effect size. Cognitive subdomain analyses found a significant association such that better speed of processing/attention was positively associated with better on-road driving performance (correlation = .236, $p < .001$) and a significant association such that better executive function was positively associated with better on-road driving performance (correlation = .260, $p < .001$). Neither average sample age nor sample recruitment strategy/generalizability significantly moderated the associations with either of these cognitive subdomains, while studies with a smaller percentage of women had significantly larger effects sizes for the executive function subdomain only. There were insufficient studies to examine the association between the cognitive subdomain dementia status and on-road driving performance at this level of confidence. There was limited evidence of publication bias as determined by funnel plots (not shown).

All other analyses were based on sets of five-to-nine articles. To begin, nine studies supported an analysis showing a significant association such that better performance on dementia status tasks was positively associated with better on-road driving performance (correlation = .308, $p < .001$). Across all cognitive domains, based on five studies there was a significant but weak association such that better performance on cognitive tasks was positively associated with fewer crashes (correlation = .034, $p < .001$). In addition, based on six studies there was a significant association such that better performance on cognitive tasks was positively associated with better simulated driving performance (correlation = .237, $p < .001$); five of these six studies supported an analysis of the cognitive subdomain speed of processing/attention, revealing a significant association such that better speed of processing/attention performance was positively associated with better simulated driving performance (correlation = .236, $p < .001$).

Meta-analyses of vision and physical function as predictors were possible only for the outcome on-road driving performance, and in neither case were sufficient data available to examine associations at the subdomain level. Based on seven studies, there was a significant association such that better visual performance was positively associated with better on-road driving performance (correlation = .182, $p < .001$). Also based on seven studies, there was a significant association such that better physical function was positively associated with better on-road driving performance (correlation = .147, $p < .001$).

The most common studies included in the meta-analyses were those that examined the association between driving behaviors and cognition. Within the domain of cognition, speed of processing/attention, executive function, and dementia status were the most commonly examined sub-domains. Memory, situational awareness, and everyday cognition were less commonly examined. Overall, studies that included measures of visual function tended to use VA most frequently, followed by CS. In terms of physical function, there was a trend towards using complex lower limb function (e.g., balance and gait); however, there were also studies that examined static strength and range of motion measures. On-road driving performance was the most commonly examined outcome in this meta-analysis.

Several originally proposed questions were not able to be addressed using the more conservative cutoff of 10 or more studies. While there is support for conducting analyses with fewer studies (Valentine et al., 2010), results from analyses with fewer articles should be interpreted with caution. The research team did not conduct any analyses if there were fewer than five studies.

On-road driving performance was the only driving outcome examined across all predictors (cognitive, vision, physical). From the largest to the smallest effect size, on-road driving performance was associated with dementia status (cognitive sub-domain; correlation = .31), overall cognition (correlation = .26), speed of processing/attention (cognitive sub-domain; correlation = .24), vision (correlation = .18), and physical function (correlation = .15).

Cognition was the only predictor that spanned several driving outcomes and was associated with on-road driving performance (correlation = .26), simulated driving performance (correlation =. 24), and crashes (correlation = .03). The somewhat weaker associations with the latter driving outcomes may be driven by the smaller number of eligible studies for this analysis. It is also possible that the smaller associations were partly driven by publication bias, as there was greater evidence of bias for both simulated driving performance and crashes but not on-road driving performance.

When examining sub-domains within cognition, associations tended to be stronger for higher order domains (e.g., executive function and dementia status) and on-road driving performance compared to lower order cognitive domains (e.g., speed of processing/attention). Importantly, lower order cognitive domains typically support higher order domains. Furthermore, based on the results of the moderator analyses, the magnitude of the association between cognition was largely unaffected by sample characteristics, specifically the percent of women, the average sample age, and whether the recruited sample was intended to generalize to a larger population.

A more detailed description of meta-analysis procedures and results is presented in Appendix B, including all predictor and outcome variable definitions and measures, at the domain and subdomains levels, as sourced from each individual article included in the meta-analysis.

Test Batteries

Several test batteries incorporating several domains of cognitive function have been developed, with the goal of predicting older driver safety. Because they yield composite scores, it is difficult to associate safety or performance differences with any particular indicator of functional status. Therefore, research involving these batteries is considered separately from the preceding discussion of univariate relationships. One of the most frequently used batteries in older-driver safety research is the MMSE. The MMSE is a 30-point test used in clinical practice as a screening tool for possible cognitive impairment/dementia. The MMSE includes several domains: orientation to time, orientation to place, three-word registration, attention and calculation, three-word recall, language, and visual construction. Some criticisms of the MMSE are that it was not originally designed to assess driving safety, and it may not be as sensitive as other measures in detecting cognitive impairment. The MMSE also has demonstrated ceiling effects in which most older adults score in the higher range.

In this review, 23 articles were identified that examined MMSE as a predictor of driving safety and/or performance. In terms of safety, three longitudinal studies did not find an association between MMSE and future crash involvement (Lesikar et al., 2002; Margolis et al., 2002, Rozzini et al., 2013), though one large longitudinal study found worse MMSE performance to be associated with future crash involvement in 1,995 older adults (Huisingh et al., 2018). In terms of driving performance, evidence was mixed: nine studies reported a significant association between worse MMSE score and driving performance, while 10 did not. Two of the studies examining the MMSE and driving performance noted that while the test was significantly associated with driving performance, its accuracy to predict passing or failing an on-road test was poor (Crizzle et al., 2012; Ferreira et al., 2012). Longitudinal studies generally did not find significant associations between baseline MMSE score and driving performance (West et al., 2010) or crashes (Huisingh et al., 2018; Lesikar et al., 2002; Margolis et al., 2002; Rozzini et al., 2013). One longitudinal study, however, found that MMSE decline, measured as a decrease of one point or more on the MMSE over 1 year, was associated with a higher risk of at-fault crash involvement across 3 years (Huisingh et al., 2018). The authors note that while MMSE performance assessed at one time may not be a good predictor of driving safety, substantial declines in MMSE over time may indicate greater crash risk. Overall, the current review did not find strong evidence for the use of MMSE as a predictor of driving performance or safety.

Other test batteries of cognitive impairment used to predict driving safety and performance in older adults include the MoCA and the CDT that is a subtest of the MoCA. Four out of six studies did not find a significant association between the MoCA and driving safety or performance, and six out of 10 studies did not find a significant association between CDT and driving safety or performance. Both articles that found a significant association between poor MoCA performance and driving performance found that participants who scored below 26 on the MoCA were more likely to have worse on-road driving performance (Kandasamy et al., 2019; Vaucher, Herzig, et al., 2014). In comparison, three of the four studies that found no association between MoCA and driving used continuous MoCA scores to predict driving (Bieri et al., 2014; Cuenen et al., 2019; Koppel et al., 2017). Though MoCA performance may not be a strong predictor of driving safety and performance, cut-off values indicating possible cognitive impairment may be more predictive than continuous scores.

Another test battery that combines measures across functional domains is the Assessment of Driving-Related Skills developed by the American Medical Association in cooperation with

NHTSA. This battery gives healthcare providers an indicator of their patients' crash risk through tests of vision, cognition, and physical function. This review identified two articles that assessed the relationship between ADReS measures and driving safety. One study found no association with ADReS and crashes in the past 2 years (Woolnough et al., 2013). Another study found that while the ADReS identified 100% of people who were scored as unsafe on an on-road test, it also identified 32% of the sample as being unsafe even though they passed the road test (McCarthy et al., 2009). While there is little evidence that the ADRes predicts driving safety or performance among older adults, only two studies were identified that met the review inclusion criteria.

Validity of Driving Ability Measures

While some research aims to identify functional tests that can predict driving safety and performance, another avenue of research is identifying measures of driving performance that can predict driving safety. The ultimate goal of driving safety research is to prevent crashes, but crashes are rare events that cannot always be captured in research studies. Research has therefore used a number of driving measures as indicators of driving safety and performance, including on-road assessments, driving simulators, and self- or proxy-reported driving safety/performance. While there were no specific search strings designed to capture articles examining the validity of driving safety assessments for older drivers, the literature search identified 11 articles that aimed to define the validity of proxy measures of driving safety/performance.

On-road driving evaluations carried out by a professional such as a driving instructor or an occupational therapist—ideally, a CDRS—are considered the "gold standard" of driving risk assessment for older adults (Dickerson et al., 2014; Koppel et al., 2016). Such on-road assessments involve an older adult driving either on a closed course, a standardized route in real traffic conditions, or a route chosen by the older driver to reach a destination specified by the driving evaluator. On-road assessments can be scored based on number of errors or a holistic rating by the professional, such as safe or unsafe. Only two studies examined the predictive validity of older drivers' on-road assessments for crashes. A small study of 56 older drivers in New Zealand aimed to determine the validity of an on-road assessment for predicting State-reported crashes across 2 years, but no State-reported crashes occurred in the 2-year follow-up period (Hoggarth et al., 2013). The on-road assessment also failed to predict self-reported crashes or traffic offenses across the 2-year interval. Another study examined the validity of an on-road assessment in predicting crashes in a sample of 488 older Australian drivers (Anstey et al., 2009). In this study, the on-road assessment did not significantly predict either self-reported or State-reported crashes across 12 months. Both studies recruited healthy participants from the community, so it is possible that performance on on-road assessments is only predictive of future crashes among people with an elevated crash risk due to functional decline. However, the review only identified two articles that reported the validity of on-road assessments for predicting older-driver crashes in healthy samples, so it is difficult to make conclusions about whether on-road assessments indeed represent a gold standard of driving risk assessment.

Driving simulators are another method used to assess older driver performance and predict older adults' driving safety in real-world conditions. Driving simulators involve a computer-generated display showing a dynamic traffic situation to which research participants must respond using traditional brake, accelerator, and steering wheel controls. Driving simulators provide varying levels of 'realism,' conceptualized as low-fidelity or high-fidelity simulators. Cheaper and less time-consuming than on-road assessments, driving simulators are also safer than on-road studies because there is no risk of crashes. For this reason, simulators can expose drivers to more challenging traffic conditions than on-road assessments, such as heavy rain or nighttime driving.

The review identified one study that attempted to establish the validity of a simulator assessment for older drivers (Eramudugolla et al., 2016). The study, conducted in Australia, found a moderate correlation between simulator errors and occupational therapist-rated driving safety scores. However, simulator performance, simulator sickness, and age only explained about 28% of the variance in on-road driving safety scores. While the simulator assessment did have acceptable sensitivity and specificity, one difficulty highlighted in this study was simulator sickness, or feelings of discomfort associated with driving in a simulator. Simulator sickness (or "simulator adaptation syndrome") is a common issue in driving simulator studies that causes participants to be unable to complete parts or all of a study. This problem may be exacerbated among older people, leading to a concern that older adults who are worse drivers will drop out of simulator studies and skew results. However, one small study identified in the review found that older adults who dropped out of studies due to simulator sickness had significantly better on-road driving performance than older adults who completed the studies (Mullen et al., 2010).

Another proxy measure for driving safety involves ratings by older adults of their driving performance and driving difficulties. The validity of a self-reported measure of driving depends on the type of assessment and the identity of the rater. Older adults, and people in general, are not very accurate when reporting their own driving performance, as evidenced by one study identified in the review that asked older adults to rate their driving compared to others their age: drivers who considered themselves better than others their age were more likely to have worse simulator performance than drivers who rated themselves similar or worse than others their age (Freund et al., 2005). In fact, in this study, only one out of 47 drivers rated themselves as worse than others their age. A more detailed self-screening instrument focused on health conditions and their impact on specific measures of driving safety found small to moderate correlations between the self-screening results and on-road driving performance (Molnar et al., 2010).

Some research suggests that proxy raters such as caregivers and clinicians may be more accurate than older adults' own self-ratings of driving performance. One such screening instrument identified in this review is the Fitness-to-Drive Screening Measure, a web-based screening instrument for proxy raters, who rate the older driver on their performance on a set of specific driving behaviors. An evaluation of the measure found that while drivers' own ratings were not predictive of their performance in an on-road test, caregivers' ratings were (Classen et al., 2015).

While some studies obtain official crash records from State authorities to obtain objective measures of driving safety, other studies ask participants to self-report their own crash involvement. On the one hand, there may be State-reported crashes that are not reported by older adults because they either forget the crash or do not wish to admit crash involvement to researchers. On the other hand, there may be more crashes reported by participants than in official State records because not all crashes are reported to the State, such as crashes in which the police are not called to the scene or where there is no bodily injury. Two of the reviewed studies examined the agreement between older drivers' self-reports of crashes and State-reported crashes. One study found high agreement between older drivers' self-reports of crashes and State reports of crashes in a sample of 1,747 Alabama drivers 70 to 96 years old (Singletary et al., 2017). Over 3 years, there were 208 crashes reported among participants, whereas 225 crashes were recorded in State crash records. Another study found low agreement between older drivers' self-reports of crashes and State reports in a sample of 488 Australian drivers 69 to 95 (Anstey et al., 2009). In this study, participants reported 47 crashes over 1 year, whereas there were only three official crash records during the same period. Importantly, the authors report that participants who did not consent to having their official crash records released had higher self-reported crashes than people who consented. The prevalence of State-reported crashes in the sample may therefore be biased toward people with fewer State-reported crashes.

The low prevalence of crashes in the study by Anstey et al. (2009) is echoed in other studies that include both self- and State-reported crash outcomes. In a small New Zealand study of 56 healthy older adults, there were five self-reported crashes and no State-reported crashes across 2 years (Hoggarth et al., 2013). These findings highlight another challenge with using crashes as an outcome: crashes, particularly State-reported crashes, are rare in typical samples. However, because only two studies examined the correspondence between self-reported and State-reported crashes and the studies were conducted in different countries with potentially different reporting guidelines, the evidence remains inconclusive. Self-reported and State-reported crashes may be considered complementary measures that can provide a fuller picture of older driver safety.

State Driver Licensing Policies in North America to Detect Drivers Who Are Unfit to Drive

Moving from research settings to real-world settings, one of the goals of State licensing agencies is to detect drivers who are unfit to drive. State licensing agencies use different tools to detect these drivers, including the length of time between license renewals, requiring in-person renewals, and age-based testing at renewal. The length of time between renewals varies widely within the United States. As of 2019 renewal cycle length in the United States ranged from 1 year to 12 years (Graham et al., 2020). In some States, length of renewal cycle becomes shorter for older drivers. For example, Illinois' 4-year renewal cycle is reduced to 2 years for drivers 81 to 86 and to 1 year for drivers 87 and older.

States also have different policies regarding whether licenses must be renewed at a licensing center or whether they can be renewed online or via mail. One of the reasons for a State to require in-person license renewal is to provide license center counter staff with the opportunity for trained observers to flag potentially unsafe applicants. As of 2019 there were 45 States in the United States required in-person renewal for older drivers (Graham et al., 2020). Another reason to require in-person license renewal is to conduct screening tests for driver safety. Screening tests specific to older drivers are referred to as ABT. The most common ABT requirement is passing a vision test that measures VA and, sometimes, horizontal visual field. While some States mandate that vision testing is conducted at licensing centers at renewal, other States allow older adults to complete vision testing at doctors' offices and provide certificates reporting they passed the test. A much less common version of ABT is a road test administered at a licensing office. Only Illinois requires older drivers to pass road tests to renew their licenses; this requirement begins at age 75 according to the Office of the Illinois Secretary of State and is coupled with a decreasing interval between renewals (2 years) for those 81 to 86, with a further reduction to a 1-year renewal cycle for those 87 and older.

This section of Chapter 3 includes articles examining the impact of such licensing policies on driver safety in the United States and Canada; articles with data from other countries were excluded. The following search string was used to find articles related to DMV practices: older* AND driv* AND licens*. The search string was applied across four databases, yielding 1,421 total search results. Out of the total search results, 1,135 were ineligible based on title and abstract, and 242 were duplicates of another search, leaving 44 articles to be fully reviewed. Six were review articles. The most common reason for not including an article was that it did not publish results for a sample of people 65 and older. Four articles were eligible but only one was relevant to the topic. Six additional articles were identified from other search strings, leading to seven eligible articles for the topic of State driver licensing policies. Four articles used data from FARS, two articles used State crash records, and one article used crash-related hospitalizations as safety outcomes. The crash data reported in the reviewed studies includes data from as far back as 1985 to as recent as 2009. All but one study used retrospective analysis of historic crash records to explore the association between license renewal policies and older-driver crashes.

Although some States have renewal requirements based on vision, observational research (reviewed earlier in this chapter) has failed to find associations between VA and crashes among older drivers. A longitudinal study of license renewal policies in 46 showed that States from 1986 to 2011 found that an in-person renewal requirement was associated with fewer fatalities only among drivers 85 and older (Tefft, 2014). When in-person renewal was not required, requiring results of a vision test from a healthcare provider at mail or online renewal was associated with fewer fatalities for drivers 85 and older. However, when in-person renewal was required, additional testing at renewal, whether a vision test, knowledge test, or on-road test, was not associated with fewer fatalities. These study results suggest that requiring older adults to renew their license in-person may be more relevant to preventing crashes than requiring specific age-based testing at renewal.

Another study of fatal crashes in the United States from 1990 to 2000 found that vision testing and road testing at renewal were not significantly associated with fatalities (Grabowski et al., 2004). The only licensing policy associated with fatalities among older drivers was, again, whether a State had in-person renewal requirements. The association between requiring in-person renewal and fewer crashes is supported by an additional study that found that requiring in-person renewal for older drivers was significantly associated with fewer daytime fatalities, though only for drivers 85 and older (Morrisey & Grabowski, 2005). However, studies have not found consistent evidence of fewer crashes in States with shorter overall renewal cycles (Grabowski et al., 2004; Morrisey & Grabowski, 2005; Tefft, 2014). One study found that longer in-person renewal cycles were associated with higher rates of crashes for drivers 70 and older (Sharp & Johnson, 2005), though another study found that, after controlling for hospitalization rates of drivers 55 to 59, in-person renewal was not significantly associated with crash-related hospitalization for drivers 65 and older (Agimi et al., 2018).

Four studies found no significant effects of requiring a road test at renewal on crashes (Sharp & Johnson, 2005) or fatal crashes (Grabowski et al., 2004; Morrisey & Grabowski, 2005; Tefft, 2014). One study did find requiring a road test at renewal was significantly associated with a *greater* likelihood of crash-related hospitalizations among older drivers 85 and older but was not associated with crash-related hospitalizations for younger drivers, after controlling for the hospitalization rate of drivers 55 to 59 (Agimi et al., 2018). However, the incident rate ratio was small: drivers 85 and older who lived in a State that required a road test at renewal had 1.01 times the rate of crash-related hospitalizations compared to drivers 85 and older who lived in a State that did not require a road test at renewal. The authors note that only two States required a road test during the study period, and as noted above only Illinois currently requires a road test for license renewal for older adults. There is currently not enough evidence to draw conclusions about the safety benefits of road testing at renewal for older driver safety.

Two studies identified in the review examined the impact of a change in a single State's licensing law. McGwin et al. (2008) examined crash fatalities before and after implementation of a Florida State law requiring drivers 80 and older to submit a vision test before renewing their license (previously, only people applying in-person had to take a vision test). While the crash fatality rates among all Florida drivers increased pre-post law, and fatality rates in neighboring States for drivers 80 and older did not increase, fatality rates among drivers 80 and older in Florida decreased. The authors concluded that the addition of a vision test requirement for drivers who did not apply for license renewal in-person led to reduced fatalities.

Camp (2013) examined a pilot program in California conducted in 2007 that involved administering a 3-tier assessment system to drivers 70 and older at the time of license renewal. The first tier consisted of screening for impairment in cognition, physical function, and/or vision. The second tier added a written rules-of-the-road test and a perceptual response test. The third tier added a standardized road test. Each tier also included educational materials associated with each of the measures. The authors compared crashes among drivers 70 and older before and after implementation of the program and in other regions in California without the program during the same time period. The authors found no significant differences in time to first crash for drivers in the pilot program compared to baseline or drivers in nearby regions.

Evidence from the seven reviewed articles provides limited support for an association between license renewal policy and older-driver crash risk in the United States. One limitation of the reviewed studies is that all but one were retrospective analyses of historic crash records. While studies can control for possible factors related to older-driver crash risk, it is impossible to determine with retrospective studies whether any changes in older-driver crash rates are directly caused by changes in license renewal policy. Camp (2013) noted that the California license renewal policy provides stronger evidence than retrospective studies as it used quasi-random assignment to prospectively examine State-reported crash risk before and after participation in a pilot license renewal program. However, the study did not find differences in crash risk between drivers who participated in the program and drivers who did not. Another methodological difference in licensing studies relates to the way crashes are defined. Most of the studies looked at fatal crashes or State-reported crashes as outcomes of license renewal policy. As reviewed earlier, State-reported crashes are rare in healthy samples, and fatal crashes are even rarer. It is possible that license renewal policies may be related to a reduction in less severe crashes among older drivers that is not captured in the reviewed studies. Among all licensing renewal policies, the reviewed studies suggest that requiring older drivers to renew their license in-person may be the most salient predictor of fatal crashes and State-reported crashes among older drivers.

Managing Older-Driver Crash Risk

Assessments and interventions by clinicians offer another avenue for managing older drivers' crash risk. Preserving older people's ability to drive safely is within the scope of services provided by doctors, nurses, occupational therapists, and other healthcare professionals (Staplin et al., 2017). Supported by NHTSA, the American Geriatrics Society published *Clinician's Guide to Assessing and Counseling Older Drivers*, 4th edition (Pomidor et al., 2019). This guide specifies the roles of different types of clinicians in assessing older drivers. Primary care providers, such as physicians and nurse practitioners, perform medical evaluations to diagnose medical conditions. If the patient is diagnosed with a medical condition that may affect their ability to drive safely, the primary care provider can discuss the potential impact the medical condition has on driving, recommend treatment for the medical condition, and/or refer the patient for a comprehensive driving evaluation. Occupational therapists provide assessment and intervention for functional impairments to support older adults' driving mobility. Some healthcare professionals, called driver rehabilitation specialists, specialize in assessing older drivers' fitness-to-drive. Other members of the clinical team perform important roles in assessing and managing older driver safety risk, including nurses, pharmacists, and social workers.

The purpose of this section was to review studies on clinical examination and counseling for fitness to drive by clinicians, comprehensive driving evaluation by DRS, and their association with driving safety and performance in the United States and Canada. Articles using data from other countries were excluded. Search strings for this topic were "older*" AND "driv*" AND one of the following: "occupational therapist," "clinic*," "physician*," "evaluation," or "practitioner." There were 4,949 search results, 3,929 of which were deemed ineligible based on title and abstract and 902 of which were duplicates of a previous search, leaving 118 to be fully reviewed. After excluding articles that were ineligible for other reasons (73) and review articles (26), only one article relevant to this topic was identified (Agimi et al., 2018); it is discussed below under clinical examination and counseling.

Clinical Examination and Counseling for Fitness to Drive

The American Medical Association believes that physicians are in important positions to address older driver safety. Physician's interactions with older drivers can occur within or outside of a licensing context. As of 2019 all 50 States allow physicians to voluntarily report medically at-risk drivers, though only six States mandate such reporting (Graham et al., 2020). Medical-fitness-to-drive evaluation protocols are implemented through medical advisory boards in a majority of States (Lococo & Staplin, 2005); however, variations from State to State make it difficult to compare States. A review of all-inclusive physician reporting forms in 2008 found that no two States had the same medical evaluation form (Meuser et al., 2012). For example, only five States used forms that prompt physicians to obtain the patient driving histories, and 27 States' forms prompt physicians to provide license restriction recommendations. Another challenge of physician reporting is a lack of training: physicians report that they do not feel as though they have adequate training and/or knowledge to make fitness-to-drive assessments (Jang et al., 2007; Meuser et al., 2006).

Only one eligible study was identified in the review that looked at the association between physician reporting and driver safety. The study examined the risk of crash-related hospitalizations in all drivers 65 and older involved in a crash in 37 States from 2004 to 2009 (Agimi et al., 2018). The authors found that there was no difference in crash-related hospitalization based on whether the driver lived in a State with mandated physician reporting to license authorities, nor by whether the driver lived in a State with protected physician reporting. Though there is great emphasis placed on clinician assessment of older driver safety, there were no studies that examined how clinician assessments are related to driving performance or how clinician counseling is related to future driving safety that met the inclusion criteria for the review.

Comprehensive Driving Evaluation by a (C)DRS

DRS are another type of professional that interacts with older drivers. A DRS is usually, but not exclusively, an occupational therapist that is qualified to carry out a comprehensive driving evaluation and provide counseling and training services to maintain and enhance mobility for older drivers. A DRS provides a clinical assessment of older drivers, including a review of driving history; in-clinic cognitive, physical, and visual assessments; and a comprehensive on-road driving evaluation (Dickerson, 2013). Based on assessment results, the DRS provides recommendations to older drivers about potential interventions to reduce driving risk, including vehicle modifications and/or driving instruction. In many States, DRSs also provide similar information to the licensing authority.

The current review did not identify any qualifying articles that examined the validity of DRS assessments for driving safety or performance, though many of the physical, visual, and cognitive status measures reviewed earlier as predictors of driving safety or performance are used by a DRS when assessing medical (functional) fitness to drive. The review did identify three additional systematic reviews that examined interventions that are within the scope of occupational therapy but not necessarily provided by occupational therapists (Golisz, 2014; Justiss, 2013; Unsworth & Baker, 2014). For example, Unsworth and Baker (2014) conclude that there is evidence that skill training, simulator training, and education-based approaches, which can be used by occupational therapists, improve on-road performance among drivers of all ages.

Summary

Research over the past two decades has examined diverse techniques and procedures for identifying risk factors among older drivers that can diminish performance and increase their likelihood of crash involvement. Epidemiological studies have focused largely on the extent to which measures of functional status can predict safety and performance outcomes. These include measures of vision, cognition, and physical function. Cognitive status—particularly subdomains of cognition including attention, speed of processing, and executive function—has been shown in both retrospective and prospective analyses, and in the meta-analysis conducted here, to be the strongest predictor of safety and performance outcomes, although researchers have also found evidence that visual sensory impairments and a loss of lower limb strength and mobility are significantly associated with increased risk. Test batteries incorporating several (cognitive) measures, and sometimes several functional domains, have shown some promise in identifying older drivers scored as unsafe on road tests and have been promoted in guidelines to clinicians and healthcare providers as useful resources for counseling their older patients on issues relating to aging and driving. There are questions about the validity of older driver safety indices other than crashes; yet performance on a comprehensive driving evaluation by a (certified) driver rehabilitation specialist is widely regarded as the 'gold standard' for risk assessment. Self-reports of driving difficulties are likely to be not as reliable as those provided by family members or caregivers. Among the various approaches used by State driver license agencies to detect people who are medically/functionally unfit to drive, the strongest evidence for a safety benefit is associated with a requirement for in-person renewal by older drivers; the introduction of vision tests and shorter renewal cycles with advancing age are additional policies adopted by several States, though differences exist across jurisdictions regarding what age such practices are implemented.

