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Interventions to Improve Older Driver Safety

by

Bernadette A. Fausto

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
School of Aging Studies
College of Behavioral and Community Sciences
University of South Florida

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Keywords: older adults, transportation, driving remediation, functional decline

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DEDICATION

I dedicate this dissertation to my beloved grandmother, Remedios C. Fausto. Thank you for your unconditional love and support and for being the ultimate example of tenacity and resilience.

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ABSTRACT

Increased longevity coupled with age-related declines that compromise driving safety and fragility render older adults as vulnerable road users (Oxley & Whelan, 2008). To address this public health concern, researchers continue to investigate interventions to improve older driver safety. The current dissertation consists of two papers examining: a) the state of the literature on older driver interventions and b) the efficacy of one approach, Useful Field of View cognitive training, to reduce at-fault crash involvement. The first paper sought to identify and quantify the effects of different interventions among older adults on outcomes of crashes, on-road driving performance, self-reported outcomes (errors and crashes), and driving simulator performance in a systematic review and meta-analysis ($k = 31$). Skill-specific interventions (i.e., physical retraining/exercise, visual-perceptual training) and combined approaches demonstrated medium to large effects on driving performance among those trained across studies, *d*s = 0.564–1.061, *p*s < .050. Cognitive training approaches reduced at-fault crashes by almost 30%, $OR = 0.729$, 95% CI [0.553, 0.962], $p = .026$. Education and context-specific approaches were not efficacious to improve driving safety outcomes. The second paper examined the longitudinal impact of adaptive Useful Field of View cognitive training on at-fault crash involvement. Results showed that cognitive training did not significantly reduce at-fault crashes per person-year of travel across 10 years as compared to the control group, $RR = 0.672$, 95% CI [0.326, 1.385], $p = .281$. However, this paper was limited by inadequate power due to a relatively low base rate of at-fault crashes. Future directions include identifying components within skill-specific and combined training approaches that contribute to improved driving safety and evaluating the durability of

adaptive Useful Field of View cognitive training to reduce at-fault crashes among high-risk drivers in an adequately powered study.

CHAPTER ONE:

INTRODUCTION

As our population ages, older drivers will become increasingly common on the roads, raising concerns about safety as well as maintained independence (Anstey, Eramudugolla, Ross, Lautenschlager, & Wood, 2016; Windsor & Anstey, 2006). Although not all older drivers pose risks, evidence suggests that some older adults have a greater risk of crashes (Ball et al., 2006). There is a need for effective older driver interventions to preserve a balance between safety and autonomy. This dissertation aimed to identify and examine effective interventions to sustain safe driving mobility among older adults.

Older Driver Population and Safety Concerns

Older adults make up an increasing proportion of the population (Bloom, Canning, & Lubet, 2015). Likewise, older drivers comprise the fastest growing segment of the total licensed driver population (J. M. Lyman, McGwin Jr., & Sims, 2001; NHTSA, 2017). In 2016, 80% of older adults aged 70 and older were licensed drivers, representing 12% of licensed drivers of all ages (Federal Highway Administration, 2017). Whereas the number of older drivers increased by 33 percent from 2006 to 2015, the total number of licensed drivers increased by only eight percent during the same time frame (NHTSA, 2017). As the number of older drivers continues to grow, concerns regarding the safety of these drivers will become increasingly salient.

Older Driver Crashes Will Increase

Some population-based evidence demonstrates that on a per licensed driver and per-mile-driven basis, older drivers' crash involvement rates are the highest compared to other age groups

(Insurance Institute for Highway Safety, 2017). By 2030, the number of police-reported crashes among older drivers is projected to increase by 178 percent (S. Lyman, Ferguson, Braver, & Williams, 2002). Another projection purports a 286 percent increase in fatal crash involvements among older drivers from 1995 to 2025, even after taking into account other factors such as technological advances, migration patterns, driving behavior, infrastructure, and personal health and wealth (Hu, Jones, Reuscher, Schmoyer, & Truett, 2000). In addition, older drivers (65+) are expected to account for approximately 40 percent of all crashes and more than half of the fatal crashes by 2030 (S. Lyman et al., 2002). This evidence is consistent with findings that older drivers are more vulnerable to injury and death in crashes than their younger counterparts due to increased fragility (Langford & Koppel, 2006; Li, Braver, & Chen, 2003).