Page intentionally left blank.

Chapter 4: Medical Conditions, Medications, and Other Health Considerations

In general, the prevalence of medical conditions increases with age. Certain medical conditions that are more common among older adults, as well as the medications used to treat these conditions, can affect the ability to drive safely through effects on cognition, vision, and physical function. Lococo et al. (2018) prepared a review of peer-reviewed articles and other technical reports published between 2000 and 2011 relevant to medical fitness to drive, with special emphasis on older drivers. This section summarizes the Lococo et al. (2018) review, referred throughout Chapter 4 as "the 2018 review," and notes any new peer-reviewed or agency-reviewed papers identified in the current search that examined driving safety or performance, medical conditions, and medications among drivers 65 or older.

The search terms for Chapter 4 were a combination of "older*" and "driv*" and one of the following terms: fitness, medical*, medication*, health, physical*, and polypharm*. Out of 7,379 search results, 6,777 were excluded based on title and abstract, 365 were duplicates of another search, and 237 were sent to full review. An additional article was identified from a literature review, leading to 238 articles being fully reviewed for eligibility. At this step, 173 were excluded. The most common reason an article was excluded was that it did not report results for a sample of people 65 and older (101 articles). The next most common reason was that it did not report a safety or performance outcome (37 articles). Twenty-six eligible articles were identified from the full article review, and six additional articles were pulled from other chapters that were originally excluded during full abstract review. In total 32 articles were eligible and included here. The articles in Chapter 4 were not restricted by country.

Arthritis

Arthritis refers to the swelling of the joints, associated with more than 100 conditions and characterized by joint pain, stiffness, and other symptoms. Specific types of arthritis common among older adults include osteoarthritis, rheumatoid arthritis, fibromyalgia, and gout. Osteoarthritis is the most common type of arthritis among older adults. Osteoarthritis is characterized by the breakdown of cartilage over time; symptoms of osteoarthritis include pain, stiffness, and swelling at the feet, hands, knees, and other joint areas. Rheumatoid arthritis is caused by the immune system attacking the joints, resulting in inflammation, swelling, and potential joint damage. From 2013 to 2015, an estimated 54 million adults in the United States had some form of arthritis diagnosed by a doctor (Barbour et al., 2017).

Though arthritis can occur at any age, the majority of adults with arthritis are over the age of 65, and almost half of adults 65 and older, or 22 million people, have arthritis. Arthritis is also more prevalent among women than men. A large study of drivers hospitalized after a crash in New South Wales, Australia from 2003 to 2012 reported an incidence rate of 11.8 hospitalized car drivers 70 and older with arthritis per 10,000 licensed drivers; this rate was much higher than the rate for drivers 50 to 59 (Mitchell et al., 2020). These rates provide an estimate of the number of drivers 70 and older hospitalized because of a crash that have the specific medical condition, but the rates do not account for the number of drivers with the specific condition not involved in a crash that required hospitalization.

As described in Lococo et al. (2018) pain and stiffness in the joints associated with arthritis can affect several abilities needed for safe driving, including turning the steering wheel and using the pedals. The 2018 review identified one study that examined the driving performance of older drivers with arthritis. This study by Zhang et al. (2007) found that reporting pain in the feet, hips, or legs, or receiving current treatment for arthritis was associated with slower brake reaction speed. The current review identified one additional study of driving performance and arthritis. This large naturalistic driving study of 980 older drivers did not find an association between a history of arthritis and lane-change failures (Munro et al., 2010).

The 2018 review cites three studies examining arthritis and crashes, one of which is also included in the present review (McGwin et al., 2000). In this study, arthritis history was significantly associated with being a driver in a police-reported at-fault crash in the past 5 years, but only among female drivers. However, a study of female older drivers also included in the present review did not find osteoarthritis history to predict future police-reported crashes regardless of fault across 7 years (Margolis et al., 2002). Both studies adjusted for age and driving mileage, both were large studies, and prevalence of arthritis in both studies ranged from 43 to 59%. However, Margolis et al. (2002) specifically asked participants if they had been diagnosed with osteoarthritis, while McGwin et al. (2000) asked about general arthritis. Therefore, it is possible that the association between crashes and arthritis in the study by McGwin et al. (2000) was driven by people with other forms of arthritis such as rheumatoid arthritis. Discrepancies in findings between the two studies may also be attributed to how crashes were assessed. While both studies asked participants if they had ever been told by a healthcare professional that they had arthritis, McGwin et al. (2000) assessed whether prior arthritis diagnosis was associated with crash involvement in the 5 years prior to the study. Because the date of arthritis diagnosis was not assessed, it is possible that some drivers crashed prior to arthritis diagnosis. In comparison, Margolis et al. (2002) assessed crash risk for 7 years following the study. This prospective assessment of crash risk provides stronger evidence for an association between arthritis and crash risk.

Overall, the present review does not find strong evidence of impaired driving performance and safety associated with a diagnosis of arthritis among older adults. Only three studies were identified in the present review, and two large prospective studies did not find an association between a history of arthritis and driving performance or safety. However, the three reviewed studies do not provide information on arthritis symptoms or severity. Therefore, it is possible that participants in the reviewed studies had mild arthritis that did not interfere with their driving. It is also possible that medications participants took to manage arthritis, such as steroids, narcotics, and non-steroidal anti-inflammatory drugs, may partly explain the relationship observed in one study between arthritis and driving safety and performance, as these medications have potentially driver impairing effects.

Diabetes

Diabetes mellitus, or diabetes, refers to a group of diseases that affect blood glucose levels. Type I and Type II diabetes are the most common types of diabetes among older adults in the United States. Type I diabetes is a chronic autoimmune condition in which the pancreas does not make enough insulin and is commonly diagnosed in childhood or adolescence. Type II diabetes is characterized by insulin resistance in the body and is more commonly diagnosed in people older than 40. Between 2013 and 2016, an estimated 13% of adults in the United States had diabetes (Centers for Disease Control and Prevention, 2020). Both Type I and Type II diabetes can develop at any age, though the prevalence of diabetes was much higher among people 65 and older (27%) than among people between 18 and 44 (4%). Mitchell et al. (2020) reported that 18.1 drivers 70 and older with diabetes were hospitalized after a crash per 10,000 total licensed drivers, three times the rate for hospitalized drivers 50 to 59 and higher than the rates for arthritis and dementia.

As described in the 2018 review, both acute events and chronic complications related to diabetes can affect driving. Hypoglycemia is an acute condition in which blood glucose levels are lower than normal and may be triggered by certain medications used to manage diabetes. Several symptoms of hypoglycemia may be potentially driver-impairing, including impaired cognitive function, double or blurry vision, fainting, and seizures. Hypoglycemia can be treated by consuming sugar, though medical attention may be required for severe hypoglycemia. Chronic complications of uncontrolled diabetes may also affect safe driving performance. Diabetes increases the risk of nerve damage or neuropathy, particularly in the legs, which can affect the driver's ability to operate a vehicle, and eye damage or retinopathy, which can lead to decrements in VA and peripheral vision. People with diabetes are also more likely to develop cataracts and open-angle glaucoma, both of which can impair driving performance.

None of the studies examined driving performance and diabetes. The 2018 review cited several studies of diabetes diagnosis and driving performance and safety that were excluded from the present review because they included drivers of all ages. The 2018 review concluded that simulator performance of drivers with Type II diabetes is worse than that of drivers without diabetes, especially in a state of hypoglycemia. Some evidence suggests that drivers with Type I diabetes do not have impaired driving performance compared to drivers without diabetes even in cases of hypoglycemia. However, some evidence suggests that drivers with Type I diabetes with a history of hypoglycemic incidents while driving may have impaired driving performance. These conclusions from the 2018 review are based on studies that included people under 65, so it is unclear whether the findings would apply to older drivers with diabetes.

While some studies reviewed in Lococo et al. (2018) found evidence of higher crash risk for drivers with diabetes, most studies did not. The present review also did not find evidence for an association between self-reported diabetes and prior (Lafont et al., 2008; McGwin et al., 2000) or future crash involvement (Margolis et al., 2000) among older drivers, with and without adjustment for driving mileage. A large insurance claims database study of adults with Type II diabetes did not find a difference in crash risk between older drivers with and without a history of hypoglycemia requiring medical care, though the study may have been limited by the small number of people who crashed (Signorovitch et al., 2013). The crash risk of people *under* 65 with Type II diabetes with a hypoglycemic history was significant, consistent with the findings of the 2018 review.

As stated earlier, antidiabetic medication may cause hypoglycemia that can impair driving performance. Three studies in the present review examined antidiabetic medication and crash risk among older drivers. A case-crossover study did not find insulin or use of an anti-hyperglycemic drug 14 days prior to a crash to be related to crash risk after adjusting for total number of medications (Rudisill, Zhu, Davidov, et al., 2016). A study of self-reported oral hyperglycemic prescription also found no association with crash risk (McGwin et al., 2000). Hemmelgarn et al. (2006), on the other hand, found evidence for an association between certain antidiabetic medications and crash risk. In their study, insulin use and a combination of two oral hypoglycemics (but not either medication alone) were associated with a small increase in crash risk for older drivers. The 2018 review cites a case-control study of physician-patient visits and an insurance database of people 50 and older that examined the crash risk associated with medications (LeRoy & Morse, 2008). The case-control study found significantly higher odds of a crash for people taking insulin (OR = 1.80) and for several hypoglycemics (ORs 1.35 to 1.49).

Overall, the present review did not find strong evidence for an association between diabetes and driving safety among older drivers. Antidiabetic medications and hypoglycemia resulting from these medications may impair driving safety, though their effects may be more pronounced in drivers under 65. It is possible that older drivers with diabetes have more time to learn to adapt their driving in response to their diagnosis. Further, it is possible that some effects of diabetes on older drivers stem from complications of diabetes specific to older adults, such as cognitive dysfunction and vision impairment (Kirkman et al., 2012). However, no eligible studies were identified in the present review that examined the driving safety and performance effects of specific diabetic complications.

Dementia and Mild Cognitive Impairment

Dementia is a general term referring to impaired cognitive ability that interferes with daily functioning. AD is the most common type of dementia in the United States, though several other types of dementia with varying symptomology exist, including vascular dementia, frontotemporal dementia, and dementia with Lewy bodies. In 2019 about six million people in the United States had AD, 81% of whom were 75 or older (Alzheimer's Association, 2019). The prevalence of AD increases with age: an estimated 10% of people 65 and older and 32% of people 85 and older have AD. A higher percentage of people with AD are female, likely due to females' higher life expectancy. Mitchell et al. (2020) report a crash-related hospitalization rate of 3.6 drivers 70 and older with AD per 10,000 licensed drivers, higher than the rate for hospitalized drivers 50 to 59 but lower than rates for other medical conditions.

As reviewed by Lococo et al. (2018), a variety of dementia symptoms can affect driving. Memory impairment is a prominent early symptom of dementia and can impact driving performance and safety, particularly when there are changes in familiar environments. Apraxia is another symptom of AD and refers to a deterioration of the ability to execute skilled movements. Drivers with dementia experiencing apraxia may have difficulty using vehicle controls such as the steering wheel and pedals. Drivers with AD may also experience impaired judgment and impulsivity that can impact the ability to determine when it is safe to turn across an intersection or make a lane change.

The 2018 review identified impaired driving performance in drivers with AD compared to drivers without AD. The present review identified three additional articles that examined AD and driving performance. Consistent with the 2018 review, new articles from the present review found that drivers with AD had worse naturalistic driving performance (Paire-Ficout et al., 2018) and driving simulator performance (Etienne et al., 2013) compared to drivers without AD.

The present review identified two studies that examined crash risk of older drivers with AD. A large study of electronic health records found that drivers with AD and similar dementias had significantly *lower* police-reported crash risk compared to drivers without AD and similar dementias (Fraade-Blanar et al., 2018). In contrast, a 2-year study of 1,649 older people found that drivers diagnosed with dementia at follow-up were three times more likely to self-report a crash in the 5 years prior to study baseline compared to drivers without dementia (Lafont et al., 2008). Unlike Fraade-Blanar et al. (2018) this study controlled for driving frequency. It is likely that the lower crash risk for drivers with dementia in the Fraade-Blanar et al. (2018) was partly due to overall lower driving exposure among drivers with dementia. However, the study by Lafont et al. (2008) was limited in that the measure of crashes was self-report and retrospective. Drivers with dementia may have difficulty recalling crashes that occurred in the past 5 years, which may partially explain the lack of a significant difference in crash risk based on dementia diagnosis at baseline.

The role of driving exposure in the crash risk of drivers with dementia is supported by a study cited in the 2018 review (Ott et al., 2008). The study examined the crash risk of 128 drivers 40 to 90 with and without early AD across 3 years (Ott et al., 2008). The study reported significantly fewer crashes among drivers with AD compared to drivers without AD, but crash differences disappeared after adjusting for driving mileage. However, the drivers with AD were still significantly more likely to fail an on-road test 18 months from baseline assessment than drivers without AD.

Only one study in the present review examined driving safety or performance of older drivers with a dementia type other than Alzheimer's disease. Yamin et al. (2015) examined older drivers with DLB, a form of dementia with similar symptoms to Alzheimer's disease and additional symptoms such as sleep disturbances, hallucinations, and motor impairment. DLB accounts for five to 10% of dementia cases in the United States, though it more commonly presents in conjunction with AD pathology (Alzheimer's Association, 2019). Yamin et al. (2015) compared the driving simulator performance of 15 people diagnosed with mild DLB to 21 control drivers without a DLB diagnosis. Drivers with DLB performed significantly worse than controls on all measures of simulated driving performance.

MCI is a condition that sometimes but not always progresses to dementia. People with MCI may exhibit changes in memory and/or cognitive performance that are often noticed first by friends and family. While MCI can be an indicator of early AD, MCI can also be related to, for example, a medication change and can be reversible. The Alzheimer's Association (2019) estimates that 15 to 20% of people 65 and older have MCI.

The 2018 review included three studies of drivers with MCI that were excluded from the present review because they were either not peer-reviewed or included drivers under 65. The studies cited by the 2018 review found that the driving performance of drivers with MCI is worse than drivers without MCI but better than drivers with AD. The present review identified two studies that compared the driving performance of older drivers with and without MCI. The articles found significantly worse simulator (Devlin et al., 2012) and on-road (Anstey et al., 2017) performance among older drivers with MCI compared to older drivers without MCI.

However, differences between MCI and control drivers on simulators or on-road tests may not have a meaningful impact on driving safety. Anstey et al. (2017) note that drivers with MCI only scored an average of one point lower on an on-road test with a maximum score of 10, which may not be a meaningful difference in safety. Though the average scores were lower for MCI drivers than control drivers, scores for both groups varied widely, suggesting that a diagnosis of MCI alone may not provide enough information to predict how well a person will perform on driving performance. The drivers with MCI in the sample also had similar numbers of crashes in the past 5 years compared to control drivers. Devlin et al. (2012) only found significant differences in simulator performance for one measure (number of brake applications) out of six examined, in only one out of three driving scenarios.

The findings of the present review echo the findings of the 2018 review showing that drivers with dementia, on average, have worse driving performance than drivers without dementia. However, as noted by some authors, a diagnosis of MCI or dementia may not be sufficient in determining whether a driver is safe or not. People with MCI have varying levels of cognitive ability, and dementia can range from very mild to severe. The 2018 review discusses some studies finding that the driving performance of people with AD may differ depending on the clinical dementia rating. However, none of the studies in the present review used clinical dementia rating values to group participants or compared the driving performance or safety of people with dementia of different severities.

The present review only identified one article that examined driving performance or safety among older drivers with a dementia other than Alzheimer's disease. Piersma et al. (2016) conducted a comprehensive review of driving and different etiologies of dementia among drivers of all. The authors note that the driving safety and performance among people with dementias other than AD or with MCI is not well understood. One reason may be that MCI is an ambiguous condition that may or may not progress to dementia and can be reversible. There are many articles on the driving safety/performance of drivers with dementia or MCI, but these articles typically include younger samples. In the present review, there were over 30 articles that would have been eligible for the review on dementia/MCI that were excluded because they included a sample under 65.

Parkinson's Disease

Parkinson's disease is a progressive neurological disorder characterized by motor dysfunction. In 2017, an estimated one million people in the United States had a diagnosis of PD (Yang et al., 2020). The majority of people with PD are older than 65, and the prevalence of PD increases with age. In 2017 an estimated 1% of people 65 to 74 and 2% of people 75 and older had PD. PD is more prevalent in males than females.

People with PD experience motor symptoms including tremor, muscle rigidity, and slowed movement. People with PD may also experience cognitive impairment, visual impairment, and daytime sleepiness that may be exacerbated by medications used to treat PD. Motor and cognitive symptoms of PD can affect the ability to drive safely. The 2018 review identified impaired simulator and on-road driving performance of drivers with PD compared to drivers without PD, especially while driving with distractions. Only one small study cited by Lococo et al. (2018) compared the crash risk of drivers with PD and drivers without PD, including drivers under 65 in age; there were no significant differences in crash risk between drivers with and without PD.

The present review identified one article on driving safety and one article on driving performance of older drivers with PD. Lafont et al. (2008) examined the association between PD and self-reported crashes in the previous 5 years in a sample of 2,104 drivers in France. There were no significant differences in the crash involvement of drivers with PD versus drivers without PD. However, drivers with PD were 17 times more likely to have ceased driving in the past 5 years compared to drivers without PD. It is likely that older adults with PD who may have been at risk for crashing had already ceased driving prior to the 5-year retrospective period of this study.

Aksan et al. (2015) recruited three groups of older drivers: drivers with probable AD, drivers with PD, and drivers without AD or PD who served as controls. Compared to drivers with AD, drivers with PD committed more safety errors at stop signs during the on-road drive but otherwise did not significantly differ on any of the other subtasks or total on-road score, as rated by a certified driving instructor. Drivers with PD and AD as a combined group performed significantly worse on total safety errors while distracted and while not distracted, as well as on lane observance. The authors did not report the statistical significance of tests pertaining to driving performance between drivers with PD and controls; however, descriptive data tables indicate that drivers with PD committed numerically more safety errors than controls.

The association between a PD diagnosis and driving safety and performance among older drivers is not well understood. There is a body of work examining driving performance and safety of drivers with PD, but these articles often include drivers younger than 65. In the present review, several articles were excluded because they included drivers under 65 that would have otherwise been included.

Eye Disease

Cataracts

Cataracts are a common condition among older adults in which cloudy areas appear in the lens of the eye. Cataracts affect visual abilities related to driving, including acuity, CS, color discrimination, and depth perception. According to the National Eye Institute (2019), around 17% of adults 40 and older in the United States had cataracts in 2010. The prevalence of cataracts increases with age: 25% of adults 65 to 69 have cataracts, while 68% of people 80 and older have cataracts. The prevalence of cataracts is higher for females compared to males. Mitchell et al. (2020) report the highest rate of crash-related hospitalization for drivers with vision disorders, at 27.6 drivers 70 and older hospitalized after a crash for every 10,000 licensed drivers. This was much higher than the rate for drivers 50 to 59 with vision disorders (one hospitalization for every 10,000 licensed drivers) and the highest rate for all medical conditions.

Lococo et al. (2018) reviewed studies showing that drivers with cataracts have impaired driving performance and a higher crash risk compared to drivers without cataracts. Studies cited in the review suggest that decrements in driving safety and performance among drivers with cataracts can be mostly attributed to impairments in CS. This finding is consistent with the studies reviewed in Chapter 3 of the present review that identify CS as the visual ability most consistently associated with driving safety and performance. Studies cited in the 2018 review also indicate that cataract surgery was associated with improvements in driving safety; these improvements could also be attributed to improved CS.

The present review identified two studies of self-reported cataract history and crashes and a study of crash risk before and after cataract surgery. A large representative study of patients 65 and older receiving first eye cataract surgery in Ontario from 2006 to 2010 found improvements in driving safety after surgery (Schlenker et al., 2018). The crash risk after cataract surgery was especially reduced for patients older than 75 and female and rural patients. However, two studies using a measure of self-reported cataract history did not find significant differences in crash involvement of older drivers with and without cataracts (Margolis et al., 2002; McGwin et al., 2000). These studies did not include information on whether participants had ever had cataract surgery. Given demonstrable improvements in driving safety after cataract surgery, it is possible that some of the participants in the self-report studies had a history of cataracts but had received cataract surgery prior to study entry.

The present review provides additional support to the findings of the 2018 review that cataract surgery is associated with improvements in driving safety. The present review did not identify any articles on driving performance and cataracts among older drivers. Several articles were identified in the search process, including some of the articles cited in the 2018 review, but these articles were excluded because they included participants under the age of 65. Additionally, Wood & Black (2016) suggest early cataract surgery as a crash reduction intervention. While cataract surgery has been shown to be associated with fewer crashes and improved driving performance among drivers 50 and older, it is unclear whether cataract surgery also results in performance and safety improvements for drivers 65 and older.

Glaucoma

Glaucoma refers to a group of eye conditions that damage the optic nerve. The most common type of glaucoma in the United States is open-angle glaucoma. Glaucoma results in gradual reduction of the peripheral visual field over time and can lead to a total loss of vision. The National Eye Institute (2019) estimates that in 2010, 2% of adults 40 and older had open-angle glaucoma. The prevalence of open-angle glaucoma was highest among adults 80 and older, 8% of whom had open-angle glaucoma in 2010.

The 2018 review reports impaired driving performance of drivers with glaucoma compared to drivers without glaucoma. The 2018 review also identified studies showing that drivers with glaucoma have a higher crash risk than drivers without glaucoma, though some work suggests that crash risk is only higher for people with glaucoma with a high degree of visual field loss.

The present review includes one study of driving performance and two studies of crash risk of drivers with glaucoma. Wood et al. (2016) found that older drivers with glaucoma had significantly lower safety ratings and committed more critical errors on an on-road test than drivers without glaucoma. Kwon et al. (2016) found that drivers with a glaucoma diagnosis had a 65% greater at-fault crash rate in the 5 years before participating in the study compared to drivers without a glaucoma diagnosis. In contrast, McGwin et al. (2000) did not find significant differences in prior crash involvement between people with self-reported glaucoma history and people without.

The present review identified some evidence for impaired driving performance and safety among older drivers with glaucoma, though the safety evidence was limited by retrospective analyses. The 2018 review identified a large number of articles looking at crash risk and driving performance of drivers with glaucoma, but all the articles included a sample of people younger than 50, with the exception of two articles published prior to 2000 that were excluded from the present review. There is some evidence for impaired driving performance and safety among older drivers with glaucoma identified in the present review, but only one article each supporting these findings. Wood & Black (2016) note in their review of ocular diseases and driving that crash risk of drivers with glaucoma is only elevated in cases of moderate to severe loss in vision. The association between driving safety and glaucoma may be even more elevated in older adults as glaucoma is a progressive disease. However, none of the reviewed studies included information on disease severity.

Age-Related Macular Degeneration

Age-related macular degeneration occurs when aging causes damage to the central region of the retina, resulting in deficits in central vision. According to the National Eye Institute, an estimated 2% of adults 50 and older in the United States have AMD (2019). The highest prevalence of AMD is among adults 80 and older, in which 12% of the population has AMD. In comparison, the prevalence of AMD among people 65 to 69 is less than 1%. A higher proportion of people with AMD are female, likely due to the greater life expectancy of females.

The 2018 review cites studies showing that drivers with AMD had worse driving performance and safety compared to drivers without AMD, all of which were published prior to 2000. Only one study on AMD and older driver safety/performance was identified in the current review. Consistent with the findings of the 2018 review, drivers with AMD received significantly lower on-road driving scores and committed more errors compared to drivers without AMD (Wood et al., 2018). When separated by disease severity, drivers with intermediate AMD had significantly more critical errors than controls, while drivers with early AMD had similar error rates to controls. There were no studies identified in the current review that examined the relationship between AMD and crashes.

Medications

Some medications commonly prescribed to older adults have side effects that can impair driving performance. The present review identified studies on the potential driving safety and performance effects of medications that are either commonly prescribed in older adults or have side effects that may be more driver-impairing for older drivers due to age-related changes in how the body processes medications. The literature search as described at the beginning of Chapter 4 yielded eligible studies on the potential driving safety and performance effects of three categories of medications for older drivers: benzodiazepines, antidepressants, sleep medications, and combinations of these medications. The present review identified 10 articles that included measures of medication use and measures of either driving safety or performance among older drivers.

Benzodiazepines

Benzodiazepines are a class of sedating medications that target the central nervous system. Benzodiazepines are classified into two categories: long-acting benzodiazepines, which are processed more slowly in the body, and short-acting benzodiazepines, which are processed more quickly in the body. Benzodiazepines are approved by the Food and Drug Administration to treat a number of conditions including generalized anxiety disorder, insomnia, seizures, social phobia, and panic disorder. Benzodiazepines may also be used to treat endocrine and musculoskeletal diseases like diabetes and rheumatoid arthritis. The American Geriatrics Society recommends avoiding the use of benzodiazepines in older adults due to increased risk of cognitive impairment, delirium, falls, fractures, and motor vehicle crashes (Pomidor et al., 2019). Despite this recommendation, many older adults in the United States are prescribed benzodiazepines, most often for insomnia and anxiety (Marra et al., 2015). The prevalence of benzodiazepine use in the United States increases with age and is higher among females than males. In 2008, 11% of women 65 to 80 and 6% of men 65 to 80 had a benzodiazepine prescription (Olfson et al., 2015). Long-acting benzodiazepine use also increases with age and is higher among females than males.

Benzodiazepines have a number of potentially driver-impairing side effects that may be exaggerated in older adults. Sedation and drowsiness are common side effects of benzodiazepines that can impair driving performance. Older adults are particularly at risk for cognitive and psychomotor side effects of benzodiazepines (Pomidor et al., 2019), which can interfere with the ability to use vehicle controls and react to the driving environment. Side effects of benzodiazepines may appear several hours or the next morning after taking the medication, sometimes called “hangover effects” (Couper & Logan, 2014).

The present review identified five articles that examined benzodiazepines and crash risk; no articles examined driving performance. Three crash studies used either case-control or case-crossover methods to assess the crash risk associated with benzodiazepine exposure in older drivers. Case-control and case-crossover methods are epidemiological approaches to analyze the effect of exposure on an outcome. Case-control designs compare the exposure of a risk factor between people who have experienced an outcome (cases) and people who have not (control). Case-crossover designs compare people to themselves at different windows of time to determine whether exposure during the window in which an outcome occurred (case window) was atypical compared to exposure during the window in which the outcome did not occur (control window).

Two studies used data from the Quebec government health insurance board (Régie de l'assurance maladie du Québec, RAMQ), which contains information on physician and hospital visits and prescription medications for residents enrolled in Quebec’s public health insurance plan. Case-control analyses in these studies identified an increased crash risk associated with long-acting benzodiazepine prescriptions (Fournier et al., 2015; Hebert et al., 2007) and a smaller increase (Fournier et al., 2015) or no increase (Hebert et al., 2007) in crash risk associated with short-acting benzodiazepine prescriptions. Hebert et al. (2007) also did not find an association between short-acting benzodiazepines and crash risk in case-crossover analyses. However, a case-crossover analysis found 57% greater crash risk among older adults who were infrequent users of long-acting benzodiazepines (Hebert et al., 2007). Another case-crossover study did not find a significant difference in crash risk by benzodiazepine use (Rudisill, Zhu, Davidov, et al., 2016). However, the study did not distinguish between long-acting and short-acting benzodiazepines, and the power to detect differences in crash risk may have been limited by the small number of drivers (21 out of 611) who had a benzodiazepine prescription. Two questionnaire-based studies also failed to find a significant association between self-reported benzodiazepine use and self-reported crash history (Lafont et al., 2008) or State crash records (McGwin et al., 2000). However, the strength of evidence from these two studies is limited by a retrospective measure of crashes and no information on whether benzodiazepines were short-acting or long-acting.

The present review included two large studies using well-established statistical techniques that demonstrated elevated risk of crashes among older drivers taking long-acting benzodiazepines. The sedating effect of benzodiazepines may be compounded when taken in conjunction with other medications, as detailed later in this chapter. None of the reviewed studies on benzodiazepines included a measure of driving performance, so no conclusions can be made about the association between benzodiazepine use and driving performance among older adults.

Antidepressants

Antidepressants are a commonly prescribed medication in the United States, and the prevalence of people taking antidepressants increases with age and is higher for females. Between 2015 and 2018, an estimated 24% of women and 13% of men 60 and older were prescribed an antidepressant medication (Brody & Gu, 2020). Commonly prescribed antidepressant medications include SSRIs, tricyclic antidepressants, serotonin and norepinephrine reuptake inhibitors, and monoamine oxidase inhibitors. Antidepressants may have sedating side effects that impair driving, and the sedating side effects may be aggravated when taken with other medications such as benzodiazepines (Pomidor et al., 2019).

The present review identified five articles that examined antidepressants and driving. Three studies used either case-crossover or case-control analysis, two of which used data from different years of the RAMQ. Orriols et al. (2013) conducted a case-crossover analysis of people 66 to 84 from 1988 to 2000. Fournier et al. (2015) conducted a nested case-control analysis of people from 67 to 84 from 1990 to 2000. Both studies found an increased risk of police-reported crashes associated with filling an SSRI prescription, ranging from 13 to 35% higher odds of experiencing a crash associated with an SSRI prescription. Neither study found a significant association of TCA exposure and crash risk. Similar to findings regarding benzodiazepines, the self-report studies (McGwin et al., 2000; Lafont et al., 2008) and the case-crossover analysis (Rudisill, Zhu, Davidov, et al., 2016) did not find associations between any antidepressant or SSRI prescription and crashes using case-crossover analysis. Similar limitations in the studies may have affected the results of these studies (i.e., retrospective outcomes and small samples of people taking the medication).

The present review identified two large case-control studies reporting increased crash risk of older drivers taking SSRI antidepressants. As mentioned above, the sedating effect of antidepressants may be enhanced when taken in conjunction with benzodiazepines (Fournier et al., 2015). A limitation of the findings of the present review is that none of the reviewed studies included a measure of depressive symptomology or depression diagnosis. It is possible that the association between antidepressants and crashes is driven partly by the association between depressive symptoms and crashes. It is not possible from the reviewed studies to determine the relative contribution of antidepressants versus depressive symptoms to driving safety. Orriols et al. (2013) suggest that depressive symptoms may play a role in driving safety given that the association between antidepressants and driving safety was strongest when there was a larger gap in between case and control periods (i.e., when there was likely a greater difference in depressive symptoms). There were no studies investigating the association between antidepressant use and driving performance.

Non-Benzodiazepine Sleep Aids

Sleep aids are a category of sedative and hypnotic medication used to induce or maintain sleep by suppressing central nervous system activities. From 2005 to 2010 an estimated 4% of all people 20 and older and 7% of people 80 and older in the United States used a prescription sleep aid (Chong et al., 2013). A greater proportion of people who use sleep aids are female. Prescription sleep aids include benzodiazepines, doxepin, suvorexant, and “Z-drugs” (zolpidem, zopiclone, and zaleplon). The American Geriatrics Society (Pomidor et al., 2019) recommends avoiding use of Z-drugs in older adults because they have minimal benefits to sleep and can have serious adverse effects, including delirium, falls, fractures, emergency room visits, and motor vehicle crashes. Sleep aids have the potential to be especially dangerous because their residual next-day effects on cognition and psychomotor function can affect driving performance, as a consequence of reduced coordination and drowsiness.

The present review identified three studies of non-benzodiazepine sleep aids and driving among older drivers, with varying methodological approaches. The study with the strongest methodology was a double-blind randomized experimental study of the effects of two different doses of suvorexant compared to zopiclone and a placebo group (Vermeeren et al., 2016). Participants were assessed by an on-road drive in an instrumented vehicle with a driving instructor the morning after their medication use. There was no significant difference in standard deviation of lane position or standard deviation of speed between participants taking 15 or 30 mg of suvorexant compared to a placebo group. The group taking 7.5 mg zopiclone had a significantly greater standard deviation of lane position the morning after taking the medication compared to placebo.

Booth et al. (2016) examined the 5-year crash history of people taking zolpidem in a sample of 2,000 Alabama drivers 70 and older. There was a significant difference in crash rate between people taking zolpidem and people not taking zolpidem, but only among females and among people 80 and older. People 80 and older taking zolpidem had a crash rate of 12.74 crashes per million person miles, while people 80 and older not taking zolpidem had a crash rate of 5.45 crashes per million person miles. Study results should be interpreted with caution, as the study examined how zolpidem prescriptions at the time of the study predicted crashes in the 5 years before the study. Rudisill, Zhu, Davidov, and colleagues (2016) also examined zolpidem prescriptions and crashes but did not find a significant association. Like findings regarding other medications and medical conditions in this study, findings on zolpidem and crash risk may have been limited by small sample size; only 10 patients were taking zolpidem.

The present review identified strong experimental evidence of impaired driving performance among older drivers after taking a prescription Z-drug for sleep. There was some evidence of higher crash risk associated with a prescription Z-drug among drivers 80 and older and among female drivers, though the study was limited by its retrospective design. As cited in Booth et al. (2016), zolpidem is cleared from the body more slowly in older females than older males (Greenblatt et al., 2014). Older females may be especially at risk for adverse driving safety effects of Z-drugs, though only one study in the present review examined this issue. It is also possible that the association between sleep medication and crash risk was partly driven by the effects of insomnia or lack of sleep (for which the medication was prescribed) rather than the medication itself. However, none of the reviewed studies included a measure of insomnia diagnosis or sleep quality and duration or matched medicated drivers with sleep disturbances to unmedicated ones.

Polypharmacy

Polypharmacy refers to the use of two or more medications, either prescription or over-the-counter. The adverse effects of some medications may be enhanced when taken in combination with other medications or create new adverse effects with drug interactions. Polypharmacy is more common among older adults compared to people of other ages; in the United States between 2015 and 2017, some 35% of people 60 to 79 were taking five or more prescription drugs during a 30-day period, compared to 15% of people 40 to 59 (Hales et al., 2019). In particular, drugs that target the central nervous system, including antidepressants, antipsychotics, and Z-drugs, when used in combination, can result in increased risk of falls in older adults (Pomidor et al., 2019). In the context of driving, medications used in combination can result in impaired driving safety and performance.

The search terms aimed at locating articles on polypharmacy and older drivers (polypharm*) only yielded one article that was excluded because the study described in the article included participants under 65 (Staplin et al., 2008). The article also reports descriptive results from the PharMetrics Patient-Level Database, a database of people enrolled in prescription medication insurance plans in the United States from 1998 to 2002. The average number of potentially driver impairing medications prescribed to crash-involved drivers 65 and older was 1.63, and 40% of crash-involved drivers 75 and older were prescribed two or more potentially driver impairing medications.

Two studies on polypharmacy and older-driver crash risk were identified from other search terms. Fournier et al. (2015) identified a 43% increase in crash risk for older drivers with concurrent prescriptions of long-acting benzodiazepines and antidepressants compared to older drivers not taking either medication. The increase in crash risk associated with medications in combination was higher than the increase associated with either long-acting benzodiazepines alone (21%) or antidepressants alone (8%). Long-acting benzodiazepines and TCAs was associated with 54% higher crash risk, while long-acting benzodiazepines and SSRIs was associated with a 37% higher crash risk. Henderson et al. (2016) examined the association between sedative medications and 12-month prior crash involvement among 76 older drivers in a hospital emergency department. Participants received a sedative load score based on the sedative medications they were currently taking, as assessed by a medication checklist. Medications with sedation as a prominent side effect, including SSRIs, opioids, and antihistamines, were assigned a sedative load score of one. Medications with a primary sedation effect were assigned a score of two and included hypnotics (zolpidem), TCA, and anxiolytics (alprazolam, diazepam, and lorazepam). Sedative load was calculated by the total sedative load of all medications and ranged from zero to two or higher. There was no significant difference in the crash involvement or driving mileage of drivers with a sedative load of zero, one, or two or higher. This study was limited by a retrospective, self-reported outcome and by a small number of participants reporting a crash (seven out of 76). Specific combinations of medications were not examined because a sedative load score of two could either indicate use of two or more medications or the use of one medication with prominent sedating effects. One advantage to this study over studies using prescription medication databases is that it included over-the-counter medications that may be potentially driver impairing such as first-generation antihistamines.

The present review identified evidence for impaired driving performance and higher crash risk associated with some medications commonly prescribed for older adults. Specifically, older adults taking long-acting benzodiazepines and SSRIs have an elevated crash risk. Z-drugs, prescribed as sleep aids, were associated with increased crash risk for female drivers and drivers 80 and older and associated with impaired on-road driving performance in the morning after use. Only one study examined driving performance associated with medication exposure.

A limitation of administrative datasets used in some of the reviewed studies is that they provide information on which medication was prescribed but not whether the patient adhered to the medication. The association between crash risk and medication may be diluted by participants who are prescribed a medication but are not compliant in their use of the medication as prescribed.

Summary

Overall, the results of the present review were consistent with findings from Lococo and colleagues' 2018 literature review on medical conditions and driving. The strongest evidence for an association with crash risk among older drivers was identified for long-acting benzodiazepines, SSRIs, Z-drugs, and untreated or moderate eye disease. The strongest evidence for an association with driving performance of older drivers was identified for Alzheimer's disease or general dementia, though evidence for increased crash risk in the presence of these conditions was mixed. Medical conditions with conflicting findings regarding their association with driving safety or performance included arthritis, diabetes, and glaucoma. There was some evidence for greater odds of a crash for certain medications in combination (insulin and other diabetic medication, antidepressants, and long-acting benzodiazepines) than the medications alone, though no significant interactions were found. Importantly, individual differences affect how medications are absorbed in the body. The same medication may affect people differently depending on their age, sex, and other factors.

There are several possible reasons for conflicting evidence in the identified studies. First, in most of the studies it was difficult or impossible to distinguish the possible driver-impairing effects of medical conditions from that of the medications used to treat the conditions. No studies were identified that examined treated versus untreated medical conditions. Another possible reason for conflicting findings is that medical conditions can vary in severity. Most studies did not include a measure of severity, and it is possible that a medical condition only affects driving when it is moderate to severe. Studies of driving safety also may find different associations depending on whether the study accounts for driving exposure. Research has shown that older drivers with certain medical conditions are more likely to reduce or give up driving, including diabetes (Dugan & Lee, 2013), Parkinson's disease (Lafont et al., 2008), dementia (Lafont et al., 2008; Stout et al., 2018), and glaucoma (Blane, 2016). The crash risk for a given medical condition may be underestimated if most of the drivers with the condition drive very little.

Some medical conditions did not have enough evidence to support strong conclusions on driving safety and performance. In particular, the safety and performance of older drivers with non-AD dementias, MCI, PD, and AMD is not well understood. Some of these medical conditions have been well studied in drivers younger than 65, but few articles were identified that examined driving safety and performance among older drivers. The effects of age-related medical conditions on driving may be more pronounced among older drivers because diseases and their symptoms can progress with age. Finally, no study specifically examined combinations of medical conditions. However, it is possible that older drivers with several medical conditions have specific safety and performance challenges.

Chapter 5: Changing Driving Behavior to Extend the Safe Driving Years

Given research on safety issues for older drivers and predictors of safety, a major goal of research and practice is to extend the number of years an older person can drive safely. One of the main approaches to improving older driver safety is by changing driver behavior. There have been various approaches to changing driver behavior, including reducing exposure to high-risk situations, training abilities related to driving, and using active safety systems and driving automation features to aid behind-the-wheel performance.

Reducing Exposure to High-Risk Situations

The first aim of this chapter was to review research on strategies to reduce exposure to high-risk situations. Research on driving avoidance and licensing restrictions on when and where older adults can drive are considered in the following discussion.

Driving Avoidance

One approach to improving older driver safety is through driving avoidance. Driving avoidance refers to the process of refraining from challenging driving situations. Common situations older adults report avoiding include driving at night, in unfamiliar areas, during rush hour, and on the freeway (Molnar et al., 2018). Some authors consider self-regulation to be a special case of driving avoidance in which the driver intentionally avoids challenging situations or drives less to safely preserve mobility in the community (Molnar et al., 2013). A key component of self-regulation is that the older driver is aware of their limitations and intentionally changes their driving patterns accordingly. For example, an older adult driver may limit driving at night because they believe their visual ability will impair their driving safety. Driving avoidance, on the other hand, may be for other reasons such as a change in preferences or lifestyle. In the current review, the term driving avoidance is used to refer to any type of driving avoidance, including self-regulation. There is a large body of work reporting predictors of driving avoidance such as age, sex, medical conditions, and cognitive function (e.g., Kandasamy et al., 2018; Keay et al., 2018; O'Connor et al., 2012; Ross et al., 2009). However, it is important to examine whether driving avoidance results in improved driving safety, and whether interventions that aim to increase driving avoidance among older adults have safety benefits.

The purpose of the current section is to review articles identified in the literature review focused on driving avoidance and driving safety. The relationship between driving avoidance and safety was examined via two main research questions: (1) *Is driving avoidance associated with safety and/or performance outcomes?* and (2) *Do interventions that promote driving avoidance, and show measurable behavior change, result in safety improvements?* In general, studies and analyses that reported only measures of driving avoidance as outcomes were not considered; however, studies where driving avoidance data were used to predict performance or safety outcomes were eligible for review.

The research team conducted a multi-step screening of articles published in 2000 or later extracted through searches of four databases. Each search consisted of three terms: "older* AND driv*," and either "adapt*," "self-regulat*," "restrict*," or "limit*," for a total of four unique search strings. All four search strings were repeated in the four databases, for a total of 16 searches. See Methods for additional details of our literature search activities. These searches yielded 2,434 results, 271 of which were duplicates, and 2,081 of which were deemed ineligible based on title and abstract, resulting in 82 articles that underwent full-text review. Of those, 15 were review articles, and 60 were ineligible based on a full review of the paper. The primary reason why articles were excluded is that they did not report a safety/performance outcome (*n* = 28). The secondary reason why articles were excluded was because they did not publish distinct results for a sample of adults 65 or older (*n* = 19). Additionally, 10 articles did not fit the scope of this review. Four articles identified through the driving avoidance search terms were deemed eligible for a different section of the review. Two additional articles were found in a different set of Chapter 5 search terms not originally designed to capture driving avoidance articles (older* AND driv* AND educ*), resulting in a total of five articles eligible for inclusion in the final review based on a full review of the article. Articles in this subtopic were not restricted by country.

Two out of the five studies on driving avoidance measured driving safety via retrospective self-reports of crashes in the prior 12 months (De Raedt & Ponjaert-Kristoffersen, 2000b; Betz & Lowenstein, 2010), while one study measured driving safety prospectively by obtaining State records on moving violations and crashes during the 3 to 7-year study period (Emerson et al., 2012). Two studies measured driving performance by an on-road observational score from a trained observer (Classen et al., 2013a; Koppel et al., 2016); these studies were cross-sectional in design. Sample sizes across all five studies ranged from 84 to 1,678 participants. Four studies recruited participants from the general community, while one study recruited participants who had been referred for a fitness-to-drive evaluation by a physician or insurance company.

Overall, the five reviewed articles did not find strong evidence of an association between driving avoidance and safety outcomes in older adults. Only one study found a significant association between driving avoidance and safety (De Raedt & Ponjaert-Kristoffersen, 2000b). This study of 84 Belgian drivers 65 to 96 found that drivers who performed worse on the on-road assessment but were crash-free in the past 12 months reported more driving avoidance than drivers who performed worse on the road test but had crashed in the past 12 months. The association between driving avoidance and crash involvement was not significant among older drivers with higher on-road assessment scores. The authors concluded that older adult drivers who have worse driving performance compared to other older drivers are able to avoid crashes by processes of driving avoidance. Generalizability of the results of this study is limited, as the study was conducted on a small sample of healthy drivers who were primarily men (71%). However, this was the only study to include a sample referred to a fitness-to-drive evaluation center by a physician or insurance company. The remaining studies on driving avoidance in the present review recruited samples from the general community-dwelling older adult driver population. Driving avoidance and crashes may be more prevalent among drivers referred for evaluation; this may partially explain why the study by De Raedt and Ponjaert-Kristoffersen (2000b) was the only reviewed study to find significant associations between driving avoidance and driving safety/performance.

One challenge with the study of driving avoidance and driving safety/performance is that the association between the two may be in either direction or bidirectional. While the purpose of the present review is to identify whether driving avoidance leads to driving safety benefits, it is also possible that driving safety may lead to driving avoidance. For example, an older adult driver who has been in a recent crash at night may avoid driving at night in fear of being involved in another crash. This may have been the case in the two reviewed studies using driving avoidance to predict retrospective crash involvement in the past 12 months (Betz & Lowenstein, 2010; De Raedt & Ponjaert-Kristoffersen, 2000b). Experimental and longitudinal studies provide more support for directionality of associations, but four out of the five studies in the present review were cross-sectional or retrospective in design. One study was longitudinal in design and followed 100 Iowa older drivers for 3 to 7 years (Emerson et al., 2012). The study did not find an association between baseline driving avoidance and time to a State-reported moving violation or a crash after controlling for age, sex, education, and baseline weekly driving mileage.

Only one paper specifically examined self-regulation as a specific type of driving avoidance, which was assessed by the Driving Habits Questionnaire (Emerson et al., 2012). The Driving Habits Questionnaire asks participants whether they have driven in certain situations in the past 2 months (driving avoidance), followed by asking whether they avoided these situations because of visual problems (self-regulation). The study did not find an association between either baseline driving avoidance or self-regulation and time to a State-reported moving violation or crash, after controlling for age, sex, education, and baseline weekly driving mileage. A study using on-road observations from the Candrive/Ozcandrive study found that while drivers with higher scores on driving performance reported significantly lower driving frequency in specific driving situations, they did not report intentionally avoiding these situations (Koppel et al., 2016). The authors did not ask if drivers avoided certain situations, so it is not possible to determine whether the avoidance assessed was self-regulation or not. This may be a larger issue for the study of self-regulation, as measuring self-regulation necessitates asking about the intentions behind specific behaviors that are not always assessed in studies of older drivers (e.g., Betz & Lowenstein, 2010; Classen et al., 2013a; De Raedt & Ponjaert-Kristoffersen, 2000b; Koppel et al., 2016).

The literature search identified one systematic review out of the 15 identified reviews that examined driving avoidance and driving safety (Nef et al., 2015). The systematic review also only found one article that reported safety outcomes of driving avoidance among drivers 65 and older, which is already included in the current review (De Raedt & Ponjaert-Kristoffersen, 2000b). Most observational studies examining self-regulation were excluded from the present review because they did not report a safety and/or performance outcome. These studies provide important information on which older adults practice driving avoidance but do not report whether this driving avoidance has safety benefits. Two studies were excluded because they reported safety and/or performance as a *predictor* of driving avoidance (Okonkwo et al., 2007, 2008). In these studies, the number of crashes in the past 5 years was not significantly associated with current driving avoidance across all participants (Okonkwo et al., 2008) but was significant within men only (Okonkwo et al., 2007). While sex may play a role in driving avoidance, the review did not identify any prospective studies examining whether sex differences in driving avoidance predict driving safety.

Though one of the aims of the present review was to review intervention studies aimed at promoting driving avoidance, the research team did not find any eligible articles that reported safety/performance results for this type of intervention. Some intervention studies promoting driving avoidance were excluded either because the sample age was younger than 65 years (Owsley et al., 2003, 2004) or because they relied on self-reported driving mobility and/or driving avoidance as outcomes (Coxon et al., 2017; Jones et al., 2011; Levasseur et al., 2015).

The literature reviewed in this area does not demonstrate strong evidence for safety/performance benefits of driving avoidance among adults 65 and older. Given the absence of an association between driving avoidance and safety, it is not clear whether interventions that promote driving avoidance among healthy samples will also lead to safety benefits. Avoiding driving without demonstrated safety benefits may unnecessarily reduce older driver mobility. Given the negative outcomes associated with driving cessation among older adults (Edwards et al., 2009; Freeman et al., 2006; Marottoli et al., 1997; Ragland et al., 2005), it is important to establish the safety benefits of driving avoidance. It is also unclear whether driving avoidance leads to driving safety, or whether unsafe older drivers are more likely to engage in driving avoidance compared to safe older drivers. The current evidence remains inconclusive on whether encouraging driving avoidance is an effective strategy for improving older driver safety.

Licensing Restriction

Another way to reduce older drivers' exposure to high-risk situations is through licensing restrictions. Agencies may place such restrictions on driver licenses, including restrictions to drive only during the day, restricting driving to roads with a designated posted maximum speed limit, and combinations of restrictions. The goal of a restricted driver license is to prevent older drivers from driving in situations in which they may be more at-risk for crashes. The research question for the following section is: *Are licensing restrictions associated with safety and/or performance outcomes?*

Here, only articles using data from the United States and Canada were considered. The search terms for this were "older* AND driv*" followed by either "licens*" or "restrict*," repeated across four databases. The eight search strings yielded 2,126 results, 1,855 of which were deemed ineligible based on title and abstract and 203 of which were duplicates from a prior search, leaving 68 results to be fully reviewed. Out of the 68 articles reviewed, 55 were deemed ineligible, most commonly because the article did not report a safety/performance outcome. Ten articles were review articles, and three articles were relevant to another section.

The review yielded only one eligible article that examined safety outcomes of restricted licensing for older drivers. The authors examined insurance claims crash records of all older drivers in British Columbia from 1999 to 2006 (Caragata Nasvadi & Wister, 2009). Older drivers with restricted licenses had more crash-free days from license renewal compared to older drivers with unrestricted licenses. However, restricted licenses are uncommon: in the study by Caragata Nasvadi and Wister (2009), only 2% of all drivers had restrictions placed on their driver license. A review of restricted licensing policies in Iowa, Virginia, Florida, and Maryland found that very few drivers had license restrictions, ranging from 0.05–1.70% of the total licensed older adult population (Joyce et al., 2018). Several literature reviews identified in the current systematic review also examined literature on licensing restrictions for older drivers and report some positive safety benefits of restricted licenses for older adults in a small number of studies (Asbridge et al., 2017; Stav, 2008, 2014). Similarly, NHTSA's *Countermeasures That Work* (Venkatraman et al., 2021) rates "License Restrictions" as a countermeasure that has been determined to be effective. However, the studies included in these prior reviews were not included in the current study because of the inclusion criteria of the current subtopic, including driver age, country (i.e., United States or Canada), year of publication, peer-reviewed status, and lack of a safety/performance outcome. Two of the reviews included a study on license restrictions in Iowa drivers 70 and older (Braitman et al., 2010); however, this study reported crashes and moving violations prior to license restriction and was excluded from the present review. Therefore, since the present review only identified one eligible article on this topic, there is not enough evidence within this review to make conclusions regarding the safety benefits of restricted driver licenses for older adults.

Skills Training

Driver Rehabilitation

The focus of this section is on skills training approaches to improving older driver safety/performance, including driving rehabilitation and driver improvement programs. Driver rehabilitation approaches include training of visual attention and cognitive abilities with transfer to driving safety, physical training including aerobics and flexibility with transfer to driving safety, and the use of adaptive equipment such as hand controls and pedal extenders. Driver improvement programs include classroom, simulator, and behind-the-wheel educational programs, as well as the CarFit program. The main research question for this was: *Do driver rehabilitation and driver improvement programs demonstrate benefits to older driver safety/performance?*

The research team conducted a multi-step screening of articles published in 2000 or later extracted through searches of four databases. Each search consisted of three terms: "older* AND driv*," and either "rehab*," "educ*," "train*," "intervention," "practice," or "program," for a total of six unique search strings. All six search strings were repeated in the four databases, for a total of 24 searches. See methods for additional details of our literature search activities. The 24 search strings returned 6,726 results, 6,009 of which were deemed ineligible based on title and abstract and 528 of which were duplicates from a previous search. A total of 174 empirical articles and 15 review articles were sent for full review. The most common reasons articles were excluded was that they did not publish distinct results for a sample 65 years or older (n = 57). The second most common reason was that the article did not report a safety/performance outcome. An additional three articles were eligible for other Chapter 5 topics. Two articles were taken from other Chapter 5 searches, and two additional articles were identified during NHTSA's review of drafts. In total, 21 empirical articles were deemed eligible for inclusion in the review for this section. No eligible articles were identified that examined the association between adaptive equipment (e.g., pedal extenders) and driving safety. A systematic review of intervention approaches used by occupational therapists found a single intervention using adaptive equipment, but the study was a case study of a patient with traumatic brain injury (Unsworth & Baker, 2014). Articles on skills training and older drivers were not restricted based on country.