Age-Related Declines Impair Driving

The current dissertation was guided by the common cause theory of cognitive aging and the multifactorial model of enabling driving safety. According to the common cause theory of cognitive aging, an unknown factor may account for simultaneous age-related declines in cognitive and non-cognitive (sensory and physical function) processes, which in turn may impact everyday functioning, such as driving abilities (Christensen, Mackinnon, Korten, & Jorm, 2001). In line with this hypothesis, the multifactorial model of enabling driving safety (Anstey, Wood, Lord, & Walker, 2005) purports such age-related changes increase the likelihood of crashes. These include age-related cognitive (Verhaeghen & Cerella, 2002; Wasylyshyn, Verhaeghen, & Sliwinski, 2011), sensory (Owsley & McGwin Jr., 1999; Owsley, Stalvey, Wells, Sloane, & McGwin Jr., 2001; Owsley, Wood, & McGwin Jr., 2015), and motor declines (Cross et al., 2009; Sims, Owsley, Allman, Ball, & Smoot, 1998). As a few examples, older drivers with poor Useful Field of View performance, a measure of speed of processing and visual attention, are twice as likely to incur a future crash over five years (Ball et al., 2006). Vision impairment, as indicated by contrast sensitivity, is significantly associated with crash involvement (Owsley et al., 2001). As another example, older drivers with a history of falls are more likely to incur a subsequent at-fault crash (Ball et al., 2006). A synthesis of such factors is provided in this dissertation. Fortunately, some of these factors may be amenable to intervention.

Self-Regulation Does Not Reduce Crash Risk

Although age-related declines occur, older adults may not be aware of these changes or how they affect driving. Some older drivers fail to recognize their own declines or overestimate their driving safety (Charlton et al., 2006; Freund, Colgrove, Burke, & McLeod, 2005; Wood, Lacherez, & Anstey, 2012). In the event that older adults are aware of these declines, self-regulating their driving (e.g., avoiding driving on highways or at night) is not sufficient to mitigate crash risk (Ross et al., 2009). Furthermore, research on educational programs targeting self-awareness of functional declines suggests that although use of self-regulation strategies increases, such changes may not translate to improved driving safety (i.e., reduced crashes) (Owsley, McGwin Jr, Phillips, McNeal, & Stalvey, 2004; Owsley, Stalvey, & Phillips, 2003), thus identifying effective interventions and ways to promote driving safety and mobility are needed.

Driving Importance

Much of the existing research focuses on identifying unsafe older drivers at risk for crash involvement to enforce driving cessation (Wang & Carr, 2004). However, the ability to drive is essential to maintained independence for the majority of older drivers (Coughlin, 2000; Oxley & Whelan, 2008). Older adults in the US report the personal automobile as the preferred mode of transportation (Alsnih & Hensher, 2003; Bureau of Transportation Statistics, 2003; Coughlin,

2000) and associate driving with independence (Oxley & Whelan, 2008). In addition, more recent older driver cohorts accrue greater annual mileages and make more trips than previous cohorts, suggesting increasing reliance on personal automobiles (e.g., accessing health care, goods, and services, participating in social and community events) (Coughlin, 2000).

Given the importance of driving mobility for maintained independence (Metz, 2000), not surprisingly, driving cessation in later life has been linked to a number of adverse outcomes. Driving cessation is related to decreased social engagement and functioning (Curl, Stowe, Cooney, & Proulx, 2014; Edwards, Lunsman, Perkins, Rebok, & Roth, 2009); declines in self-rated health (Edwards, Lunsman, et al., 2009); decreased physical performance (Edwards, Lunsman, et al., 2009); increased depressive symptoms (Marottoli et al., 1997); reduced out-of-home activity (Harrison & Ragland, 2007; Marottoli et al., 2000); and decreased life satisfaction (Harrison & Ragland, 2007). Further, driving cessation is an independent risk factor for long-term care entry (Freeman, Gange, Muñoz, & West, 2006). Thus, concerns about safety must be balanced with older adults' mobility, health, and quality of life.

Current Dissertation

In order to balance public safety concerns with older adults' need for autonomy, interventions targeting older driver safety deserve consideration. This dissertation consists of two papers that employed systematic review, meta-analytic, and regression methods to explore the efficacy of older driver interventions. The first paper systematically reviewed and quantified in a meta-analysis the evidence of older driver interventions on defined outcomes of crashes, on-road driving performance, driver-reported outcomes (i.e., self-reported crashes, self-reported driving errors), and driving simulator performance. The second paper examined the longitudinal effect of adaptive Useful Field of View cognitive training on at-fault crash involvement over 10 years.