Cognitive training interventions train cognitive abilities related to driving with the goal of transferring training gains to gains in driving safety/performance. Four articles examined the results from cognitive training approaches to driving safety (Ball et al., 2010; Hay et al., 2016; Nouchi et al., 2019; Staplin et al., 2013). The cognitive abilities trained in the interventions reported include processing speed, reasoning, attention, executive function, and memory. All four studies reported interventions that were adaptive, meaning that the difficulty of the intervention protocol increased as participant performance improved. Sample sizes ranged from 60 to 908 participants, and all four studies recruited healthy community-dwelling participants. In general, interventions with a processing speed component showed benefits to driving safety including reduced at-fault collision involvement over 6 years (Ball et al., 2010) and better on-road driving performance (Nouchi et al., 2019) compared to controls.

Only two eligible articles were identified that used physical training to improve driving safety (Marottoli, Allore, et al., 2007; Staplin et al., 2013). In one study, 178 older drivers with physical impairments were randomized to either an intervention delivered by a physical therapist that exercised physical abilities related to driving or a control group that received educational materials. The physical exercise group had significantly greater improvement in on-road assessment scores compared to the control group; this difference was especially apparent in participants who scored the lowest on the on-road assessment at baseline (Marottoli, Allore, et al., 2007). Staplin and colleagues (2013) also compared performance on an on-road assessment between a physical exercise intervention group and a control group among drivers 70 and older. Unlike the study by Marottoli and colleagues, this study used a smaller sample of 30 participants and did not specifically recruit participants with physical impairments. This study did not find a significant difference in on-road performance between the physical exercise and control groups.

Driver Improvement Programs

Driver improvement programs take a variety of educational approaches to improving driving safety, including training in a classroom, simulator, and on-road environment. In simulator training studies, participants receive feedback or instructions on their simulated driving during or after their simulated drive. The present review identified eight articles that presented the results of a simulator-based intervention. Sample sizes for the articles ranged from 21 to 79, and all eight articles presents results from a healthy community-dwelling sample of older drivers. In general, the reviewed simulator training studies show benefits to simulator performance (Cuenen et al., 2019; Selander et al., 2019) and benefits to specific measures of on-road performance such as checking blind spots (Lavallière et al., 2012) and secondary glances when making turns (Romoser & Fisher, 2009; Romoser, 2013; Schneider et al., 2020) for older drivers. However, simulator sickness, or feelings of discomfort during and after exposure to virtual environments including nausea and vomiting, is a limitation of simulator training studies. In the reviewed studies, dropout rates due to simulator sickness ranged from 9% of participants (Lavallière et al., 2012) to 62% (Romoser & Fisher, 2009). Research suggests that older adults may be particularly susceptible to simulator sickness from driving simulators compared to younger adults (Keshavarz et al., 2018). Driver improvement programs that use driving simulators to train driving performance may not be feasible for all older drivers.

Driver improvement programs also take the form of educational programs outside of the simulator, including classroom-based education and on-road education. One of the largest older driver educational programs is 55 Alive/Mature Driving. Because the scope of this systematic review was limited to papers reporting results of drivers 65 and older, some articles reporting results of the 55 Alive/Mature Driving program were excluded. However, three studies in the present review reported the results of the program for attendees 65 and older. One study reported the results of the 55 Alive/Mature Driving program for attendees in British Columbia 75 and older from 2000 to 2003 (Nasvadi & Vavrik, 2007). After participating in the program, 46 program participants were involved in a State-reported crash, compared to 31 participants in a control group matched for the number of crashes prior to the program. Older drivers who attended the program did not have significantly different crash rates after the program compared to the control group. In fact, men who attended the program had significantly higher crashes after the program compared to controls. This study does not provide evidence for the 55 Alive/Mature Driving program's impact on driving safety. Two studies added an individualized on-road training component to the 55 Alive/Mature Driving program (Bédard et al., 2008; Porter et al., 2013). These studies found significant improvement in on-road performance in the intervention group compared to a waitlist control group (Bédard et al., 2008) and a group that only received the 55 Alive/Mature Driving program (Porter, 2013). The on-road performance benefits of on-road plus classroom education have been found in other studies as well (Marottoli, Ness, et al., 2007), though potentially only in drivers with low on-road scores at baseline (Anstey et al., 2018).

The results of studies comparing classroom education programs with on-road components to classroom education programs alone suggest that individualized on-road training may be more effective in improving driving performance compared to classroom education. Two studies in the present review also suggest that on-road education may be more beneficial for on-road performance than simulator-based education. Gagnon and colleagues (2019) and Sawula and colleagues (2018) conducted separate studies that compared three intervention groups: classroom education, classroom plus on-road education, and classroom plus on-road plus simulator education. In both studies, the education plus on-road plus simulator groups and the education plus on-road groups had higher on-road scores compared to education alone. However, the education plus on-road plus simulator group did not have significantly better on-road performance compared to the education plus on-road group. Results of these two studies suggest that simulator-based education may not provide any additional benefit beyond that of on-road training. However, the authors of both studies note that many participants in the education plus on-road plus simulator group did not receive the full simulator training component due to simulator sickness, 50% in Sawula et al. (2018), and 53% in Gagnon et al. (2019). This may have contributed to the lack of significant training effects in the intervention group with a simulator component. Additionally, it is not clear whether the improvement in on-road test performance transferred to driving safety. Only one study compared crash rates between an educational program and a control group and did not find significant differences (Nasvadi & Vavrik, 2007).

The main research question for this subtopic was: *Do driver rehabilitation and driver improvement programs demonstrate benefits to older driver safety/performance?* The present review found support for driving performance benefits of several driver rehabilitation and driver improvement program approaches. Moving further, which programs seem to be the most effective at improving driving safety and performance? One way to help answer this question is to look at results of studies that compare different intervention approaches within the same sample. Staplin and colleagues (2013) compared four different intervention approaches to a control group in a sample of 80 community-dwelling older adults 65 to 85. The study compared four interventions: a classroom plus on-road education program, a cognitive training program based on speed of processing and divided attention, an occupational therapist-administered visual skills training program with clinical and on-road components, and a physical functioning and conditioning program. The group who received the occupational therapist-administered intervention had a higher percent of drivers scoring high at baseline and maintaining their high score compared to drivers in the control group. The occupational therapist group also had a higher percent of drivers who scored lower at baseline and then improved, as did the group who received classroom and on-road education. The study found support for an occupational therapist-administered training and an educational training that included an on-road program but did not find benefits of a cognitive training intervention or a physical exercise intervention. However, the study did not formally compare different intervention approaches, so it is not possible to determine whether the occupational therapist intervention had greater benefits than the on-road intervention. Additionally, the training benefits in the occupational therapist group and educational group were not apparent at a 3-month follow-up.

Looking at the studies in the present review, different intervention approaches may benefit different drivers. Simulator-based interventions, while potentially effective, may not work for all older adults due to a high chance of simulator sickness. Older adults who are susceptible to simulator sickness may benefit from a different type of intervention approach. Physical exercise interventions may only benefit people who have physical limitations. Marottoli et al. (2007) found significant effects of a physical exercise intervention on on-road performance. This study specifically recruited older adults with physical impairments, such as impairments in neck rotation and trunk rotation. Staplin et al. (2021) also used a physical exercise approach but did not find significant effects; this sample was recruited from the general community and not specifically related to physical impairments, which may have contributed to the null findings. While there appears to be little support for classroom education interventions for older adults' driving safety, interventions that combine classroom programs with on-road education seem to hold promise for improving older driver performance in the general population. Cognitive training is also promising, though there are few studies examining driving performance/safety benefits of cognitive training studies for drivers 65 and older.

Though there are promising results for driving performance benefits of driver rehabilitation and driver improvement programs for older adults, there is limited evidence for safety benefits of such programs. Only three of the 21 reviewed studies included a crash outcome. One study found significantly reduced at-fault crash involvement over 6 years in two cognitive training groups relative to a control group (Ball et al., 2010), and another study found no difference in crashes among participants of an educational program compared to a control group (Nasvadi & Vavrik, 2007). Anstey and colleagues (2018) also included a measure of crashes in their intervention study, looking at any self-reported crash after participating in a classroom plus on-road intervention. However, there were so few crashes during the 6-month follow-up (two in the intervention group and five in the control group) that the authors could not perform any statistical tests comparing the intervention to control group. This highlights a challenge with examining safety benefits of driver rehabilitation programs: Crashes are rare events, so they may be more difficult to examine as an outcome of intervention participation. Driving performance measures have more variability, though some authors have noted difficulties in samples where most of the drivers score highly on on-road tests at baseline (e.g., Staplin et al., 2013).

The present review identified two additional systematic reviews addressing the issue of driver rehabilitation programs for older adults (Castellucci et al., 2020; Sangrar et al., 2019). Though the scope of the reviews differed slightly from the present review, both reviews made similar conclusions to the present review in that there is moderate support for on-road intervention approaches to driving performance. While Castellucci and colleagues (2020) note the lack of support for cognitive training approaches, their review does not include the study published by Nouchi et al. (2019), which found support for a cognitive training intervention and on-road performance improvements. Both reviews also acknowledge a lack of studies that include crashes as an outcome of training. Other systematic reviews identified in the current review include studies with approaches to improving older driver safety outside of the scope of the present review, such as family involvement (Golisz, 2014) and for older drivers with medical conditions (Classen et al., 2014).

Use of Active Driver Assistance Systems and Automated Driving Technologies

Another approach to improving older driver safety is the use of advanced driver assistance systems and automated driving technologies. Levels of driving automation perform part or all of the driving task and range from Level 1 to Level 5 (SAE International, 2021). Level 0 is not considered driving automation and refers to a system where the driver is responsible for vehicle control for all elements of the driving task, at all times. Active safety systems, or vehicle systems that monitor conditions and alert the driver or take active control of the vehicle, may exist in Level 0. Examples of active safety systems include lane departure warnings and blind spot warnings. At Level 1, an ADAS can assist the driver with either lateral control (i.e., steering) or longitudinal control (i.e., braking and accelerating) but not both at the same time. At Level 2, the system can assist simultaneously with lateral and longitudinal control, but the driver must monitor the system for failures and take over control immediately when the ADAS turns off. Level 3 is considered conditional driving automation (an automated driving system, or ADS), and the system controls laterally and longitudinally and will provide the driver with a warning and a short period of time before it will disengage. Level 4 is considered an ADS with high driving automation, and it is not expected that the driver will need to intervene. However, the automation can only occur in a specific area, called an operational design domain. The operational design domain for an ADAS feature can be specific to a number of conditions including road type, lighting, weather, and presence of lane markings. Level 5 is considered full driving automation, and it can be used anywhere, not just in a specific operational design domain. Driving automation system technologies have the potential to improve older adults' driving safety. The research question for this subtopic was: *What are the demonstrated safety/performance benefits of driving automation systems for older adults?*

The search terms for this were a combination of "older* AND driv*" and a third search term relevant to the topic (either "technology," "automat*," or "advanced driver assistance system"). Each search string was repeated in four databases for a total of 12 searches. The 12 searches returned 1,690 results, 1,469 were deemed ineligible based on title and abstract and 142 of which were duplicates from a previous search. A total of 17 review articles and 62 empirical articles were sent for full review. One additional article relevant to the subtopic was identified through cross-referencing other published literature reviews, bringing the total of empirical articles reviewed in full to 63 articles. After reviewing each article in full, eight articles were deemed eligible for inclusion in the review. The most common reasons an article was excluded were that it did not publish distinct results for a sample of 65 and older ($n = 33$) or that it did not publish a safety/performance outcome ($n = 10$). Articles on ADAS and ADS were not restricted by country.

Though the objective was to identify the safety/performance benefits of driving automation systems, no eligible articles were identified that examined the safety/performance benefits of a Level 1 or higher system with older drivers. All the reviewed eligible studies examined the effects of active safety systems, or Level 0 systems. Most of the studies were experimental in design, with sample sizes ranging from 14 to 128 participants. These experimental studies examined older driver performance in a driving simulator, finding limited simulator performance benefits of active safety systems for older adults such as lane departure warnings, intersection violation alerts, and speeding alerts (Dotzauer et al., 2013; Dotzauer, Caljouw, et al., 2015; Dotzauer, de Waard, et al., 2015; Lundqvist & Eriksson, 2019; Porter et al., 2008; Souders et al., 2020). The only study to examine a safety outcome reviewed police-reported backing crashes of drivers 70 and older in 22 U.S. states between 2009 and 2014 (Cicchino, 2017). Controlling for a number of variables including driver sex and State in which crash occurred, the author found that vehicles with rearview cameras and rearview sensors driven by people 70 and older had a lower backing crash rate per insured vehicle year than vehicles without such systems driven by people 70 and older. Though other simulator studies have not found performance differences related to active safety systems, one reviewed study found driving performance benefits in a high-fidelity driving simulator in a sample of 24 older adults. Older adults who drove in the simulator with a warning system for failure to obey a stop sign or red light made fewer errors at intersections than older adults who drove without the warning system (Marshall et al., 2010).

The studies that found significant associations between active safety systems and driving performance/safety also found results that suggest that these systems may be particularly beneficial for people who are older (Cicchino, 2017; Lundqvist & Eriksson, 2019; Porter et al., 2008), people with health conditions and lower scores on a cognitive screening instrument (Marshall et al., 2010), and people with Parkinson's Disease (Dotzauer et al., 2013; Dotzauer, Caljouw, et al., 2015).

While there have been promising results of active safety systems, or Level 0 systems, for older adult driving safety, there is currently not enough evidence to fully evaluate the safety benefits of driving automation systems (Levels 1 through 5) for older drivers, such as technology available currently like adaptive cruise control and lane centering (Level 2). Eby et at. (2015) reviewed work showing that older adults have mixed feelings regarding active safety systems and Level 1 driving assistance technologies in their own vehicle. Eby and colleagues also note that there are few to no studies that examine older adults' perceptions of driving automation systems or their safety benefits, such as autonomous parking assist systems and intelligent speed adaptation systems. Research has also found that older adults with higher incomes and with more education are more likely to adopt adaptive cruise control, blind spot warning, forward collision warning, and lane departure warning systems (Eby et al., 2018). Some authors have called for more research on how ADAS can support older driver safety, taking into account declines in older drivers' cognitive, visual, and physical function (Young et al., 2017). In addition to safety benefits of ADAS, there is also a paucity of research on the usability and accessibility of ADAS for all older adults.

Summary

Driving avoidance, a broad term including self-regulation of driving in what are perceived to be challenging conditions, may be a strategy to reduce older drivers' exposure to high-risk situations, though it is unclear whether driving avoidance produces direct safety benefits or whether more at-risk (i.e., functionally impaired) older drivers are more likely to engage in driving avoidance compared to older drivers without significant functional deficits. The evidence is similarly inconclusive regarding the use of formal license restrictions to reduce exposure to high-risk situations, although analyses of insurance claims data have shown that older drivers with restricted licenses had more crash-free days following license renewal compared to older drivers with unrestricted licenses. The use of such restrictions for other than vision deficits remains rare, however, which limits their impact.

Skills training, through driver rehabilitation and driver improvement programs, seeks to increase safety/performance among older drivers without imposing any limits on mobility, as may be associated with driving avoidance. Among rehabilitation strategies, the strongest evidence for cognitive training benefits is associated with speed of processing training, while one study has suggested that visual scanning training may benefit older drivers. Also, significant gains in on-road performance for physically impaired older drivers have been demonstrated as the result of physical exercise programs; however, this review did not find evidence that exercise programs designed to improve overall fitness among healthy older adults are effective as an intervention to improve driving performance. A review of driver improvement programs using classroom education and simulator training identified limiting factors with both methods. Older adults' greater susceptibility to simulator sickness led to high dropout rates with such training, and research has shown that if 'refresher' classes for older drivers are to realize significant improvements in driving skills, they may require complementary behind-the-wheel instruction.

As noted above, this review found no eligible articles that examined the safety/performance benefits for older drivers of Level 1 or higher automation; consequently, all the reviewed studies examined the effects of active safety systems (Level 0). While results to date have been mixed, those studies finding significant associations between active safety systems and driving performance/safety also suggest that these systems may be particularly beneficial for older drivers, citing declines in older drivers' cognitive, visual, and physical function. The willingness of older drivers to accept automation that assumes actual vehicle control, beyond the presentation of warnings and alerts, is an emerging research focus.

However, it is impossible to document the crash that did not happen, whether the result of a self-restriction or a formal restriction that reduces exposure, interventions designed to improve driving skills, or the embrace of advanced driver assistance technologies. The evidence discussed in this section may be equivocal about the safety benefits of the reviewed strategies for changing the behavior of older drivers in the United States, but such behavior change is precisely the target of a wide and growing array of interventions offered to older adults and defines a rapidly evolving area of research with implications for the safe mobility of tens of millions in this society.

Page intentionally left blank.

References

*(*Indicates article with data included in meta-analysis in Chapter 3.)*

Agimi, Y., Albert, S. M., Youk, A. O., Documet, P. I., & Steiner, C. A. (2018). Mandatory physician reporting of at-risk drivers: The older driver example. *The Gerontologist*, *58*(3), 578–587. https://doi.org/10.1093/geront/gnw209

Aksan, N., Anderson, S. W., Dawson, J., Uc, E., & Rizzo, M. (2015). Cognitive functioning differentially predicts different dimensions of older drivers' on-road safety. *Accident Analysis and Prevention*, *75*, 236–244. https://doi.org/10.1016/j.aap.2014.12.007

*Aksan, N., Dawson, J. D., Emerson, J. L., Yu, L., Uc, E. Y., Anderson, S. W., & Rizzo, M. (2013). Naturalistic distraction and driving safety in older drivers. *Human Factors*, *55*(4), 841–853. https://doi.org/10.1177/0018720812465769

Alzheimer's Association. (2019). 2019 Alzheimer's disease facts and figures. *Alzheimer's & Dementia*, *15*(3), 321–387. https://doi.org/10.1016/j.jalz.2019.01.010

American Geriatrics Society. (2019). American Geriatrics Society 2019 updated AGS Beers Criteria for potentially inappropriate medication use in older adults. *Journal of the American Geriatrics Society*, *67*(4), 674–694. https://doi.org/10.1111/jgs.15767

Anstey, K. J., Eramudugolla, R., Chopra, S., Price, J., & Wood, J. M. (2017). Assessment of driving safety in older adults with mild cognitive impairment. *Journal of Alzheimer's Disease*, *57*(4), 1197–1205. https://doi.org/10.3233/JAD-161209

Anstey, K. J., Eramudugolla, R., Kiely, K. M., & Price, J. (2018). Effect of tailored on-road driving lessons on driving safety in older adults: A randomised controlled trial. *Accident Analysis and Prevention*, *115*, 1–10. https://doi.org/10.1016/j.aap.2018.02.016

Anstey, K. J., Eramudugolla, R., Ross, L. A., Lautenschlager, N. T., & Wood, J. (2016). Road safety in an aging population: Risk factors, assessment, interventions, and future directions. *International Psychogeriatrics*, *28*(3), 349–356. https://doi.org/10.1017/S1041610216000053

*Anstey, K. J., & Wood, J. (2011). Chronological age and age-related cognitive deficits are associated with an increase in multiple types of driving errors in late life. *Neuropsychology*, *25*(5), 613–621. https://doi.org/10.1037/a0023835

Anstey, K. J., Wood, J., Caldwell, H., Kerr, G., & Lord, S. R. (2009). Comparison of self-reported crashes, state crash records and an on-road driving assessment in a population-based sample of drivers aged 69-95 years. *Traffic Injury Prevention*, *10*(1), 84–90. https://doi.org/10.1080/15389580802486399

Anstey, K. J., Wood, J., Lord, S., & Walker, J. G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review*, *25*(1), 45–65. https://doi.org/10.1016/j.cpr.2004.07.008

Antin, J. F., Guo, F., Fang, Y., Dingus, T. A., Hankey, J. M., & Perez, M. A. (2017). The influence of functional health on seniors' driving risk. *Journal of Transport & Health*, *6*, 237–244. https://doi.org/10.1016/j.jth.2017.07.003

Antin, J. F., Guo, F., Fang, Y., Dingus, T. A., Perez, M. A., & Hankey, J. M. (2017). A validation of the low mileage bias using naturalistic driving study data. *Journal of Safety Research*, *63*, 115–120. https://pubmed.ncbi.nlm.nih.gov/29203008/

Asbridge, M., Desapriya, E., Ogilvie, R., Cartwright, J., Mehrnoush, V., Ishikawa, T., & Nuwan Weerasinghe, D. (2017). The impact of restricted driver's licenses on crash risk for older drivers: A systematic review. *Transportation Research Part A: Policy and Practice*, *97*, 137–145. https://doi.org/10.1016/j.tra.2017.01.006

Babulal, G. M., Chen, S., Williams, M. M., Trani, J. -F., Bakhshi, P., Chao, G. L., Stout, S. H., Fagan, A. M., Benzinger, T. L. S., Holtzman, D. M., Morris, J. C., & Roe, C. M. (2018). Depression and Alzheimer's disease biomarkers predict driving decline. *Journal of Alzheimer's Disease*, *66*(3), 1213–1221. https://doi.org/10.3233/JAD-180564

Babulal, G. M., Stout, S. H., Head, D., Holtzman, D. M., Fagan, A. M., Morris, J. C., & Roe, C. M. (2017). Neuropsychiatric symptoms and Alzheimer's disease biomarkers predict driving decline: Brief report. *Journal of Alzheimer's Disease*, *58*(3), 675–680. https://doi.org/10.3233/JAD-170067

Ball, K., Edwards, J. D., Ross, L. A., & McGwin, G. (2010). Cognitive training decreases motor vehicle collision involvement of older drivers. *Journal of the American Geriatrics Society*, *58*(11), 2107–2113. https://doi.org/10.1111/j.1532-5415.2010.03138.x

Baker, T. K., Falb, T., Voas, R., & Lacey, J. (2003). Older women drivers: Fatal crashes in good conditions. *Journal of Safety Research*, *34*(4), 399–405. DOI: 10.1016/j.jsr.2003.09.012

Barbour, K. E., Helmick, C. G., Boring, M., & Brady, T. J. (2017). Vital signs: Prevalence of doctor-diagnosed arthritis and arthritis-attributable activity limitation - United States, 2013-2015. *Morbidity and Mortality Weekly Report*, *66*(9), 246–253. https://doi.org/10.15585/mmwr.mm6609e1

Bédard, M., & Meyers, J. R. (2004). The influence of passengers on older drivers involved in fatal crashes. *Experimental Aging Research*, *30*(2), 205–215. DOI: 10.1080/03610730490275111

Bédard, M., Porter, M. M., Marshall, S., Isherwood, I., Riendeau, J., Weaver, B., Tuokko, H., Molnar, F., & Miller-Polgar, J. (2008). The combination of two training approaches to improve older adults' driving safety. *Traffic Injury Prevention*, *9*(1), 70–76. https://doi.org/10.1080/15389580701670705

Bélanger, A., Gagnon, S., & Stinchcombe, A. (2015). Crash avoidance in response to challenging driving events: The roles of age, serialization, and driving simulator platform. *Accident Analysis and Prevention*, *82*, 199–212. https://doi.org/10.1016/j.aap.2015.04.030

*Bélanger, A., Gagnon, S., & Yamin, S. (2010). Capturing the serial nature of older drivers' responses towards challenging events: A simulator study. *Accident Analysis and Prevention*, *42*(3), 809–817. https://doi.org/10.1016/j.aap.2009.07.010

Berning, A., & Smither, D. D. (2014, November). *Understanding the limitations of drug test information, reporting, and testing practices in fatal crashes* (Report No. DOT HS 812 072). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/40777

Betz, M. E., Haukoos, J. S., Schwartz, R., DiGuiseppi, C., Kandasamy, D., Beaty, B., Juarez-Colunga, E., & Carr, D. B. (2018). Prospective validation of a screening tool to identify older adults in need of a driving evaluation. *Journal of the American Geriatrics Society*, *66*(2), 357–363. https://doi.org/10.1111/jgs.15222

Betz, M. E., & Lowenstein, S. R. (2010). Driving patterns of older adults: Results from the Second Injury Control and Risk Survey. *Journal of the American Geriatrics Society*, *58*(10), 1931–1935. https://doi.org/10.1111/j.1532-5415.2010.03010.x

*Bieri, R., Jäger, M., Gruber, N., Nef, T., Müri, R. M., & Mosimann, U. P. (2014). A novel computer test to assess driving-relevant cognitive functions - A pilot study. *International Psychogeriatrics*, *26*(2), 229–238. https://doi.org/10.1017/S104161021300183X

Blane, A. (2016). Through the looking glass: A review of the literature investigating the impact of glaucoma on crash risk, driving performance, and driver self-regulation in older drivers. *Journal of Glaucoma*, *25*(1), 113–121. https://doi.org/10.1097/IJG.0000000000000193

Blomberg, R. D., Thomas, F. D., Long, W., Sifrit, K. J., & Korbelak, K. T. (2014, September). *BAC and crash responsibility of injured older drivers: An analysis of trauma center data* (Report No. DOT HS 812 062). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/1998

Bohannon, R. W. (2019). Grip strength: An indispensable biomarker for older adults. *Clinical Interventions in Aging*, *14*, 1681–1691. https://doi.org/10.2147/CIA.S194543

Booth, J. N., Behring, M., Cantor, R. S., Colantonio, L. D., Davidson, S., Donnelly, J. P., Johnson, E., Jordan, K., Singleton, C., Xie, F., & McGwin, G. (2016). Zolpidem use and motor vehicle collisions in older drivers. *Sleep Medicine*, *20*, 98–102. https://doi.org/10.1016/j.sleep.2015.12.004

Braitman, K. A., Chaudhary, N. K., & McCartt, A. T. (2010). Restricted licensing among older drivers in Iowa. *Journal of Safety Research*, *41*(6), 481–486. https://doi.org/10.1016/j.jsr.2010.10.001

Braitman, K. A., Chaudhary, N. K., & McCartt, A. T. (2014). Effect of passenger presence on older drivers' risk of fatal crash involvement. *Traffic Injury Prevention*, *15*(5), 451–456. DOI: 10.1080/15389588.2013.839992

Braver, E. R., & Trempel, R. E. (2004). Are older drivers actually at higher risk of involvement in collisions resulting in deaths or non-fatal injuries among their passengers and other road users? *Injury Prevention*, *10*(1), 27–32. DOI: 10.1136/ip.2003.002923

Brody, D. J., & Gu, Q. (2020). *Antidepressant use among adults: United States, 2015-2018*. National Center for Health Statistics. https://www.cdc.gov/nchs/data/databriefs/db377-H.pdf

Bryden, K. J., Charlton, J., Oxley, J., & Lowndes, G. (2014). Older driver and passenger collaboration for wayfinding in unfamiliar areas. *International Journal of Behavioral Development*, *38*(4), 378–385. https://doi.org/10.1177/0165025414531466

Caird, J. K., Johnston, K. A., Willness, C. R., Asbridge, M., & Steel, P. (2014). A meta-analysis of the effects of texting on driving. *Accident Analysis and Prevention*, *71*, 311–318. DOI: 10.1016/j.aap.2014.06.005

Camp, B. J. (2013). The overall program effects of California's 3-Tier Assessment System pilot on crashes and mobility among senior drivers. *Journal of Safety Research*, *47*, 1–8. https://doi.org/10.1016/j.jsr.2013.06.002

Caragata Nasvadi, G., & Wister, A. (2009). Do restricted driver's licenses lower crash risk among older drivers? A survival analysis of insurance data from British Columbia. *The Gerontologist*, *49*(4), 474–484. DOI: 10.1093/geront/gnp039

Castellucci, H. I., Bravo, G., Arezes, P. M., & Lavallière, M. (2020). Are interventions effective at improving driving in older drivers? A systematic review. *BMC Geriatrics*, *20*(1), 125. https://doi.org/10.1186/s12877-020-01512-z

Centers for Disease Control and Prevention. (2020). *National Diabetes Statistics Report 2020: Estimates of diabetes and its burden in the United States*. National Center for Health Statistics. https://www.cdc.gov/diabetes/pdfs/data/statistics/national-diabetes-statistics-report.pdf

Cheung, I., & McCartt, A. T. (2011). Declines in fatal crashes of older drivers: Changes in crash risk and survivability. *Accident Analysis and Prevention*, *43*(3), 666–674. DOI: 10.1016/j.aap.2010.10.010

Chevalier, A., Coxon, K., Rogers, K., Chevalier, A. J., Wall, J., Brown, J., Clarke, E., Ivers, R., & Keay, L. (2017). Predictors of older drivers' involvement in high-range speeding behavior. *Traffic Injury Prevention*, *18*(2), 124–131. https://doi.org/10.1080/15389588.2016.1225297

*Choi, H., Kasko, J., & Feng, J. (2019). An attention assessment for informing older drivers' crash risks in various hazardous situations. *The Gerontologist*, *59*(1), 112–123. https://doi.org/10.1093/geront/gny079

Chong, Y., Fryer, C. D., & Gu, Q. (2013). Prescription sleep aid use among adults: United States, 2005-2010. *National Center for Health Statistics Data Brief*, *127*, 1–8.

Cicchino, J. B. (2015). Why have fatality rates among older drivers declined? The relative contributions of changes in survivability and crash involvement. *Accident Analysis and Prevention*, *83*, 67–73. DOI: 10.1016/j.aap.2015.06.012

Cicchino, J. B. (2017). Effects of rearview cameras and rear parking sensors on police-reported backing crashes. *Traffic Injury Prevention*, *18*(8), 859–865. https://doi.org/10.1080/15389588.2017.1317758

Cicchino, J. B., & McCartt, A. T. (2014). Trends in older driver crash involvement rates and survivability in the United States: An update. *Accident Analysis and Prevention*, *72*, 44–54. DOI: 10.1016/j.aap.2014.06.011

Classen, S., Monahan, M., Auten, B., & Yarney, A. (2014). Evidence-based review of interventions for medically at-risk older drivers. *The American Journal of Occupational Therapy*, *68*(4), e107–14. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4086415/

Classen, S., Velozo, C. A., Winter, S. M., Bédard, M., & Wang, Y. (2015). Psychometrics of the fitness-to-drive screening measure. *OTJR : Occupation, Participation and Health*, *35*(1), 42–52. https://doi.org/10.1177/1539449214561761

Classen, S., Wang, Y., Crizzle, A. M., Winter, S. M., & Lanford, D. N. (2013a). Gender differences among older drivers in a comprehensive driving evaluation. *Accident Analysis and Prevention*, *61*, 146–152. https://doi.org/10.1016/j.aap.2012.10.010

Classen, S., Wang, Y., Crizzle, A. M., Winter, S. M., & Lanford, D. N. (2013b). Predicting older driver on-road performance by means of the Useful Field of View and Trail Making Test Part B. *The American Journal of Occupational Therapy*, *67*(5), 574–582. https://doi.org/10.5014/ajot.2013.008136

Classen, S., Witter, D. P., Lanford, D. N., Okun, M. S., Rodriguez, R. L., Romrell, J., Malaty, I., & Fernandez, H. H. (2011). Usefulness of screening tools for predicting driving performance in people with Parkinson's disease. *The American Journal of Occupational Therapy*, *65*(5), 579–588. https://pubmed.ncbi.nlm.nih.gov/22026326/

Couper, F. J., & Logan, B. K. (2014, April). *Drugs and human performance fact sheets* (Report No. DOT HS 809 725). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/2003

Coxon, K., Chevalier, A., Brown, J., Clarke, E., Billot, L., Boufous, S., Ivers, R., & Keay, L. (2017). Effects of a safe transportation educational program for older drivers on driving exposure and community participation: A randomized controlled trial. *Journal of the American Geriatrics Society*, *65*(3), 540–549. https://doi.org/10.1111/jgs.14550

Crizzle, A. M., Classen, S., Bédard, M., Lanford, D., & Winter, S. (2012). MMSE as a predictor of on-road driving performance in community dwelling older drivers. *Accident Analysis and Prevention*, *49*, 287–292. https://doi.org/10.1016/j.aap.2012.02.003

*Cuenen, A., Jongen, E. M. M., Brijs, T., Brijs, K., Lutin, M., Van Vlierden, K., & Wets, G. (2016). The relations between specific measures of simulated driving ability and functional ability: New insights for assessment and training programs of older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *39*, 65–78. https://doi.org/10.1016/j.trf.2015.05.007

Cuenen, A., Jongen, E. M. M., Brijs, T., Brijs, K., Van Vlierden, K., & Wets, G. (2019). The effect of a simulator based training on specific measures of driving ability in older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *64*, 38–46. https://doi.org/10.1016/j.trf.2019.04.014

Davis, J., Casteel, C., Hamann, C., & Peek-Asa, C. (2018). Risk of motor vehicle crash for older adults after receiving a traffic charge: A case-crossover study. *Traffic Injury Prevention*, *19*(5), 506–512. DOI: 10.1080/15389588.2018.1453608

Dawson, J. D., Uc, E. Y., Anderson, S. W., Johnson, A. M., & Rizzo, M. (2010). Neuropsychological predictors of driving errors in older adults. *Journal of the American Geriatrics Society*, *58*(6), 1090–1096. https://doi.org/10.1111/j.1532-5415.2010.02872.x

Dellinger, A. M., Kresnow, M. -J., White, D. D., & Sehgal, M. (2004). Risk to self versus risk to others: How do older drivers compare to others on the road? *American Journal of Preventive Medicine*, *26*(3), 217–221. DOI: 10.1016/j.amepre.2003.10.021

*De Raedt, R., & Ponjaert-Kristoffersen, I. (2000a). The relationship between cognitive/neuropsychological factors and car driving performance in older adults. *Journal of the American Geriatrics Society*, *48*(12), 1664–1668.

De Raedt, R., & Ponjaert-Kristoffersen, I. (2000b). Can strategic and tactical compensation reduce crash risk in older drivers? *Age and Ageing*, *29*(6), 517–521. https://pubmed.ncbi.nlm.nih.gov/11191244/

De Raedt, R., & Ponjaert-Kristoffersen, I. (2001). Predicting at-fault car accidents of older drivers. *Accident Analysis and Prevention*, *33*(6), 809–819. https://doi.org/10.1016/s0001-4575(00)00095-6

Devlin, A., McGillivray, J., Charlton, J., Lowndes, G., & Etienne, V. (2012). Investigating driving behaviour of older drivers with mild cognitive impairment using a portable driving simulator. *Accident Analysis and Prevention*, *49*, 300–307. https://doi.org/10.1016/j.aap.2012.02.022

Dickerson, A. E. (2013). Driving assessment tools used by driver rehabilitation specialists: Survey of use and implications for practice. *The American Journal of Occupational Therapy*, *67*(5), 564–573. https://pubmed.ncbi.nlm.nih.gov/23968795/

Dickerson, A. E., Meuel, D. B., Ridenour, C. D., & Cooper, K. (2014). Assessment tools predicting fitness to drive in older adults: A systematic review. *The American Journal of Occupational Therapy*, *68*(6), 670–680. https://pubmed.ncbi.nlm.nih.gov/25397762/

Donmez, B., & Liu, Z. (2015). Associations of distraction involvement and age with driver injury severities. *Journal of Safety Research*, *52*, 23–28. https://doi.org/10.1016/j.jsr.2014.12.001

Dotzauer, M., Caljouw, S. R., de Waard, D., & Brouwer, W. H. (2013). Intersection assistance: A safe solution for older drivers? *Accident Analysis and Prevention*, *59*, 522–528. https://doi.org/10.1016/j.aap.2013.07.024

Dotzauer, M., Caljouw, S. R., de Waard, D., & Brouwer, W. H. (2015). Longer-term effects of ADAS use on speed and headway control in drivers diagnosed with Parkinson's disease. *Traffic Injury Prevention*, *16*(1), 10–16. https://doi.org/10.1080/15389588.2014.909037

Dotzauer, M., de Waard, D., Caljouw, S. R., Pöhler, G., & Brouwer, W. H. (2015). Behavioral adaptation of young and older drivers to an intersection crossing advisory system. *Accident Analysis and Prevention*, *74*, 24–32. https://doi.org/10.1016/j.aap.2014.09.030

*Douissembekov, E., Michael, G. A., Rogé, J., Bonhoure, P., Gabaude, C., & Navarro, J. (2015). Effects of shrinkage of the visual field through ageing on parking performance: A parametric manipulation of salience and relevance of contextual components. *Ergonomics*, *58*(5), 698–711. https://doi.org/10.1080/00140139.2014.987699

Dugan, E., & Lee, C. M. (2013). Biopsychosocial risk factors for driving cessation: Findings from the Health and Retirement Study. *Journal of Aging and Health*, *25*(8), 1313–1328. https://doi.org/10.1177/0898264313503493

Dukic Willstrand, T., Broberg, T., & Selander, H. (2017). Driving characteristics of older drivers and their relationship to the Useful Field of View Test. *Gerontology*, *63*(2), 180–188. https://pubmed.ncbi.nlm.nih.gov/27764828/

Duncanson, H., Hollis, A. M., & O'Connor, M. G. (2018). Errors versus speed on the trail making test: Relevance to driving performance. *Accident Analysis and Prevention*, *113*, 125–130. https://doi.org/10.1016/j.aap.2018.01.004

Eby, D. W., Molnar, L. J., Zakrajsek, J. S., Ryan, L. H., Zanier, N., St. Louis, R. M., Stanciu, S. C., LeBlanc, D., Kostyniuk, L. P., Smith, J., Yung, R., Nyquist, L., DiGuiseppi, C., Li, G., Mielenz, T. J., Strogatz, D., & LongROAD Research Team. (2018). Prevalence, attitudes, and knowledge of in-vehicle technologies and vehicle adaptations among older drivers. *Accident Analysis and Prevention*, *113*, 54–62. https://doi.org/10.1016/j.aap.2018.01.022

Eby, D. W., Molnar, L. J., Zakrajsek, J. S., Ryan, L. H., Zanier, N., St. Louis, R. M., Stanciu, S. C., LeBlanc, D., Bogard, S., Kostyniuk, L. P., Smith, J., Yung, R., Nyquist, L., Betz, M. E., DiGuiseppi, C., Jones, V., Li, G., Mielenz, T. J., Strogatz, D, & AAA LongROAD Research Team. (2019). Factors related to rapid deceleration events among a large cohort of older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *66*, 76–86. https://doi.org/10.1016/j.trf.2019.08.021

Eby, D. W., Molnar, L. J., Zhang, L., St. Louis, R. M., Zanier, N., & Kostyniuk, L. P. (2015). *Keeping older adults driving safely: A research synthesis of advanced in-vehicle technologies*. AAA Foundation for Traffic Safety. https://aaafoundation.org/wp-content/uploads/2015/12/KeepingOlderAdultsDrivingSafelyReport.pdf

*Edwards, J. D., Leonard, K. M., Lunsman, M., Dodson, J., Bradley, S., Myers, C. A., & Hubble, B. (2008). Acceptability and validity of older driver screening with the DrivingHealth Inventory. *Accident Analysis and Prevention*, *40*(3), 1157–1163. https://doi.org/10.1016/j.aap.2007.12.008

Edwards, J. D., Perkins, M., Ross, L. A., & Reynolds, S. L. (2009). Driving status and three-year mortality among community-dwelling older adults. *The Journals of Gerontology. Series A*, *64A*(2), 300–305. https://doi.org/10.1093/gerona/gln019

Emerson, J. L., Johnson, A. M., Dawson, J. D., Uc, E. Y., Anderson, S. W., & Rizzo, M. (2012). Predictors of driving outcomes in advancing age. *Psychology and Aging*, *27*(3), 550–559. https://doi.org/10.1037/a0026359

Enriquez, J. (2021, September). *Occupant restraint use in 2020: Results from the NOPUS controlled intersection study* (Report No. DOT HS 813 186). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813186

*Eramudugolla, R., Price, J., Chopra, S., Li, X., & Anstey, K. J. (2016). Comparison of a virtual older driver assessment with an on-road driving test. *Journal of the American Geriatrics Society*, *64*(12), e253–e258. https://doi.org/10.1111/jgs.14548

Etienne, V., Marin-Lamellet, C., & Laurent, B. (2013). Mental flexibility impairment in drivers with early Alzheimer's disease: A simulator-based study. *IATSS Research*, *37*(1), 16–20. https://doi.org/10.1016/j.iatssr.2013.06.005

Ferdinand, A. O., & Menachemi, N. (2014). Associations between driving performance and engaging in secondary tasks: A systematic review. *American Journal of Public Health*, *104*(3), e39–48. DOI: 10.2105/AJPH.2013.301750

*Ferreira, I. S., Simões, M. R., & Marôco, J. (2012). The Addenbrooke's Cognitive Examination Revised as a potential screening test for elderly drivers. *Accident Analysis and Prevention*, *49*, 278–286. https://doi.org/10.1016/j.aap.2012.03.036

*Ferreira, I. S., Simões, M. R., & Marôco, J. (2013). Cognitive and psychomotor tests as predictors of on-road driving ability in older primary care patients. *Transportation Research Part F: Traffic Psychology and Behaviour*, *21*, 156–158. https://doi.org/10.1016/j.trf.2013.09.007

Finison, K. S., & Dubrow, R. B. (2002, February). *A comparison of Maine crashes involving older drivers using CODES linked data* (Report No. DOT HS 809 407). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/Publication/809407

Fournier, J.-P., Wilchesky, M., Patenaude, V., & Suissa, S. (2015). Concurrent use of benzodiazepines and antidepressants and the risk of motor vehicle accident in older drivers: A nested case-control study. *Neurology and Therapy*, *4*, 39–51. https://doi.org/10.1007/s40120-015-0026-0

Fraade-Blanar, L. A., Hansen, R. N., Chan, K. C. G., Sears, J. M., Thompson, H. J., Crane, P. K., & Ebel, B. E. (2018). Diagnosed dementia and the risk of motor vehicle crash among older drivers. *Accident Analysis and Prevention*, *113*, 47–53. https://doi.org/10.1016/j.aap.2017.12.021

Freeman, E. E., Gange, S. J., Muñoz, B., & West, S. K. (2006). Driving status and risk of entry into long-term care in older adults. *American Journal of Public Health*, *96*(7), 1254–1259. https://doi.org/10.2105/AJPH.2005.069146

Freund, B., Colgrove, L. A., Burke, B. L., & McLeod, R. (2005). Self-rated driving performance among elderly drivers referred for driving evaluation. *Accident Analysis and Prevention*, *37*(4), 613–618. https://doi.org/10.1016/j.aap.2005.03.002

*Friedman, C., McGwin, G., Ball, K. K., & Owsley, C. (2013). Association between higher order visual processing abilities and a history of motor vehicle collision involvement by drivers ages 70 and over. *Investigative Ophthalmology & Visual Science*, *54*(1), 778–782. https://doi.org/10.1167/iovs.12-11249

Gagnon, S., Stinchcombe, A., Curtis, M., Kateb, M., Polgar, J., Porter, M. M., & Bédard, M. (2019). Driving safety improves after individualized training: An RCT involving older drivers in an urban area. *Traffic Injury Prevention*, *20*(6), 595–600. https://doi.org/10.1080/15389588.2019.1630826

Geyer, J. A., & Ragland, D. R. (2005). Vehicle occupancy and crash risk. *Transportation Research Record: The Journal of the Transportation Research Board*, *1908*(1), 187–194. https://doi.org/10.1177/0361198105190800123

Glassbrenner, D. (2012, June). *An analysis of recent improvements to vehicle safety* (Report No. DOT HS 811 572). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811572

Golisz, K. (2014). Occupational therapy interventions to improve driving performance in older adults: A systematic review. *The American Journal of Occupational Therapy*, *68*(6), 662–669. https://doi.org/10.5014/ajot.2014.011247

Gorrie, C. A., Rodriguez, M., Sachdev, P., Duflou, J., & Waite, P. M. E. (2007). Mild neuritic changes are increased in the brains of fatally injured older motor vehicle drivers. *Accident Analysis and Prevention*, *39*(6), 1114–1120. https://doi.org/10.1016/j.aap.2007.02.008

Grabowski, D. C., Campbell, C. M., & Morrisey, M. A. (2004). Elderly licensure laws and motor vehicle fatalities. *The Journal of the American Medical Association*, *291*(23), 2840–2846. https://doi.org/10.1001/jama.291.23.2840

Graham, L. A., Darrah, J. R., & Thomas, F. D. (2020). *Older driver licensing policies and practices database update*. AAA Foundation for Traffic Safety. https://aaafoundation.org/older-driver-licensing-policies-and-practices-database-update/

*Green, K. A., McGwin, G., & Owsley, C. (2013). Associations between visual, hearing, and dual sensory impairments and history of motor vehicle collision involvement of older drivers. *Journal of the American Geriatrics Society*, *61*(2), 252–257. https://doi.org/10.1111/jgs.12091

Greenblatt, D. J., Harmatz, J. S., Singh, N. N., Steinberg, F., Roth, T., Moline, M. L., Harris, S. C., & Kapil, R. P. (2014). Gender differences in pharmacokinetics and pharmacodynamics of zolpidem following sublingual administration. *Journal of Clinical Pharmacology*, *54*(3), 282–290. https://doi.org/10.1002/jcph.220

Gruber, N., Mosimann, U. P., Müri, R. M., & Nef, T. (2013). Vision and night driving abilities of elderly drivers. *Traffic Injury Prevention*, *14*(5), 477–485. https://doi.org/10.1080/15389588.2012.727510

Guo, F., Fang, Y., & Antin, J. F. (2015). Older driver fitness-to-drive evaluation using naturalistic driving data. *Journal of Safety Research*, *54*, 49.e29–54. https://doi.org/10.1016/j.jsr.2015.06.013

Hakamies-Blomqvist, L., Raitanen, T., & O'Neill, D. (2002). Driver ageing does not cause higher accident rates per km. *Transportation Research Part F: Traffic Psychology and Behaviour*, *5*(4), 271–274. DOI: 10.1016/S1369-8478(03)00005-6

Hales, C. M., Servais, J., Martin, C. B., & Kohen, D. (2019). *Prescription drug use among adults aged 40-79 in the United States and Canada* (NCHS Data Brief, no 347). National Center for Health Statistics. https://www.cdc.gov/nchs/data/databriefs/db347-h.pdf

Hanrahan, R. B., Layde, P. M., Zhu, S., Guse, C. E., & Hargarten, S. W. (2009). The association of driver age with traffic injury severity in Wisconsin. *Traffic Injury Prevention*, *10*(4), 361–367. DOI: 10.1080/15389580902973635

Hay, M., Adam, N., Bocca, M. -L., & Gabaude, C. (2016). Effectiveness of two cognitive training programs on the performance of older drivers with a cognitive self-assessment bias. *European Transport Research Review*, *8*, 20. https://doi.org/10.1007/s12544-016-0207-7

Hebert, C., Delaney, J. A. C., Hemmelgarn, B., Lévesque, L. E., & Suissa, S. (2007). Benzodiazepines and elderly drivers: A comparison of pharmacoepidemiological study designs. *Pharmacoepidemiology and Drug Safety*, *16*(8), 845–849. https://doi.org/10.1002/pds.1432

Hemmelgarn, B., Lévesque, L. E., & Suissa, S. (2006). Anti-diabetic drug use and the risk of motor vehicle crash in the elderly. *The Canadian Journal of Clinical Pharmacology*, *13*(1), e112–20.

Henderson, A. W., Beaudoin, F. L., Mello, M. J., & Baird, J. (2016). Prevalence of sedating medication use among older drivers presenting in the emergency department. *Rhode Island Medical Journal (2013)*, *99*(1), 15–19.

Hing, J. Y. C., Stamatiadis, N., & Aultman-Hall, L. (2003). Evaluating the impact of passengers on the safety of older drivers. *Journal of Safety Research*, *34*(4), 343–351. https://doi.org/10.1016/j.jsr.2003.09.011

Hoggarth, P. A., Innes, C. R. H., Dalrymple-Alford, J. C., & Jones, R. D. (2013). Prospective study of healthy older drivers: No increase in crash involvement or traffic citations at 24 months following a failed on-road assessment. *Transportation Research Part F: Traffic Psychology and Behaviour*, *16*, 73–80. https://doi.org/10.1016/j.trf.2012.08.012

*Hoggarth, P. A., Innes, C. R. H., Dalrymple-Alford, J., Severinsen, J. E., & Jones, R. D. (2010). Comparison of a linear and non-linear model for using sensory-motor, cognitive, personality, and demographic data to predict driving ability in healthy older adults. *Accident Analysis and Prevention*, *42*(6), 1759–1768. https://doi.org/10.1016/j.aap.2010.04.017

Horswill, M. S., Anstey, K. J., Hatherly, C. G., & Wood, J. M. (2010). The crash involvement of older drivers is associated with their hazard perception latencies. *Journal of the International Neuropsychological Society*, *16*(5), 939–944. https://doi.org/10.1017/S135561771000055X

*Horswill, M. S., Kemala, C. N., Wetton, M., Scialfa, C. T., & Pachana, N. A. (2010). Improving older drivers' hazard perception ability. *Psychology and Aging*, *25*(2), 464–469. https://doi.org/10.1037/a0017306

*Huisingh, C., Levitan, E. B., Irvin, M. R., MacLennan, P., Wadley, V., & Owsley, C. (2017). Visual sensory and visual-cognitive function and rate of crash and near-crash involvement among older drivers using naturalistic driving data. *Investigative Ophthalmology & Visual Science*, *58*(7), 2959–2967. https://doi.org/10.1167/iovs.17-21482

Huisingh, C., Owsley, C., Wadley, V. G., Levitan, E. B., Irvin, M. R., MacLennan, P., & McGwin, G. (2018). General cognitive impairment as a risk factor for motor vehicle collision involvement: A prospective population-based study. *Geriatrics*, *3*(1). https://doi.org/10.3390/geriatrics3010011

Islam, S., & Mannering, F. (2006). Driver aging and its effect on male and female single-vehicle accident injuries: Some additional evidence. *Journal of Safety Research*, *37*(3), 267–276. https://doi.org/10.1016/j.jsr.2006.04.003

Janke, M. K. (1991). Accidents, mileage, and the exaggeration of risk. *Accident Analysis and Prevention*, *23*(2–3), 183–188. https://doi.org/10.1016/0001-4575(91)90048-A

Jang, R. W., Man-Son-Hing, M., Molnar, F. J., Hogan, D. B., Marshall, S. C., Auger, J., Graham, I. D., Korner-Bitensky, N., Tomlinson, G., Kowgier, M. E., & Naglie, G. (2007). Family physicians' attitudes and practices regarding assessments of medical fitness to drive in older persons. *Journal of General Internal Medicine*, *22*, 531–543. https://doi.org/10.1007/s11606-006-0043-x

*Janke, M. K. (2001). Assessing older drivers: Two studies. *Journal of Safety Research*, *32*, 43–74. https://doi.org/10.1016/S0022-4375(00)00048-7

Johnson, L. N., & Baloh, F. G. (1991). The accuracy of confrontation visual field test in comparison with automated perimetry. *Journal of the National Medical Association*, *83*(10), 895–898.

Jones, V. C., Cho, J., Abendschoen-Milani, J., & Gielen, A. (2011). Driving habits and risk exposure in older drivers: Lessons learned from the implementation of a self-regulation curriculum. *Traffic Injury Prevention*, *12*(5), 468–474. https://doi.org/10.1080/15389588.2011.586448

Joyce, J., Lococo, K. H., Gish, K. W., Mastromatto, T., Stutts, J., Thomas, D., & Blomberg, R. (2018, April). *Older driver compliance with license restrictions* (Report No. DOT HS 812 486). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/36716

Justiss, M. D. (2013). Occupational therapy interventions to promote driving and community mobility for older adults with low vision: A systematic review. *The American Journal of Occupational Therapy*, *67*(3), 296–302. https://doi.org/10.5014/ajot.2013.005660

Kahane, C. J. (2013, May). *Injury vulnerability and effectiveness of occupant protection technologies for older occupants and women* (Report No. DOT HS 811 766). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811766

Kahane, C. J. (2000, December). *Fatality reduction by safety belts for front-seat occupants of cars and light trucks: Updated and expanded estimates based on 1986-99 FARS data* (Report No. DOT HS 809 199). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/5157

Kandasamy, D., Betz, M. E., DiGuiseppi, C., Mielenz, T. J., Eby, D. W., Molnar, L. J., Hill, L., Strogatz, D., & Li, G. (2018). Self-reported health conditions and related driving reduction in older drivers. *Occupational Therapy in Health Care*, *32*(4), 363–379. https://doi.org/10.1080/07380577.2018.1522681

Kandasamy, D., Williamson, K., Carr, D. B., Abbott, D., & Betz, M. E. (2019). The utility of the Montreal Cognitive Assessment in predicting need for fitness to drive evaluations in older adults. *Journal of Transport & Health*, *13*, 19–25. https://doi.org/10.1016/j.jth.2019.03.005

Keay, L., Coxon, K., Chevalier, A., Brown, J., Rogers, K., Clarke, E., & Ivers, R. Q. (2018). Sex differences evident in self-reported but not objective measures of driving. *Accident Analysis and Prevention*, *111*, 155–160. https://doi.org/10.1016/j.aap.2017.11.011

Keay, L., Jasti, S., Munoz, B., Turano, K. A., Munro, C. A., Duncan, D. D., Baldwin, K., Bandeen-Roche, K. J., Gower, E. W., & West, S. K. (2009). Urban and rural differences in older drivers' failure to stop at stop signs. *Accident Analysis and Prevention*, *41*(5), 995–1000. https://doi.org/10.1016/j.aap.2009.06.004

Keay, L., Munoz, B., Duncan, D. D., Hahn, D., Baldwin, K., Turano, K. A., Munro, C. A., Bandeen-Roche, K., & West, S. K. (2013). Older drivers and rapid deceleration events: Salisbury Eye Evaluation Driving Study. *Accident Analysis and Prevention*, *58*, 279–285. https://doi.org/10.1016/j.aap.2012.06.002

Keshavarz, B., Ramkhalawansingh, R., Haycock, B., Shahab, S., & Campos, J. L. (2018). Comparing simulator sickness in younger and older adults during simulated driving under different multisensory conditions. *Transportation Research Part F: Traffic Psychology and Behaviour*, *54*, 47–62. https://doi.org/10.1016/j.trf.2018.01.007

Khattak, A. J., Pawlovich, M. D., Souleyrette, R. R., & Hallmark, S. L. (2002). Factors related to more severe older driver traffic crash injuries. *Journal of Transportation Engineering*, *128*(3), 243–249. DOI: 10.1061/(ASCE)0733-947X(2002)128:3(243)

Kim, J. -K., Ulfarsson, G. F., Kim, S., & Shankar, V. N. (2013). Driver-injury severity in single-vehicle crashes in California: A mixed logit analysis of heterogeneity due to age and gender. *Accident Analysis and Prevention*, *50*, 1073–1081. https://doi.org/10.1016/j.aap.2012.08.011

Kimlin, J. A., Black, A. A., & Wood, J. M. (2017). Nighttime driving in older adults: Effects of glare and association with mesopic visual function. *Investigative Ophthalmology & Visual Science*, *58*(5), 2796–2803. https://doi.org/10.1167/iovs.16-21219

Kirkman, M. S., Briscoe, V. J., Clark, N., Florez, H., Haas, L. B., Halter, J. B., Huang, E. S., Korytkowski, M. T., Munshi, M. N., Odegard, P. S., Pratley, R. E., & Swift, C. S. (2012). Diabetes in older adults. *Diabetes Care*, *35*(12), 2650–2664. https://doi.org/10.2337/dc12-1801

Koppel, S., Charlton, J. L., Langford, J., Di Stefano, M., MacDonald, W., Vlahodimitrakou, Z., Mazer, B. L., Gelinas, I., Vrkljan, B., Eliasz, K., Myers, A., Tuokko, H. A., & Marshall, S. C. (2016). Driving task: How older drivers' on-road driving performance relates to abilities, perceptions, and restrictions. *Canadian Journal on Aging*, *35*(S1), 15–31. https://doi.org/10.1017/S0714980816000015

Koppel, S., Charlton, J. L., Richter, N., Di Stefano, M., Macdonald, W., Darzins, P., Newstead, S. V., D'Elia, A., Mazer, B., Gelinas, I., Vrkljan, B., Eliasz, K., Myers, A., & Marshall, S. (2017). Are older drivers' on-road driving error rates related to functional performance and/or self-reported driving experiences? *Accident Analysis and Prevention*, *103*, 1–9. https://doi.org/10.1016/j.aap.2017.03.006

Kosuge, R., Okamura, K., Kihira, M., Nakano, Y., & Fujita, G. (2017). Predictors of driving outcomes including both crash involvement and driving cessation in a prospective study of Japanese older drivers. *Accident Analysis and Prevention*, *106*, 131–140. https://doi.org/10.1016/j.aap.2017.05.019

Kwon, M., Huisingh, C., Rhodes, L. A., McGwin, G., Wood, J. M., & Owsley, C. (2016). Association between glaucoma and at-fault motor vehicle collision involvement among older drivers: A population-based study. *Ophthalmology*, *123*(1), 109–116. https://doi.org/10.1016/j.ophtha.2015.08.043

*Lacherez, P., Wood, J. M., Anstey, K. J., & Lord, S. R. (2014). Sensorimotor and postural control factors associated with driving safety in a community-dwelling older driver population. *The Journals of Gerontology. Series A*, *69A*(2), 240–244. https://doi.org/10.1093/gerona/glt173

Lafont, S., Laumon, B., Helmer, C., Dartigues, J. -F., & Fabrigoule, C. (2008). Driving cessation and self-reported car crashes in older drivers: The impact of cognitive impairment and dementia in a population-based study. *Journal of Geriatric Psychiatry and Neurology*, *21*(3), 171–182. https://doi.org/10.1177/0891988708316861

Langford, J., Methorst, R., & Hakamies-Blomqvist, L. (2006). Older drivers do not have a high crash risk—A replication of low mileage bias. *Accident Analysis and Prevention*, *38*(3), 574–578. https://doi.org/10.1016/j.aap.2005.12.002

Lavallière, M., Simoneau, M., Tremblay, M., Laurendeau, D., & Teasdale, N. (2012). Active training and driving-specific feedback improve older drivers' visual search prior to lane changes. *BMC Geriatrics*, *12*, 5. https://doi.org/10.1186/1471-2318-12-5

LeRoy, A. A., & Morse, M. L. (2008, May). *Multiple medications and vehicle crashes: Analysis of databases* (Report No. DOT HS 810 858). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/1836

Lesikar, S. E., Gallo, J. J., Rebok, G. W., & Keyl, P. M. (2002). Prospective study of brief neuropsychological measures to assess crash risk in older primary care patients. *The Journal of the American Board of Family Practice*, *15*(1), 11–19.

Levasseur, M., Audet, T., Gélinas, I., Bédard, M., Langlais, M. -È., Therrien, F. -H., Renaud, J., Coallier, J. -C., & D'Amours, M. (2015). Awareness tool for safe and responsible driving (OSCAR): A potential educational intervention for increasing interest, openness and knowledge about the abilities required and compensatory strategies among older drivers. *Traffic Injury Prevention*, *16*(6), 578–586. https://doi.org/10.1080/15389588.2014.994742

Li, G., Braver, E. R., & Chen, L. -H. (2003). Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. *Accident Analysis and Prevention*, *35*(2), 227–235. DOI: 10.1016/S0001-4575(01)00107-5

Lococo, K., & Staplin, L. (2005, July). *Strategies for medical advisory boards and licensing review* (Report No. DOT HS 809 874). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/1971

Lococo, K. H., Staplin, L., & Schultz, M. W. (2018, July). *The effects of medical conditions on driving performance: A literature review and synthesis* (Report No. DOT HS 812 526). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/38687

Lombardi, D. A., Horrey, W. J., & Courtney, T. K. (2017). Age-related differences in fatal intersection crashes in the United States. *Accident Analysis and Prevention*, *99*(Part A), 20–29. https://doi.org/10.1016/j.aap.2016.10.030

Lundqvist, L. -M., & Eriksson, L. (2019). Age, cognitive load, and multimodal effects on driver response to directional warning. *Applied Ergonomics*, *76*, 147–154. https://doi.org/10.1016/j.apergo.2019.01.002

Lyman, S., Ferguson, S. A., Braver, E. R., & Williams, A. F. (2002). Older driver involvements in police reported crashes and fatal crashes: Trends and projections. *Injury Prevention*, *8*(2), 116–120. DOI: 10.1136/ip.8.2.116

Margolis, K. L., Kerani, R. P., McGovern, P., Songer, T., Cauley, J. A., Ensrud, K. E., & Study of Osteoporotic Fractures Research Group. (2002). Risk factors for motor vehicle crashes in older women. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *57*(3), M186–91. https://doi.org/10.1093/gerona/57.3.m186

Marottoli, R. A., Allore, H., Araujo, K. L. B., Iannone, L. P., Acampora, D., Gottschalk, M., Charpentier, P., Kasl, S., & Peduzzi, P. (2007). A randomized trial of a physical conditioning program to enhance the driving performance of older persons. *Journal of General Internal Medicine*, *22*(5), 590–597. https://doi.org/10.1007/s11606-007-0134-3

Marottoli, R. A., Ness, P. H. V., Araujo, K. L. B., Iannone, L. P., Acampora, D., Charpentier, P., & Peduzzi, P. (2007). A randomized trial of an education program to enhance older driver performance. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *62*(10), 1113–1119. https://doi.org/10.1093/gerona/62.10.1113

Marottoli, R. A., Mendes de Leon, C. F., Glass, T. A., Williams, C. S., Cooney, L. M., Berkman, L. F., & Tinetti, M. E. (1997). Driving cessation and increased depressive symptoms: Prospective evidence from the New Haven EPESE. Established Populations for Epidemiologic Studies of the Elderly. *Journal of the American Geriatrics Society*, *45*(2), 202–206. https://doi.org/10.1111/j.1532-5415.1997.tb04508.x

Marra, E. M., Mazer-Amirshahi, M., Brooks, G., van den Anker, J., May, L., & Pines, J. M. (2015). Benzodiazepine prescribing in older adults in U.S. ambulatory clinics and emergency departments (2001-10). *Journal of the American Geriatrics Society*, *63*(10), 2074–2081. https://doi.org/10.1111/jgs.13666

Marshall, D. C., Wallance, R. B., Torner, J. C., & Leeds, M. B. (2010, December). *Enhancing the effectiveness of safety warning systems for older drivers* (Report No. DOT HS 811 417). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/39600

Mayhew, D. R., Simpson, H. M., & Ferguson, S. A. (2006). Collisions involving senior drivers: High-risk conditions and locations. *Traffic Injury Prevention*, *7*(2), 117–124. DOI: 10.1080/15389580600636724

McCarthy, D. P., & Mann, W. C. (2006). Sensitivity and specificity of the assessment of driving-related skills older driver screening tool. *Topics in Geriatric Rehabilitation*, *22*(2), 139–152. https://doi.org/10.1097/00013614-200604000-00006

*McCarthy, D. P., Mann, W. C., & Lanford, D. (2009). *Process and outcomes evaluation of older driver screening programs: The Assessment of driving-related skills (ADReS) older-driver screening tool* (Report No. DOT HS 811 113). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/1878

McGwin, G., Sarrels, S. A., Griffin, R., Owsley, C., & Rue, L. W. (2008). The impact of a vision screening law on older driver fatality rates. *Archives of Ophthalmology*, *126*(11), 1544–1547. https://doi.org/10.1001/archopht.126.11.1544

McGwin, G., Sims, R. V., Pulley, L., & Roseman, J. M. (2000). Relations among chronic medical conditions, medications, and automobile crashes in the elderly: A population-based case-control study. *American Journal of Epidemiology*, *152*(5), 424–431. https://doi.org/10.1093/aje/152.5.424

Merickel, J., High, R., Dawson, J., & Rizzo, M. (2019). Real-world risk exposure in older drivers with cognitive and visual dysfunction. *Traffic Injury Prevention*, *20*(sup2), S110–S115. https://doi.org/10.1080/15389588.2019.1688794

Meuser, T. M., Berg-Weger, M., Niewoehner, P. M., Harmon, A. C., Kuenzie, J. C., Carr, D. B., & Barco, P. P. (2012). Physician input and licensing of at-risk drivers: A review of all-inclusive medical evaluation forms in the US and Canada. *Accident Analysis and Prevention*, *46*, 8–17. https://doi.org/10.1016/j.aap.2011.12.009

Meuser, T. M., Carr, D. B., Berg-Weger, M., Niewoehner, P., & Morris, J. C. (2006). Driving and dementia in older adults: Implementation and evaluation of a continuing education project. *The Gerontologist*, *46*(5), 680–687. https://doi.org/10.1093/geront/46.5.680

Mitchell, R., Harvey, L., Toson, B., Draper, B., Brodaty, H., & Close, J. (2020). The association of select medical conditions with road transport and other hospitalised injury among older adults. *Journal of Regional Security*, *31*(1), 20–29. https://doi.org/10.33492/JRS-D-19-00131

Molnar, L. J., Eby, D. W., Charlton, J. L., Langford, J., Koppel, S., Marshall, S., & Man-Son-Hing, M. (2013). Driving avoidance by older adults: Is it always self-regulation? *Accident Analysis and Prevention*, *57*, 96–104. https://doi.org/10.1016/j.aap.2013.04.010

Molnar, L. J., Eby, D. W., Kartje, P. S., & St. Louis, R. M. (2010). Increasing self-awareness among older drivers: The role of self-screening. *Journal of Safety Research*, *41*(4), 367–373. https://doi.org/10.1016/j.jsr.2010.06.003

Molnar, L. J., Eby, D. W., Vivoda, J. M., Bogard, S. E., Zakraksek, J. S., St. Louis, R. M., Zanier, N., Ryan, L. H., LeBlanc, D., Smith, J., Yung, R., Nyquist, L., DiGuiseppi, C., Li, G., Mielenz, T. J., Strogatz, D., & LongROAD Research Team. (2018). The effects of demographics, functioning, and perceptions on the relationship between self-reported and objective measures of driving exposure and patterns among older adults. *Transportation Research. Part F: Traffic Psychology and Behaviour*, *54*, 367–377. https://doi.org/10.1016/j.trf.2018.02.026

Molnar, F. J., Marshall, S. C., Man-Son-Hing, M., Wilson, K. G., Byszewski, A. M., & Stiell, I. (2007). Acceptability and concurrent validity of measures to predict older driver involvement in motor vehicle crashes: An emergency department pilot case-control study. *Accident Analysis and Prevention*, *39*(5), 1056–1063. https://doi.org/10.1016/j.aap.2007.02.003

Morrisey, M. A., & Grabowski, D. C. (2005). State motor vehicle laws and older drivers. *Health Economics*, *14*(4), 407–419. https://doi.org/10.1002/hec.955

Mullen, N. W., Weaver, B., Riendeau, J. A., Morrison, L. E., & Bédard, M. (2010). Driving performance and susceptibility to simulator sickness: Are they related? *The American Journal of Occupational Therapy*, *64*(2), 288–295. https://doi.org/10.5014/ajot.64.2.288

Munro, C. A., Jefferys, J., Gower, E. W., Muñoz, B. E., Lyketsos, C. G., Keay, L., Turano, K. A., Bandeen-Roche, K., & West, S. K. (2010). Predictors of lane-change errors in older drivers. *Journal of the American Geriatrics Society*, *58*(3), 457–464. https://doi.org/10.1111/j.1532-5415.2010.02729.x

Nasvadi, G. E., & Vavrik, J. (2007). Crash risk of older drivers after attending a mature driver education program. *Accident Analysis and Prevention*, *39*(6), 1073–1079. https://doi.org/10.1016/j.aap.2007.02.005

National Center for Statistics and Analysis. (2013, August). *How vehicle age and model year relate to driver injury severity in fatal crashes* (Traffic Safety Facts. Report No. DOT HS 811 825). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/Publication/811825

National Center for Statistics and Analysis. (2021a, April). *Distracted driving 2019* (Traffic Safety Facts. Report No. DOT HS 813 111). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813111

National Center for Statistics and Analysis. (2021b, May). *Older population: 2019 data* (Traffic Safety Facts. Report No. DOT HS 813 121). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/Publication/813121

National Center for Statistics and Analysis. (2023, January). *Older population: 2020 data* (Traffic Safety Facts. Report No. DOT HS 813 341). National Highway Traffic Safety Administration. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813341

National Eye Institute. (2019). *Eye Health Data and Statistics*. www.nei.nih.gov/learn-about-eye-health/outreach-campaigns-and-resources/eye-health-data-and-statistics

Nef, T., Bieri, R., Müri, R. M., & Mosimann, U. P. (2015). Non-illness-related factors contributing to traffic safety in older drivers: A literature review. *Experimental Aging Research*, *41*(3), 325–360. https://doi.org/10.1080/0361073X.2015.1021650

Nouchi, R., Kobayashi, A., Nouchi, H., & Kawashima, R. (2019). Newly developed TV-based cognitive training games improve car driving skills, cognitive functions, and mood in healthy older adults: Evidence from a randomized controlled trial. *Frontiers in Aging Neuroscience*, *11*, 99. https://doi.org/10.3389/fnagi.2019.00099

O'Connor, M. L., Edwards, J. D., Small, B. J., & Andel, R. (2012). Patterns of level and change in self-reported driving behaviors among older adults: Who self-regulates? *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *67*(4), 437–446. https://doi.org/10.1093/geronb/gbr122

Okonkwo, O. C., Crowe, M., Wadley, V. G., & Ball, K. (2008). Visual attention and self-regulation of driving among older adults. *International Psychogeriatrics*, *20*(1), 162–173. https://doi.org/10.1017/S104161020700539X

Okonkwo, O. C., Wadley, V. G., Crowe, M., Roenker, D. L., & Ball, K. (2007). Self-regulation of driving in the context of impaired visual attention: Are there gender differences? *Rehabilitation Psychology*, *52*(4), 421–428. https://doi.org/10.1037/0090-5550.52.4.421

Olfson, M., King, M., & Schoenbaum, M. (2015). Benzodiazepine use in the United States. *Journal of the American Medical Association Psychiatry*, *72*(2), 136–142.

Orriols, L., Wilchesky, M., Lagarde, E., & Suissa, S. (2013). Prescription of antidepressants and the risk of road traffic crash in the elderly: A case-crossover study. *British Journal of Clinical Pharmacology*, *76*(5), 810–815. https://doi.org/10.1111/bcp.12090

Ott, B. R., Heindel, W. C., Papandonatos, G. D., Festa, E. K., Davis, J. D., Daiello, L. A., & Morris, J. C. (2008). A longitudinal study of drivers with Alzheimer disease. *Neurology*, *70*(14), 1171–1178. https://doi.org/10.1212/01.wnl.0000294469.27156.30

Owsley, C., & McGwin, G. (2010). Vision and driving. *Vision Research*, *50*(23), 2348–2361. https://doi.org/10.1016/j.visres.2010.05.021

Owsley, C., McGwin, G., Phillips, J. M., McNeal, S. F., & Stalvey, B. T. (2004). Impact of an educational program on the safety of high-risk, visually impaired, older drivers. *American Journal of Preventive Medicine*, *26*(3), 222–229. https://doi.org/10.1016/j.amepre.2003.12.005

Owsley, C., Stalvey, B. T., & Phillips, J. M. (2003). The efficacy of an educational intervention in promoting self-regulation among high-risk older drivers. *Accident Analysis and Prevention*, *35*(3), 393–400.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., M, Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *British Medical Journal, 372*, n71. DOI:10.1136/bmj.n71

Painter, P., Stewart, A. L., & Carey, S. (1999). Physical functioning: Definitions, measurement, and expectations. *Advances in Renal Replacement Therapy*, *6*(2), 110–123. https://doi.org/10.1016/s1073-4449(99)70028-2

Paire-Ficout, L., Lafont, S., Conte, F., Coquillat, A., Fabrigoule, C., Ankri, J., Blanc, F., Gabel, C., Novella, J. -L., Morrone, I., & Mahmoudi, R. (2018). Naturalistic driving study investigating self-regulation behavior in early Alzheimer's disease: A pilot study. *Journal of Alzheimer's Disease*, *63*(4), 1499–1508. https://doi.org/10.3233/JAD-171031

Palumbo, A. J., Pfeiffer, M. R., Metzger, K. B., & Curry, A. E. (2019). Driver licensing, motor-vehicle crashes, and moving violations among older adults. *Journal of Safety Research*, *71*, 87–93. DOI: 10.1016/j.jsr.2019.09.019

*Park, S. -W., Choi, E. S., Lim, M. G., Kim, E. J., Hwang, S. I., Choi, K. -I., Yoo, H. -C., Lee, K. J., & Jung, H. -E. (2011). Association between unsafe driving performance and cognitive-perceptual dysfunction in older drivers. *PM&R: The Journal of Injury, Function, and Relabilitation*, *3*(3), 198–203. https://doi.org/10.1016/j.pmrj.2010.12.008

Piersma, D., de Waard, D., Davidse, R., Tucha, O., & Brouwer, W. (2016). Car drivers with dementia: Different complications due to different etiologies? *Traffic Injury Prevention*, *17*(1), 9–23. https://doi.org/10.1080/15389588.2015.1038786

Pomidor, A., Dickerson, A. E., Gray, S., Marotti, R., Moore, I., Resnick, B., Schold-Davis, E., & Aiello, S. E. (Eds.). (2019). *Clinician's guide to assessing and counseling older drivers* (4th ed.). American Geriatrics Society.

Porter, M. M. (2013). Older driver training using video and global positioning system technology—A randomized controlled trial. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *68*(5), 574–580. https://doi.org/10.1093/gerona/gls160

Porter, M. M., Irani, P., & Mondor, T. A. (2008). Effect of auditory road safety alerts on brake response times of younger and older male drivers. *Transportation Research Record: The Journal of the Transportation Research Board*, *2069*(1), 41–47. https://doi.org/10.3141/2069-06

Ragland, D. R., Satariano, W. A., & MacLeod, K. E. (2005). Driving cessation and increased depressive symptoms. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *60*(3), 399–403. https://doi.org/10.1093/gerona/60.3.399

Ranney, T. A. (2008, April). *Driver distraction: A review of the current state-of-knowledge* (Report No. DOT HS 810 787). National Highway Traffic Safety Administration. https://www.nhtsa.gov/sites/nhtsa.gov/files/810787_0.pdf

Robertson, S., & Aultman-Hall, L. (2001). Impact of road conditions on elderly drivers. *Journal of Transportation Engineering*, *127*(3), 244–246. DOI: 10.1061/(ASCE)0733-947X(2001)127:3(244)

Roe, C. M., Babulal, G. M., Head, D. M., Stout, S. H., Vernon, E. K., Ghoshal, N., Garland, B., Barco, P. P., Williams, M. M., Johnson, A., Fierberg, R., Fague, M. S., Xiong, C., Mormino, E., Grant, E. A., Holtzman, D. M., Benzinger, T. L. S., Fagan, A. M., Ott, B. R., … Morris, J. C. (2017). Preclinical Alzheimer's disease and longitudinal driving decline. *Alzheimer's & Dementia: Translational Research & Clinical Interventions*, *3*(1), 74–82. https://doi.org/10.1016/j.trci.2016.11.006

Rolison, J. J., & Moutari, S. (2018). Risk-exposure density and mileage bias in crash risk for older drivers. *American Journal of Epidemiology*, *187*(1), 53–59. DOI: 10.1093/aje/kwx220

Romoser, M. R. E. (2013). The long-term effects of active training strategies on improving older drivers' scanning in intersections: A two-year follow-up to Romoser and Fisher (2009). *Human Factors*, *55*(2), 278–284. https://doi.org/10.1177/0018720812457566

Romoser, M. R. E., & Fisher, D. L. (2009). The effect of active versus passive training strategies on improving older drivers' scanning in intersections. *Human Factors*, *51*(5), 652–668. https://doi.org/10.1177/0018720809352654

Ross, L. A., Clay, O. J., Edwards, J. D., Ball, K. K., Wadley, V. G., Vance, D. E., Cissell, G. M., Roenker, D. L., & Joyce, J. J. (2009). Do older drivers at-risk for crashes modify their driving over time? *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *64*(2), 163–170. https://doi.org/10.1093/geronb/gbn034

Rozzini, L., Riva, M., Zanetti, M., Gottardi, F., Caratozzolo, S., Vicini Chilovi, B., Trabucchi, M., & Padovani, A. (2013). The impact of cognitive deficit on self-reported car crashes in ultra-octogenarian population: Data of an Italian population-based study. *International Journal of Geriatric Psychiatry*, *28*(6), 562–566. https://doi.org/10.1002/gps.3857

Rubin, G. S., Ng, E. S. W., Bandeen-Roche, K., Keyl, P. M., Freeman, E. E., & West, S. K. (2007). A prospective, population-based study of the role of visual impairment in motor vehicle crashes among older drivers: The SEE study. *Investigative Ophthalmology & Visual Science*, *48*(4), 1483–1491. https://doi.org/10.1167/iovs.06-0474

Rudisill, T. M., Zhu, M., Abate, M., Davidov, D., Delagarza, V., Long, D. L., Sambamoorthi, U., & Thornton, J. D. (2016). Characterization of drug and alcohol use among senior drivers fatally injured in U.S. motor vehicle collisions, 2008-2012. *Traffic Injury Prevention*, *17*(8), 788–795. DOI: 10.1080/15389588.2016.1165809

Rudisill, T. M., Zhu, M., Davidov, D., Long, D. L, Sambamoorthi, U., Abate, M., & Delagarza, V. (2016). Medication use and the risk of motor vehicle collision in West Virginia drivers 65 years of age and older: A case-crossover study. *BMC Research Notes*, *9*, 166. https://doi.org/10.1186/s13104-016-1974-x

SAE International. (2021). *Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles* (Report No. J3016). https://www.sae.org/standards/content/j3016_202104/

Sangrar, R., Mun, J., Cammarata, M., Griffith, L. E., Letts, L., & Vrkljan, B. (2019). Older driver training programs: A systematic review of evidence aimed at improving behind-the-wheel performance. *Journal of Safety Research*, *71*, 295–313. https://doi.org/10.1016/j.jsr.2019.09.022

Sawula, E., Polgar, J., Porter, M. M., Gagnon, S., Weaver, B., Nakagawa, S., Stinchcombe, A., & Bédard, M. (2018). The combined effects of on-road and simulator training with feedback on older drivers' on-road performance: Evidence from a randomized controlled trial. *Traffic Injury Prevention*, *19*(3), 241–249. https://doi.org/10.1080/15389588.2016.1236194

Schlenker, M. B., Thiruchelvam, D., & Redelmeier, D. A. (2018). Association of cataract surgery with traffic crashes. *JAMA Ophthalmology*, *136*(9), 998–1007. https://doi.org/10.1001/jamaophthalmol.2018.2510

Schneider, C. A., Hajiseyedjavadi, F., Tainter, F., Knodler, M., Zhang, J., Romoser, M., Samuel, S., & Fisher, D. (2020). Measuring the applicability of intersection-based older driver training programs. *Transportation Research Record: 2674*(9), 878–886. https://doi.org/10.1177/0361198120932566

*Selander, H., Lee, H. C., Johansson, K., & Falkmer, T. (2011). Older drivers: On-road and off-road test results. *Accident Analysis and Prevention*, *43*(4), 1348–1354. https://doi.org/10.1016/j.aap.2011.02.007

Selander, H., Stave, C., Willstrand, T. D., & Peters, B. (2019). Driving simulator-based training to improve self-rating ability of driving performance in older adults – A pilot study. *European Transport Research Review*, *11*(1), 35. https://doi.org/10.1186/s12544-019-0372-6

Sharp, E. B., & Johnson, P. E. (2005). Taking the keys from Grandpa. *Review of Policy Research*, *22*(2), 187–204. https://doi.org/10.1111/j.1541-1338.2005.00129.x

Shimada, H., Hotta, R., Makizako, H., Doi, T., Tsutsumimoto, K., Nakakubo, S., & Makino, K. (2019). Effects of driving skill training on safe driving in older adults with mild cognitive impairment. *Gerontology*, *65*(1), 90–97. https://doi.org/10.1159/000487759

Signorovitch, J. E., Macaulay, D., Diener, M., Yan, Y., Wu, E. Q., Gruenberger, J. B., & Frier, B. M. (2013). Hypoglycaemia and accident risk in people with type 2 diabetes mellitus treated with non-insulin antidiabetes drugs. *Diabetes, Obesity & Metabolism*, *15*(4), 335–341. https://doi.org/10.1111/dom.12031

Simmons, S. M., Hicks, A., & Caird, J. K. (2016). Safety-critical event risk associated with cellphone tasks as measured in naturalistic driving studies: A systematic review and meta-analysis. *Accident Analysis and Prevention*, *87*, 161–169. DOI: 10.1016/j.aap.2015.11.015

Sims, R. V., McGwin, G., Pulley, L. V., & Roseman, J. M. (2001). Mobility impairments in crash-involved older drivers. *Journal of Aging and Health*, *13*(3), 430–438. https://doi.org/10.1177/089826430101300306

Singletary, B. A., Do, A. N., Donnelly, J. P., Huisingh, C., Mefford, M. T., Modi, R., Mondesir, F. L., Ye, Y., Owsley, C., & McGwin, G. (2017). Self-reported vs. state-recorded motor vehicle collisions among older community dwelling individuals. *Accident Analysis and Prevention*, *101*, 22–27. https://doi.org/10.1016/j.aap.2017.01.021

Souders, D. J., Charness, N., Roque, N. A., & Pham, H. (2020). Aging: Older adults' driving behavior using longitudinal and lateral warning systems. *Human Factors*, *62*(2), 229–248. https://doi.org/10.1177/0018720819864510

Spector, R. H. (1990). Visual Fields. In H. K. Walker, W. D. Hall, & J. W. Hurst (Eds.), *Clinical methods: The history, physical, and laboratory examinations* (3rd ed.). Butterworths.

*Spreng, L., Favrat, B., Borruat, F. -X., & Vaucher, P. (2018). Cross-sectional study assessing the addition of contrast sensitivity to visual acuity when testing for fitness to drive. *BMJ Open*, *8*(1), e018546. https://doi.org/10.1136/bmjopen-2017-018546

Staplin, L., Gish, K. W., & Joyce, J. (2008). 'Low mileage bias' and related policy implications—A cautionary note. *Accident Analysis and Prevention*, *40*(3), 1249–1252. DOI: 10.1016/j.aap.2007.10.012

Staplin, L., Gish, K. W., & Sifrit, K. J. (2014). Using cognitive status to predict crash risk: Blazing new trails? *Journal of Safety Research*, *48*, 19–25. https://doi.org/10.1016/j.jsr.2013.10.004

Staplin, L., Lococo, K. H., Brooks, J. O., & Srinivasan, R. (2013, April). *Validation of rehabilitation training programs for older drivers* (Report No. DOT HS 811 749). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/1945

Staplin, L. K, Lococo, K. H., Gish, K. W., & Martell, C. (2008, June). *A pilot study to test multiple medication usage and driving functioning* (Report No. DOT HS 810 980). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/1843

Staplin, L., Lococo, K. H., Mastromatto, T., Sifrit, K. J., & Trazzera, K. M. (2017). Can your older patients drive safely? *American Journal of Nursing, 117(9)*, 34–43. https://doi.org/10.1097/01.NAJ.0000524519.45105.8d

Staplin, L., Lococo, K. H., Stutts, J., Robison, K., Levitt, D., Srinivasan, R., & Sifrit, K. J. (2021, May). *Physical fitness training and older driver performance and exposure* (Report No. DOT HS 813 107). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/55934

Stav, W. B. (2008). Review of the evidence related to older adult community mobility and driver licensure policies. *The American Journal of Occupational Therapy*, *62*(2), 149–158. https://doi.org/10.5014/ajot.62.2.149

Stav, W. B. (2014). Updated systematic review on older adult community mobility and driver licensing policies. *The American Journal of Occupational Therapy*, *68*(6), 681–689. https://doi.org/10.5014/ajot.2014.011510

*Stav, W. B., Justiss, M. D., McCarthy, D. P., Mann, W. C., & Lanford, D. N. (2008). Predictability of clinical assessments for driving performance. *Journal of Safety Research*, *39*(1), 1–7. https://doi.org/10.1016/j.jsr.2007.10.004

Sterne, J. A. C., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., Cates, C. J., Cheng, H. -Y., Corbett, M. S., Eldridge, S. M., Hernán, M. A., Hopewell, S., Hróbjartsson, A., Junqueira, D. R., Jüni, P., Kirkham, J. J., Lasserson, T., Li, T., McAleenan, A., … & Higgins, J. P. T. (2019). RoB 2: A revised tool for assessing risk of bias in randomised trials. *British Medical Journal*, 366.

Stout, S. H., Babulal, G. M., Ma, C., Carr, D. B., Head, D. M., Grant, E. A., Williams, M. M., Holtzman, D. M., Fagan, A. M., Morris, J. C., & Roe, C. M. (2018). Driving cessation over a 24-year period: Dementia severity and cerebrospinal fluid biomarkers. *Alzheimer's & Dementia*, *14*(5), 610–616. https://doi.org/10.1016/j.jalz.2017.11.011

Stutts, J., Martell, C., & Staplin, L. (2009, June). *Identifying behaviors and situations associated with increased crash risk for older drivers* (Report No. DOT HS 811 093). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/1880

*Szlyk, J. P., Myers, L., Zhang, Y., Wetzel, L., & Shapiro, R. (2002). Development and assessment of a neuropsychological battery to aid in predicting driving performance. *Journal of Rehabilitation Research and Development*, *39*(4), 483–496.

Tefft, B. C. (2008). Risks older drivers pose to themselves and to other road users. *Journal of Safety Research*, *39*(6), 577–582. DOI: 10.1016/j.jsr.2008.10.002

Tefft, B. C. (2014). Driver license renewal policies and fatal crash involvement rates of older drivers, United States, 1986-2011. *Injury Epidemiology*, *1*(1), 25. https://doi.org/10.1186/s40621-014-0025-0

Thompson, K. R., Johnson, A. M., Emerson, J. L., Dawson, J. D., Boer, E. R., & Rizzo, M. (2012). Distracted driving in elderly and middle-aged drivers. *Accident Analysis and Prevention*, *45*, 711–717. https://doi.org/10.1016/j.aap.2011.09.040

Ulak, M. B., Ozguven, E. E., Vanli, O. A., Dulebenets, M. A., & Spainhour, L. (2018). Multivariate random parameter Tobit modeling of crashes involving aging drivers, passengers, bicyclists, and pedestrians: Spatiotemporal variations. *Accident Analysis and Prevention*, *121*, 1–13. DOI: 10.1016/j.aap.2018.08.031

Unsworth, C. A., & Baker, A. (2014). Driver rehabilitation: A systematic review of the types and effectiveness of interventions used by occupational therapists to improve on-road fitness-to-drive. *Accident Analysis and Prevention*, *71*, 106–114. https://doi.org/10.1016/j.aap.2014.04.017

Urlings, J. H. J., Cuenen, A., Brijs, T., Lutin, M., & Jongen, E. M. M. (2018). Aiding medical professionals in fitness-to-drive screenings for elderly drivers: Development of an office-based screening tool. *International Psychogeriatrics*, *30*(8), 1211–1225. https://doi.org/10.1017/S1041610217002678

Valentine, J. C., Pigott, T. D., & Rothstein, H. (2010). How many studies do you need? A primer on statistical power for meta-analysis. *Journal of Educational and Behavioral Statistics, 35(2),* 215–247. https://doi.org/10.3102/1076998609346961

van Wely, M. (2014). The good, the bad and the ugly: Meta-analysis. *Human Reproduction, 29(8),* 1622–6. https://doi.org/10.1093/humrep/deu127

*Vaucher, P., Herzig, D., Cardoso, I., Herzog, M. H., Mangin, P., & Favrat, B. (2014). The trail making test as a screening instrument for driving performance in older drivers; A translational research. *BMC Geriatrics*, *14*, 123. https://doi.org/10.1186/1471-2318-14-123

*Vaucher, P., Cardoso, I., Veldstra, J. L., Herzig, D., Herzog, M., Mangin, P., & Favrat, B. (2014). A neuropsychological instrument measuring age-related cerebral decline in older drivers: Development, reliability, and validity of MedDrive. *Frontiers in Human Neuroscience*, *8*, 772. https://doi.org/10.3389/fnhum.2014.00772

Venkatraman, V., Richard, C. M., Magee, K., & Johnson, K. (2021, July). *Countermeasures that work: A highway safety countermeasures guide for State Highway Safety Offices,* 10th edition, 2020 (Report No. DOT HS 813 097). National Highway Traffic Safety Administration. www.nhtsa.gov/sites/nhtsa.gov/files/2021-09/Countermeasures-10th_080621_v5_tag.pdf

Vermeeren, A., Vets, E., Vuurman, E. F. P. M., Van Oers, A. C. M., Jongen, S., Laethem, T., Heirman, I., Bautmans, A., Palcza, J., Li, X., Troyer, M. D., Wrishko, R., McCrea, J., & Sun, H. (2016). On-the-road driving performance the morning after bedtime use of suvorexant 15 and 30 mg in healthy elderly. *Psychopharmacology*, *233*(18), 3341–3351. https://doi.org/10.1007/s00213-016-4375-x

Viswanathan, M., & Berkman, N. D. (2012). Development of the RTI item bank on risk of bias and precision of observational studies. *Journal of Clinical Epidemiology, 65*(2), 163–178. https://doi.org/10.1016/j.jclinepi.2011.05.008

Wells, G. A., O'Connell, D., Peterson, J., Welch, V., Losos, M., & Tugwell, P. (n.d.). The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Ottawa Hospital Research Institute. www.ohri.ca/programs/clinical_epidemiology/oxford.asp

West, S. K., Hahn, D. V., Baldwin, K. C., Duncan, D. D., Munoz, B. E., Turano, K. A., Hassan, S. E., Munro, C. A., & Bandeen-Roche, K. (2010). Older drivers and failure to stop at red lights. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *65*(2), 179–183. https://doi.org/10.1093/gerona/glp136

Williams, A. F., & Shabanova, V. I. (2003). Responsibility of drivers, by age and gender, for motor-vehicle crash deaths. *Journal of Safety Research*, *34*(5), 527–531.

*Willstrand, T. D., Broberg, T., & Selander, H. (2017). Driving characteristics of older drivers and their relationship to the Useful Field of View test. *Gerontology*, *63*(2), 180–188. https://doi.org/10.1159/000448281

*Wood, J. M., Anstey, K. J., Kerr, G. K., Lacherez, P. F., & Lord, S. (2008). A multidomain approach for predicting older driver safety under in-traffic road conditions. *Journal of the American Geriatrics Society*, *56*(6), 986–993. https://doi.org/10.1111/j.1532-5415.2008.01709.x

Wood, J. M., & Black, A. A. (2016). Ocular disease and driving. *Clinical & Experimental Optometry*, *99*(5), 395–401. https://doi.org/10.1111/cxo.12391

Wood, J. M., Black, A. A., Mallon, K., Kwan, A. S., & Owsley, C. (2018). Effects of age-related macular degeneration on driving performance. *Investigative Ophthalmology & Visual Science*, *59*(1), 273–279. https://doi.org/10.1167/iovs.17-22751

Wood, J. M., Black, A. A., Mallon, K., Thomas, R., & Owsley, C. (2016). Glaucoma and driving: On-road driving characteristics. *Plos One*, *11*(7), e0158318. https://doi.org/10.1371/journal.pone.0158318

*Wood, J. M., Horswill, M. S., Lacherez, P. F., & Anstey, K. J. (2013). Evaluation of screening tests for predicting older driver performance and safety assessed by an on-road test. *Accident Analysis and Prevention*, *50*, 1161–1168. https://doi.org/10.1016/j.aap.2012.09.009

*Woolnough, A., Salim, D., Marshall, S. C., Weegar, K., Porter, M. M., Rapoport, M. J., Man-Son-Hing, M., Bédard, M., Gélinas, I., Korner-Bitensky, N., Mazer, B., Naglie, G., Tuokko, H., & Vrkljan, B. (2013). Determining the validity of the AMA guide: A historical cohort analysis of the assessment of driving related skills and crash rate among older drivers. *Accident Analysis and Prevention*, *61*, 311–316. https://doi.org/10.1016/j.aap.2013.03.020

Yadav, A. K., & Velaga, N. R. (2021). A comprehensive systematic review of the laboratory-based research investigating the influence of alcohol on driving behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour*, *81*, 557–585. https://doi.org/10.1016/j.trf.2021.07.010

Yamin, S., Stinchcombe, A., & Gagnon, S. (2015). Driving competence in mild dementia with Lewy bodies: In search of cognitive predictors using driving simulation. *International Journal of Alzheimer's Disease*, *2015*, 806024. https://doi.org/10.1155/2015/806024

Yang, W., Hamilton, J. L., Kopil, C., Beck, J. C., Tanner, C. M., Albin, R. L., Ray Dorsey, E., Dahodwala, N., Cintina, I., Hogan, P., & Thompson, T. (2020). Current and projected future economic burden of Parkinson's disease in the U.S. *npj* [sic] *Parkinson's Disease*, *6*, 15. https://doi.org/10.1038/s41531-020-0117-1

Young, K. L., Koppel, S., & Charlton, J. L. (2017). Toward best practice in Human Machine Interface design for older drivers: A review of current design guidelines. *Accident Analysis and Prevention*, *106*, 460–467. https://doi.org/10.1016/j.aap.2016.06.010

Zhang, L., Baldwin, K., Munoz, B., Munro, C., Turano, K., Hassan, S., Lyketsos, C., Bandeen-Roche, K., & West, S. K. (2007). Visual and cognitive predictors of performance on brake reaction test: Salisbury Eye Evaluation Driving Study. *Ophthalmic Epidemiology*, *14*(4), 216–222. https://doi.org/10.1080/09286580701502988

Zhang, J., Lindsay, J., Clarke, K., Robbins, G., & Mao, Y. (2000). Factors affecting the severity of motor vehicle traffic crashes involving elderly drivers in Ontario. *Accident Analysis and Prevention*, *32*(1), 117–125. DOI: 10.1016/s0001-4575(99)00039-1

Appendix A: Study Quality Criteria

Table A-1. Study Data Collection/Study Quality Assessment Instrument

Item	Score
Quality Control: All Studies	
1. Is the study design prospective?	Yes/No/NA/NR
2. Was a recruitment strategy designed to provide a degree of generalizability beyond a convenience sample?	Yes/No/NA/NR
3. Are inclusion/exclusion criteria clearly stated?	Yes/No/NA/NR
4. For studies that recruit across multiple sites or groups, are recruitment methods similar across sites?	Yes/No/NA/NR
5. Are variables assessed using valid and reliable measures, implemented consistently across all study participants?	Yes/No/NA/NR
6. Does the study use statistical methods appropriate to the data?	Yes/No/NA/NR
7. Were potentially confounding and effect modifying variables taken into account in the design and/or analysis (e.g., through matching, stratification, interaction terms, multivariate analysis, or other statistical adjustment)?	Yes/No/NA/NR
8. In the case of longitudinal analyses, was attrition addressed (e.g., through sensitivity analysis or other adjustment method)?	Yes/No/NA/NR
9. Was a power analysis reported?	Yes/No/NA/NR
10. Is the source of funding identified?	Yes/No/NA/NR
11. Are study authors free of conflicts of interest?	Yes/No/NA/NR
Quality Control: Experimental studies	
12. Does the study include a comparison group?	Yes/No/NA/NR
13. Does the study have an active or social-contact control group?	Yes/No/NA/NR
14. Is there sufficient detail provided describing the intervention or exposure to replicate the study?	Yes/No/NA/NR

15. Is there any attempt to balance the allocation between the groups (e.g., through stratification, matching, propensity scores)?	Yes/No/NA/NR
16. Were the outcome assessors blinded to the intervention or exposure status of participants?	Yes/No/NA/NR
17. Were participants aware of their assigned intervention during the trial?	Yes/No/NA/NR
18. Is the length of follow-up the same for all groups?	Yes/No/NA/NR
19. Was the allocation sequence random?	Yes/No/NA/NR
20. Did the study apply inclusion/exclusion criteria uniformly to all comparison groups/arms of the study?	Yes/No/NA/NR
21. Is the length of time following the intervention/exposure sufficient to support the evaluation of primary outcomes and harms?	Yes/No/NA/NR
22. Did the study control for any baseline differences in relevant variables between intervention and control groups? (If study states no baseline differences, check 'Yes')	Yes/No/NA/NR
Article information	
Article type	Peer-reviewed journal article Agency-reviewed report Other
Study design	
Study design	Intervention Experimental Observational Other
Sample recruitment location	Community Hospital Nursing home/assisted living Retirement/55+ community Licensing agency National sample (e.g., FARS) Other Not reported
Region of study	United States Canada Other

Population density of study site	Urban Rural Suburban Other Not reported
Outcome measure	Crashes (self-report, at-fault/not at-fault) Crashes (state report, at-fault/not at-fault) On-road performance: professional evaluation (e.g., occupational therapist, driving instructor) On-road performance: DMV On-road performance: naturalistic Closed course/driving range performance Simulator: high fidelity (e.g., NADS) Simulator: low fidelity/fixed base/part-task Citations/tickets (self-report) Citations/tickets (state-report) Number of times pulled over Licensing outcome Medical outcome (e.g., number of drivers referred by clinicians) Indirect measure (e.g., seat belt use, scanning behavior, and attention allocation) Other
Sample information	
Analytic sample size	[Continuous variable] Not reported
Analytic sample age range, mean, and standard deviation	[Continuous variable] Not reported
Percentage of women in analytic sample	[Continuous variable] Not reported
Percentage of nonwhite participants in analytic sample	[Continuous variable] Not reported
Sample health	Healthy Alzheimer's disease/dementia MCI Stroke or TIA Diabetes Cardiovascular disease Obstructive sleep apnea/obstructive breathing Peripheral neuropathy General population Other
(Intervention studies) Intervention adherence rate	[Continuous variable] Not reported Not applicable

Page intentionally left blank.

Appendix B: Meta-Analysis Methodology and Results

Data Collection

All articles included in the systematic review for Chapter 3 were screened for inclusion in the meta-analysis. To be included in the meta-analysis, articles needed to report sufficient statistics to calculate effect sizes. Sample statistics included means, standard deviations, and sample sizes among different types of drivers (e.g., unsafe versus safe driver), correlations among predictors with driving outcomes, or the odds of engaging in some driving behavior based on some cognitive, physical, or visual threshold.

Meta-analysis data were recorded and entered by two independent reviewers. Inconsistent entries were reviewed by a third reviewer. If unclear, Ross or Staplin reviewed and provided the final decision. After entry, Ross and Sprague reviewed the predictor and outcome measures. These measures were assessed through reviewing the study description. If unclear, additional sources (e.g., references, standard assessment procedure manuals, etc.) were consulted. In situations where additional adjudication was necessary, Staplin served as a third reviewer.

Analysis

Comprehensive Meta-Analysis is an advanced and widely validated software program for meta-analyses. CMA is able to use a large number of different types of reported statistics. Additionally, CMA allows for the assessment of possible moderators, publication bias metrics, analyses of subsets of data, and the inclusion of several outcomes from a single study. The current analyses included the following statistics from the reviewed studies:

- Unadjusted correlations between predictors and driving outcomes (including other effect size calculations such as Cohen's *d*)
- *T*-test and sample size of each subgroup (e.g., crash versus no crash)
- Odds/hazard ratio

Variables

Predictor variables were categorized into cognitive, vision, and physical domains. Predictors in the cognitive domain were further categorized into either the speed of processing/attention, executive function, or dementia status subdomain. For vision and physical domains, there were too few studies to further divide into subdomains. Based on the final list of eligible articles, outcome variables were categorized into on-road performance, crashes, and simulated driving. The articles that qualified for meta-analysis under each domain and subdomain and the specific measures included in each are reported in Table B1. The following moderators were also considered.

- Percentage of women in sample
- Average age of sample
- Sample recruitment strategy (whether the sample recruitment strategy was intended to generalize to a larger population). Studies that recruited convenience samples through strategies such as flyers and word-of-mouth were coded as "No." Studies that recruited samples with a strategy designed to be generalizable to a larger population, such as randomized sampling and recruitment at driver license centers, were coded as "Yes." Studies that did not provide enough detail to determine sample recruitment strategy were coded as "Not reported."

Table B-1. Predictor Variable Terms, Definitions, and Measures

Variable	Definition
Cognition	Individual or composite measures of processing speed/attention, memory, executive function, and/or dementia status

Measures Included, by Article:

(Anstey & Wood, 2011): Speeded Attention and Task Switching, UFOV 1, Inhibition (CRT-C), Reaction Time, UFOV

(Aksan et al., 2013): COGSTAT, visual cognition, visual perception, executive function, AVLT-Recall

(Bélanger et al., 2010): UFOV 2, UFOV 3, Visual Secondary Task Latency in Complex Environment

(Bieri et al., 2014): MoCA total score, Clock Drawing Task (CDT), Trail Making Test B, Executive Functions: Number of Errors, Executive Functions: Reaction Time Correct Responses, Distance and Speed Regulation: Number of Collisions, Distance and Speed Regulation: Duration of Collisions, Eye-Hand Coordination: Number of Collisions, Trail Making Test A, Divided Attention: Number of Collisions, Divided Attention: Number of Errors, Divided Attention: Reaction Time Correct, Selective Attention: Number of Errors, Selective Attention: Reaction Time Correct

(Choi et al., 2019): ANT Accuracy, ANT Reaction time, Executive attentional functioning (ANT), Alerting functioning (ANT), Orienting functioning (ANT), Alerting attentional function, Executive Efficiency Index, Executive Functioning, Executive Attention

(Cuenen et al., 2016): MMSE, MoCA, Road Sign Recognition Test, Digit Span Forward, UFOV 1, UFOV 2, UFOV3, ANT Alerting, ANT Orienting, ANT Conflict, ANT Mean Accuracy, ANT Mean Reaction Time

(De Raedt & Ponjaert-Kristoffersen, 2000a): Cognitive Flexibility Test, Visuospatial Paperfolding Test, Divided Attention Tracking Task, Mental Flexibility Incompatibility Test, Movement Perception Test, UFOV, Dot Counting Task

(Douissembekov et al., 2015): Field of View

(Edwards et al., 2008): Working Memory, Visualization of Missing information, Divided Visual Search (Trail Making Test B), UFOV 2, UFOV 3

(Eramudugolla et al., 2016): MMSE, Trail Making Test B, California Verbal Learning Test Delayed Recall, Choice Reaction Time, DriveSafe Score, DriveSafe Intersection Test, UFOV, Choice Reaction Time

(Ferreira et al., 2012): Addenbrooke MMSE subscore, Addenbrooke Attention-Orientation Subscale, Addenbrooke Memory Subscale, Addenbrooke Fluency Subscale, Addenbrooke Language Subscale, Addenbrooke Visuospatial Subscale, ACE-R (Addenbrooke's Cognitive Examination-Revised) Total Score

(Ferreira et al., 2013): Addenbrooke MMSE sub-score, Addenbrooke Attention-Orientation Subscale, Addenbrooke Memory Subscale, Addenbrooke Fluency Subscale, Addenbrooke Language Subscale, Addenbrooke Visuospatial Subscale, ACE-R (Addenbrooke's Cognitive Examination- Revised) Total Score, Continuous Visual

Recognition Task- Correct Reactions, Continuous Visual Recognition Task- False Positives, Determination Test-Median Reaction Time, Determination Test- Correct Reaction Time, Determination Test-Incorrect Reaction Time, Trail Making Test B, Stroke Drivers Screening Assessment- Square Matrices Directions, Behavioural Assessment of the Dysexecutive Syndrome- Key Search, WAIS-III Block Design, Stroke Drivers Screening Assessment: Road Sign Recognition, Choice Reaction Time- decision time, Choice Reaction Time- motor time, Senior Drivers Battery Cognitrone- incorrect reactions %, Senior Drivers Battery Cognitrone-reactions, Simple Reaction Time- decision time, Simple Reaction Time- motor time, Stroke Drivers Screening Assessment- Dot Cancellation Test errors, Stroke Drivers Screening Assessment- Dot Cancellation Test false positives, Stroke Drivers Screening Assessment- Dot Cancellation Test time, Trail Making Test A, UFOV 1, UFOV 2

(Friedman et al., 2013): Trail Making Test B, Motor-Free Visual Perception Test (MVPT), UFOV 2

(Hoggarth et al., 2010): MMSE, Dementia Rating Scale, Trail Making Test B, Road Sign Test

(Horswill et al., 2010): Mean hazard perception response latency, UFOV

(Huisingh et al., 2017): Motor-Free Visual Perception Test (MVPT), Trail Making Test B, UFOV 2

(Janke, 2001): MMSE, Waypoint Channel Capacity, Waypoint Risk, Waypoint Errors-1st administration, Waypoint Errors-2nd administration, Traffic Sign Test Errors, Judgment Question Error-Sign Test

(McCarthy et al., 2009): MMSE, Trail Making Test B

(Park et al., 2011): Cognitive-Perceptual Assessment for Driving

(Selander et al., 2011): Trail Making Test B, NorSDSA-Compass, NorSDSA Road Sign Recognition 3 minute, NorSDSA Road Sign Recognition 5 minute, NorSDSA Total Score, NorSDSA Directions, Median Number of Errors, NorSDSDA Dot Cancellation Errors, NorSDSA Dot Cancellation Time, NorSDSA Dot Cancellation (the NorSDSA = Nordic Stroke Driver Screener Assessment), Trail Making Test A, UFOV 1, UFOV 2, UFOV 3

(Szlyk et al., 2002): Block Design, Trail Making Test B, Logical Memory I, Logical Memory II, Visual Memory I, Digit Symbol, Trail Making Test A, Digit Span, Seashore Rhythm

(Stav et al., 2008): MMSE, Trail Making Test B, Motor-Free Perceptual Task-Spatial Orientation, Road Sign Test, Digit Span Forward, UFOV

(Vaucher, Cardoso, et al., 2014): Working Spatial Memory Task 4, Working Memory-1st Cue, Working Memory-Last Cue, Dual Tasking, Execution with Orientation Cue, Movement Detection with Attention Shift, Peripheral Visual Processing, Trail Making Test A, UFOV Divided Attention, UFOV Risk Categories, UFOV Selective Attention, UFOV Visual Processing, UFOVMod, Visual Processing

(Vaucher, Herzig, et al., 2014): MoCA, Trail Making Test B

(Willstrand et al., 2017): UFOV 3

(Wood et al., 2008): Dot Motion Log Threshold, Self-Ordered Point Score, Position Choice Reaction Time, Color Choice Reaction Time, Distractor Choice Reaction Time, Trail

Making Test B, Choice Reaction Time, UFOV 2, Simple Reaction Time, Digit Symbol Mean Reaction Time of Correct Responses **(Wood et al., 2013):** Digit Symbol Matching, Hazard Perception Test Score, MMSE, Gestalt, Snowy **(Woolnough et al., 2013)**: Clock Drawing Test (# correct/not correct), Trailmaking Test B	
Cognition subdomain: Speed of Processing/Attention	This lower-level cognitive function is the speed with which a person can interpret (and typically react to) information in their environment. Attention, in this context, incorporates speed of processing and the ability to attend to the relevant stimuli. Speed of processing/attention are functions needed to support higher-level cognitive abilities, such as working memory and executive function. Speed of processing/attention typically decline with age but can be improved with targeted behavioral interventions.
Measures Included, by Article: **(Anstey & Wood, 2011):** Discrimination (UFOV 1), Inhibition (CRT-C), Reaction Time, UFOV **(Bélanger et al., 2010):** UFOV 2, UFOV 3, Visual Secondary Task Latency in Complex Environment **(Bieri et al., 2014):** Divided Attention-Number of Collisions, Divided Attention-Number of Errors, Divided Attention- Reaction Time Correct Responses, Trail Making Test A, Selective Attention-Number of Errors, Selective Attention- Reaction Time Correct Responses **(Choi et al., 2019):** Alerting Attentional Function, Alerting Efficiency, Alerting Functioning (ANT), ANT Accuracy, ANT Reaction Time, Executive Attention, Executive Attentional Efficiency, Executive Attentional Functioning (ANT), Executive Efficiency Index, Executive Functioning, Orienting Efficiency, Orienting Functioning (ANT) **(Cuenen et al., 2016):** ANT Alerting, ANT conflict, ANT mean accuracy, ANT mean reaction time, ANT orienting, Digit Span Forward, UFOV 1, UFOV 2, UFOV 3 **(De Raedt & Ponjaert-Kristoffersen, 2000a):** Dot Counting Task, Movement Perception Task, UFOV **(Douissembekov et al., 2015):** Field of View **(Edwards et al., 2008):** UFOV 2, UFOV 3 **(Ferreira et al., 2013):** Choice Reaction Time- Decision Time, Choice Reaction Time-Motor Time, Senior Drivers Battery Cognitrone- Incorrect Reactions %, Senior Drivers Battery Cognitrone-Reactions, Simple Reaction Time-Decision Time, Simple Reaction Time-Motor Time, Stroke Drivers Screening Assessment- Dot Cancellation Test Errors, Stroke Drivers Screening Assessment- Dot Cancellation Test False Positives, Stroke Drivers Screening Assessment- Dot Cancellation Test Time, Trail Making Test A, UFOV 1, UFOV 2 **(Friedman et al., 2013):** UFOV 2 **(Hoggarth et al., 2010):** Arrows Test Number Correct, Complex Attention Test Movement Time, Complex Attention Test Movement Time SD, Complex Attention Test Number of	

<table>
<tr><td colspan="2">Invalid Trials, Complex Attention Test Number of Lapse Errors, Complex Attention Test Reaction Time, Complex Attention Test Reaction Time SD, Divided Attention Test Arrows Correct, Divided Attention Test Tracking Error, Trail Making Test A, Visual Search Number Correct, Visual Search Reaction Time
(Horswill et al., 2010): UFOV
(Huisingh et al., 2017): UFOV 2
(Janke et al., 2001): Pentagon Task, Perceptual Response Time
(McCarthy et al., 2009): UFOV
(Selander et al., 2011): Median Number of Errors, NorSDSA Dot Cancellation Errors, NorSDSA Dot Cancellation Time, NorSDSA Dot Cancellation, Trail Making Test A, UFOV 1, UFOV 2, UFOV 3
(Stav et al., 2008): UFOV
(Szlyk et al., 2002: Digit Span, Digit Symbol, Seashore Rhythm, Trail Making Test A
(Vaucher, Cardoso, et al., 2014): Central Visual Processing, Dual Tasking, Execution with Orientation Cue, Movement Detection with Attention Shift, Peripheral Visual Processing, UFOV Divided Attention, UFOV Risk Categories, UFOV Selective Attention, UFOV Visual Processing, UFOVMod, Visual Processing
(Vaucher, Herzig, et al., 2014): Trail Making Test A
(Willstrand et al., 2017): UFOV 3
(Wood et al., 2008): Choice Reaction Time, Digit Symbol Mean Reaction Time of Correct Responses, Simple Reaction Time, UFOV 2</td></tr>
<tr><td>Cognition subdomain: Executive Function</td><td>Higher-level cognitive function that involves the ability to attend to complex stimuli and inhibit irrelevant stimuli, multitask, problem solve, and reason. Definitions can vary across studies and within the field. Requires skills like planning, reasoning, and working memory.</td></tr>
<tr><td colspan="2"><u>Measures Included, by Article:</u>
(Bieri et al., 2014): Trail Making Test B, Executive Functions-Number of Errors, Executive Functions- Reaction Time Correct Responses, Distance and Speed Regulation-Number of Collisions, Distance and Speed Regulation-Duration of Collisions, Eye-Hand Coordination-Number of Collisions
(De Raedt & Ponjaert-Kristoffersen, 2000a): Visuospatial Paperfolding Test, Cognitive Flexibility Test, Divided Attention Tracking Test, Mental Flexibility Incompatibility Test
(Edwards et al., 2008): Working Memory, Visualization of Missing Information, Divided Visual Search (Trail Making Test B)
(Eramudugolla et al., 2016): Trail Making Test B
(Hoggarth et al., 2010): Trail Making Test B, Road Sign Test
(Huisingh et al., 2017): Trail Making Test B, Motor-Free Perceptual Test
(Ferreira et al., 2013): WAIS-III Block Design, Determination Test- Median Reaction Time, Determination Test-Correct Reactions, Determination Test-Incorrect Reactions, Stroke Drivers Screening Assessment- Square Matrices Directions, Trail Making Test B, Behavioural Assessment of the Dysexecutive Syndrome-Key Search, Stroke Drivers Screening Assessment: Road Sign Recognition</td></tr>
</table>

(Friedman et al., 2013): Trail Making Test B, Motor-Free Perceptual Test **(Janke, 2001):** Waypoint Channel Capacity, Waypoint Risk, Waypoint Errors-1st Administration, Waypoint Errors-2nd Administration, Traffic Sign Test Errors, Judgment Question Error Sign Test **(McCarthy et al., 2009):** Trail Making Test B **(Selander et al., 2011):** Trail Making Test B, NorSDSA Compass, NorSDSA Road Sign Recognition 3 Min, NorSDSA Road Sign Recognition 5 min, NorSDSA total score, NorSDSA Directions **(Stav et al., 2008):** Trail Making Test B, Motor-Free Perceptual Task-Spatial Orientation score, Road Sign Test **(Vaucher, Cardoso, et al., 2014):** Working Spatial Memory, Working Memory-1st Cue, Working Memory-Last Cue, MedDrive Score **(Vaucher, Herzig, et al., 2014):** Trail Making Test B **(Wood et al., 2008):** Self-Ordered Pointing Score, Position Choice Reaction, Color Choice Reaction Time, Distractor Choice ReactionTime, Trail Making Test B **(Wood et al., 2013):** Gestalt, Snowy **(Woolnough et al., 2013):** Trail Making Test B	
Cognition subdomain: Dementia Screener	Screening measures that typically include several domains as well as basic orientation assessments (e.g., does the person know where they are and what day it is). Importantly, these measures have restricted range as they are designed to screen for possible dementia. Failure of such a screening tool should result in a referral for a full neurological and medical exam. These should not be considered as broad measures of cognition due to the restricted range and design/validation of the measures.
Measures Included, by Article: **(Eramudugolla et al., 2016):** MMSE **(Ferreira et al., 2012):** ACE-R MMSE Subscale, ACE-R (Addenbrooke's Cognitive Examination- Revised), ACE-R Attention-Orientation Subscale, ACE-R Memory Subscale, ACE-R Fluency Subscale, ACE-R Language Subscale, ACE-R Visuospatial Subscale (**Ferreira et al., 2013):** ACE-R MMSE Subscale, ACE-R (Addenbrooke's Cognitive Examination- Revised), ACE-R Attention-Orientation Subscale, ACE-R Memory Subscale, ACE-R Fluency Subscale, ACE-R Language Subscale, ACE-R Visuospatial Subscale **(Hoggarth et al., 2010):** MMSE, Dementia Rating Scale-2 AEMSS **(Janke, 2001):** MMSE **(McCarthy et al., 2009):** Clock Drawing Test, TICS, MMSE **(Stav et al., 2008):** MMSE **(Vaucher, Herzig, et al., 2014):** MoCA **(Wood et al., 2013):** MMSE	
Vision (Note: There were too few studies to examine subdomains)	The most common research (i.e., nonclinical) vision assessments in driving studies are traditional acuity charts (e.g., reading letters from a distance of 10 feet) and charts that detect the contrast threshold, or the amount of contrast needed between a stimuli and

	background, for a participant to correctly identify the target.

Measures Included, by Article:
(Bieri et al., 2014): Best Far Visual Acuity, Best Near Visual Acuity, Contrast Sensitivity
(Edwards et al., 2008): Visual Acuity High Contrast, Visual Acuity Low Contrast
(Green et al., 2013): Vision Impairment
(Hoggarth et al., 2010): Visual Acuity Left Eye, Visual Acuity Right Eye
(Huisingh et al., 2017): Contrast Sensitivity, Near Visual Acuity, Far Visual Acuity, Peripheral Vision Field Loss
(McCarthy et al., 2009): Visual Acuity Deficit, Visual Field Deficit
(Spreng et al., 2018): Both Eyes Contrast Sensitivity, Worst Eye Contrast Sensitivity, Difference Between Eye Contrast Sensitivity, Difference Between Eye Visual Acuity
(Stav et al., 2008): Contrast Sensitivity A, Contrast Sensitivity B, Contrast Sensitivity C, Contrast Sensitivity D, Contrast Sensitivity E, Depth Perception
(Vaucher, Herzig, et al., 2014): Visual Acuity
(Wood et al., 2008): High-Contrast Visual Acuity, Visual Fields Better Eye, Esterman, Contrast Sensitivity
(Wood et al., 2013): Visual Acuity, Contrast Sensitivity, Visual Fields Best MD
(Woolnough et al., 2013): Snellen Visual Acuity Left Eye, Snellen Visual Acuity Right Eye, Snellen Visual Acuity Both Eyes, Visual Field by Confrontation: Deficits versus None.

Physical Performance (Note: There were too few studies to examine subdomains)	Reflects one's capacity to perform various physical functions relevant for everyday life. Tasks can range from simple measures of strength (e.g., grip strength) to the complex coordination of several systems (e.g., timed walking tasks that involve the successful integration of physical and cognitive speed, agility, and attention to safely execute). While the team used an inclusive definition of physical functions, the extant literature primarily investigated the relationship between complex physical functions (e.g., walking speed tests) with driving outcomes rather than simpler strength-based physical capacity measures

Measures Included, by Article:
(Eramudugolla et al., 2016): Postural Sway
(Hoggarth et al., 2010): Footbrake and Clutch Test Reaction Time, Footbrake and Clutch Test Movement Time, Ballistic Movement Test Reaction Time Grand Mean, Ballistic Movement Test peak Velocity Grand Mean
(Lacherez et al., 2014): Proprioception, Vibration Sense, Tactile Sensitivity, Neck Rotation (Right), Quadriceps Strength, Ankle Strength, Handgrip Strength, Reaction Time, Sway (Eyes Open Floor), Sway (Eyes Closed Floor), Sway (Eyes Closed Foam), Coordinated Stability
(McCarthy et al., 2009): Rapid Pace Walk, Motor Strength Deficit, Range of Motion Deficit
(Stav et al., 2008): Rapid Pace Walk, Grip Strength Right Hand, Grip Strength Left Hand, Trunk/Neck Range of Motion Right, Trunk/Neck Range of Motion Left
(Vaucher, Herzig, et al., 2014): Timed Up and Go

(Wood et al., 2008): Total Neck Range of Motion, Knee Extension Strength Score, Sway Path Length, Average Proprioception Score

Table B-2. Outcome Variable Terms, Definitions, and Measures

On-road performance	Traditional behind-the-wheel driving evaluation by an OT/CDRS or driving instructor, or naturalistic observation. This category included studies using instrumented vehicles, naturalistic driving studies, and studies including an on-road assessment scored by an occupational therapist, driving specialist, or other observer.
<u>Measures Included, by Article:</u> **(Aksan et al., 2013):** Landmark and Traffic Sign Identification Test **(Anstey & Wood, 2011):** Approach, blind split, brake/accelerator, critical interventions, gap selection, give way, indicator, lane position, maneuvering, merging, noncritical instructor interventions, observations, one-way, traffic light, two-way **(De Raedt & Ponjaert-Kristoffersen, 2000a):** Road Test **(Douissembekov et al., 2015):** Parallel parking length, perpendicular parking trajectory adjustments **(Eramudugolla et al., 2016):** On-road error, OT-rated driving safety score **(Ferreira et al., 2012):** Safe versus Unsafe Driver, **(Ferreira et al., 2013):** Safe versus Unsafe Driver **(Hoggarth et al., 2010):** Pass versus Fail Driving Test **(Janke, 2001):** On-Road Test Total **(Lacherez et al., 2014):** Unsafe versus Safe Driver **(Selander et al., 2011):** P-Drive, Pass versus Fail On-Road Test, ROA (Ryd On-Road Assessment) **(Spreng et al., 2018):** On-Road Driving Score **(Stav et al., 2008):** Global Rating Score **(Vaucher, Cardoso, et al., 2014):** On-Road Evaluation **(Vaucher, Herzig, et al., 2014):** Poor On-Road Performance **(Willstrand et al., 2017):** Total # of on-road driving errors, attention on-road errors, interaction on-road errors **(Wood et al., 2008):** Unsafe versus Safe Driver **(Wood et al., 2013):** Safe versus Unsafe Driver	
Crashes	Objective or self-reported crashes. This category included studies with self-reported or State-reported crashes, regardless of severity or fault.
<u>Measures Included, by Article:</u> **(Bieri et al., 2014):** Safe versus unsafe driver **(De Raedt & Ponjaert-Kristoffersen, 2000a):** Accidents **(Edwards et al., 2008):** Crashes versus none **(Friedman et al., 2013):** All motor vehicle crashes **(Green et al., 2013):** Any motor vehicle crash; at-fault motor vehicle crash **(Horswill et al., 2010):** Self-reported crashes **(Huisingh et al., 2017):** Any Crash	

(Woolnough et al., 2013): Collision versus not	
Simulated driving	Included studies using a driving simulator. Outcomes from these studies were selected to ensure harmonization given the number of outcomes reported across the studies. For example, the team focused on metrics related to driving safety such as crashes, lane keeping and gap acceptance rather than other simulator metrics (e.g., acceleration metrics, mean speed and speed variances, etc.)
<u>Measures Included, by Article:</u> **(Bélanger et al., 2010):** Simulator crash versus no crash **(Choi et al., 2019):** Completion time to travel 2k ft, driver makes right turn at intersection, mean completion time (Executive-Critical hazardous situations), number of crashes during driving task, number of crashes during executive-critical hazardous situations, number of crashes during orienting-critical hazardous situations, number of crashes in positive alerting-critical situations, number of traffic violations, simulated driving performance: accidents, vehicle unexpectedly, abruptly moves in lane **(Cuenen et al., 2016):** Complete stop, simulated crashes, detection time, gap acceptance, mean driving speed, mean following distance, reaction time, standard deviation of lateral position (SDLP) **(Eramudugolla et al., 2016):** Simulator error **(Park et al., 2011):** Braking, car crash, controlling speed, lane changes, turns, vehicle positioning **(Szlyk et al., 2002):** Brake pedal pressure, horizontal eye movement, lane boundary crossing, speed	

Results

Tables B3, B4, and B5 display the results of conservative meta-analyses that are based on ten or more studies (van Wely, 2014). Tables B6 through B11 present results of exploratory meta-analyses based on fewer than ten studies (Valentine et al., 2010). The following research questions had fewer than five eligible studies and were not eligible for meta-analysis:

- Vision predicting simulated driving performance
- Vision predicting crashes
- Physical function predicting simulated driving performance

Table B-3. All Cognitive Domains Predicting On-Road Driving Performance

Study Name	Correlation	Lower Limit	Upper Limit	*z*-value	*p*-value
(Eramudugolla et al., 2016)	.23	-.07	.48	1.52	.13
(Douissembekov et al., 2015)	.30	-.17	.65	1.26	.21
(Aksan et al., 2013)	.18	-.01	.36	1.87	.06
(Wood et al., 2013)	.13	.04	.22	2.89	<.01
(Ferreira et al., 2013)	.31	.25	.35	12.60	<.001
(Selander et al., 2011)	.20	-.01	.40	1.87	.06
(Hoggarth et al., 2010)	.13	-.12	.37	1.04	.30
(Stav et al., 2008)	.38	.20	.53	4.04	<.001
(Janke, 2001)	.07	-.13	.26	0.64	.52
(De Raedt & Ponjaert-Kristoffersen, 2000a)	.51	.33	.65	5.03	<.001
(Vaucher, Herzig, et al., 2014)	.42	.27	.56	5.15	<.001
(McCarthy et al., 2009)	.49	.34	.62	5.82	<.001
(Vaucher, Cardoso, et al., 2014)	.17	.03	.31	2.29	.02
(Willstrand et al., 2017)	.19	-.03	.39	1.68	.09
(Anstey & Wood, 2011)	.02	-.10	.14	0.31	.76
(Wood et al., 2008)	.22	.11	.34	3.73	<.001
(Ferreira et al., 2012)	.34	.25	.43	7.02	<.001
OVERALL	**.26**	**.23**	**.29**	**17.06**	<.001

Table B-4. Speed of Processing/Attention Predicting On-Road Driving Performance

Study Name	Correlation	Lower Limit	Upper Limit	*z*-value	*p*-value
(Anstey & Wood, 2011)	-.01	-.14	.11	-.22	.82
(De Raedt & Ponjaert-Kristoffersen, 2000a)	.61	.46	.73	6.38	<.001
(Douissembekov et al., 2015)	.30	-.17	.65	1.26	.21
(Eramudugolla et al., 2016)	.25	-.04	.50	1.68	.09
(Ferreira et al., 2013)	.29	.22	.35	8.50	<.001
(Vaucher, Cardoso, et al., 2014)	.17	.03	.31	2.30	.02
(Willstrand et al., 2017)	.19	-.03	.39	1.68	.09
(Hoggarth et al., 2010)	.11	.04	.18	2.87	<.01
(McCarthy et al., 2009)	.62	.50	.72	7.91	<.001
(Selander et al., 2011)	.21	-.00	.41	1.94	.06
(Janke, 2001)	.12	-.07	.31	1.22	.22
(Vaucher, Herzig, et al., 2014)	.41	.13	.63	2.77	.01
(Wood et al., 2008)	.20	.08	.31	3.27	<.01
(Stav et al., 2008)	.58	.44	.68	7.08	<.001
OVERALL	**.24**	**.20**	**.27**	**12.98**	**<.001**

Table B-5. Executive Function Predicting On-Road Driving Performance

Study Name	Correlation	Lower Limit	Upper Limit	*z*-value	*p*-value
(De Raedt & Ponjaert-Kristoffersen, 2000a)	.43	.24	.59	4.14	<.001
(Eramudugolla et al., 2016)	.26	-.04	.51	1.73	.08
(Ferreira et al., 2013)	.34	.25	.42	7.33	<.001
(Vaucher, Cardoso, et al., 2014)	.17	.02	.30	2.23	.03
(Wood et al., 2013)	.16	.00	.30	1.98	.05
(Selander et al., 2011)	.20	-.02	.39	1.81	.07
(Hoggarth et al., 2010)	.22	.05	.38	2.51	.01
(McCarthy et al., 2009)	.52	.38	.64	6.29	<.001
(Janke, 2001)	.00	-.19	.20	.03	.98
(Vaucher, Herzig, et al., 2014)	.49	.23	.68	3.53	<.001
(Wood et al., 2008)	.24	.12	.35	3.94	<.001
(Stav et al., 2008)	.04	-.15	.23	.41	.68
OVERALL	**.26**	**.22**	**.30**	**11.09**	**<.001**

Table B-6. Dementia Status Predicting On-Road Driving Performance (exploratory)

Study Name	Correlation	Lower Limit	Upper Limit	*z*-value	*p*-value
(Eramudugolla et al., 2016)	.25	-.04	.50	1.71	.09
(Ferreira et al., 2012)	.34	.25	.43	7.02	<.001
(Ferreira et al., 2013)	.34	.25	.43	7.01	<.001
(Wood et al., 2013)	.01	-.21	.23	.07	.94
(Hoggarth et al., 2010)	.11	-.07	.27	1.18	.28
(McCarthy et al., 2009)	.44	.28	.57	5.07	<.001
(Janke, 2001)	.26	.07	.43	2.63	.01
(Vaucher, Herzig, et al., 2014)	.38	.11	.60	2.68	.01
(Stav et al., 2008)	.39	.21	.54	4.05	<.001
OVERALL	**.31**	**.26**	**.36**	**11.86**	**<.001**

Table B-7. All Cognitive Domains Predicting Crashes (exploratory)

Study Name	Correlation	Lower Limit	Upper Limit	*z*-value	*p*-value
(Bieri et al., 2014)	.25	-.02	.48	1.82	.07
(Woolnough et al., 2013)	.04	-.02	.09	1.36	.17
(Edwards et al., 2008)	.17	.08	.26	3.80	<.001
(Horswill et al., 2010)	.03	.01	.04	3.02	<.05
(De Raedt & Ponjaert-Kristoffersen, 2000a)	.06	-.16	.27	.52	.61
OVERALL	**.03**	**.02**	**.05**	**4.06**	**<.001**

Table B-8. All Cognitive Domains Predicting Simulated Driving Performance (exploratory)

Study Name	Correlation	Lower Limit	Upper Limit	*z*-value	*p*-value
(Eramudugolla et al., 2016)	.28	-.01	.52	1.88	.06
(Bélanger et al., 2010)	.55	.14	.80	2.56	.01
(Szlyk et al., 2002)	.53	.14	.78	2.58	.01
(Park et al., 2011)	.26	.09	.41	3.04	<.05
(Cuenen et al., 2016)	.04	-.23	.30	.30	.77
(Choi et al., 2019)	.12	-.14	.36	.89	.37
OVERALL	**.24**	**.13**	**.34**	**4.36**	**<.001**

Table B-9. Speed of Processing Predicting On-Road Driving Performance (exploratory)

Study Name	Correlation	Lower Limit	Upper Limit	*z*-value	*p*-value
(Bélanger et al., 2010)	.55	.14	.80	2.56	.01
(Choi et al., 2019)	.12	-.14	.36	.89	.37
(Eramudugolla et al., 2016)	.30	.01	.54	2.04	.04
(Szlyk et al., 2002)	.58	.20	.80	2.86	<.01
(Cuenen et al., 2016)	.04	-.22	.31	.32	.75
OVERALL	**.24**	**.10**	**.37**	**3.31**	**<.01**

Table B-10. Vision Predicting On-Road Driving Performance (exploratory)

Study Name	Correlation	Lower Limit	Upper Limit	*z*-value	*p*-value
(Wood et al., 2013)	.22	.10	.32	3.63	<.001
(Vaucher, Herzig, et al., 2014)	.11	-.23	.42	.64	.52
(Stav et al., 2008)	.40	.23	.54	4.56	<.001
(Spreng et al., 2018)	.15	-.01	.29	1.84	.07
(McCarthy et al., 2009)	.20	.02	.36	2.14	.03
(Wood et al., 2008)	.10	-.02	.22	1.61	.11
(Hoggarth et al., 2010)	.05	-.20	.30	.41	.68
OVERALL	**.18**	**.12**	**.24**	**5.91**	**<.001**

Table B-11. Physical Function Predicting On-Road Driving Performance (exploratory)

Study Name	Correlation	Lower Limit	Upper Limit	*z*-value	*p*-value
(Hoggarth et al., 2010)	.04	-.21	.29	.32	.75
(Wood et al., 2008)	.01	-.11	.13	.18	.86
(Stav et al., 2008)	.28	.10	.45	3.04	<.05
(Lacherez et al., 2014)	.15	.03	.26	2.44	.02
(Vaucher, Herzig, et al., 2014)	.31	-.01	.57	1.88	.06
(McCarthy et al., 2009)	.33	.16	.48	3.71	<.001
(Eramudugolla et al., 2016)	.11	-.18	.39	.73	.47
OVERALL	**.15**	**.08**	**.21**	**4.43**	**<.001**

Page intentionally left blank.

DOT HS 813 535
March 2024

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

16130-022824-v4a