CHAPTER TWO:

A SYSTEMATIC REVIEW AND META-ANALYSIS OF OLDER DRIVER INTERVENTIONS

Introduction

Public health work aims to prevent disease and injuries in the general population (American Public Health Association, 2016). Much of this work is achieved by researching evidence-based interventions to improve health, educating health professionals, and implementing policies to promote safe and healthy behaviors (American Public Health Association, 2016; Stover & Bassett, 2003). With the burgeoning of the baby boomer cohort, older driver safety is a growing public health concern. Increasing longevity (Kontis et al., 2017) coupled with older adults' reliance on personal vehicles to maintain mobility (Coughlin, 2000) suggest that modern cohorts of older adults drive longer than previous cohorts. Although there is evidence of a decline in motor vehicle crash (MVC) rates per vehicle miles traveled and per licensed driver for the total driving population (National Highway Traffic Safety Administration, 2016), MVCs are the second leading cause of unintentional deaths in older adults ages 65 and older (Centers for Disease Control and Prevention, 2017). Additionally, fatal MVC rates per vehicle mile traveled increase starting at age 70 and are highest among older drivers age 80 and over (Insurance Institute for Highway Safety, 2017). These trends underscore public health concerns of safety, well-being, and autonomy of older adults as well as highlight the pressing need for efficacious interventions.

Previous systematic (Justiss, 2013; Korner-Bitensky, Kua, von Zweck, & Van Benthem, 2009; Kua, Korner-Bitensky, Desrosiers, Man-Son-Hing, & Marshall, 2007) and literature reviews (Golisz, 2014) have summarized the evidence of older driver interventions. To our knowledge, there is one quantitative meta-analysis of the efficacy of older driver interventions to reduce crashes (Desapriya, Subzwari, Scime, & Pike, 2008) . This systematic review and meta-analysis sought to summarize and quantify the efficacy of older driver interventions to improve the following driving-related outcomes: MVCs, on-road driving performance, driver-reported outcomes (i.e., self-reported driving errors, self-reported crashes), and driving simulator performance.

Factors to Consider in Older Driver Safety

Many factors are associated with MVC involvement, driving performance, driver-reported outcomes, and driving simulator performance (Karthaus & Falkenstein, 2016). Some may not necessarily be amenable to remediation but could affect responsiveness to behavioral interventions such as older age (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Ball et al., 2006; Cross et al., 2009; Lee, Lee, Cameron, & Li-Tsang, 2003), being male (Ball et al., 2006; Bauer, Adler, Kuskowski, & Rottunda, 2003; Cross et al., 2009; Hu, Trumble, Foley, Eberhard, & Wallace, 1998), a history of crash involvement (Sims, McGwin Jr, Allman, Ball, & Owsley, 2000), and chronic medical conditions including eye diseases (e.g., glaucoma and cataract) (D. J. Foley, Wallace, & Eberhard, 1995; Haymes, LeBlanc, Nicolela, Chiasson, & Chauhan, 2007; Hu et al., 1998; Marshall & Man-Son-Hing, 2010; McGwin Jr., Sims, Pulley, & Roseman, 2000; Owsley, Stalvey, Wells, & Sloane, 1999; Sims et al., 2000; Sims et al., 1998). Other factors associated with driving safety are potentially amenable to behavioral interventions. A history of falls (Ball et al., 2006; Cross et al., 2009; Huisingh, McGwin Jr, Orman, & Owsley, 2013;

Margolis et al., 2002; for a review, see Scott et al., 2017) or falls risk (Gaspar, Neider, & Kramer, 2013) indicates greater likelihood for adverse driving safety outcomes (Ball et al., 2006; Classen, Wang, Crizzle, Winter, & Lanford, 2013; Emerson et al., 2012; Friedman, McGwin Jr, Ball, & Owsley, 2013; Mathias & Lucas, 2009). For example, Margolis et al. (2002) reported that older drivers with a fall in the previous year had 1.53 times the risk of a MVC. In another study, participants who sustained a fall were more likely to self-report driving difficulties (e.g., difficulty changing lanes; J. M. Lyman et al., 2001). Furthermore, high falls risk individuals (as determined by the Physiological Profile Assessment composite score that combines contrast sensitivity, hand reaction time, proprioception, leg muscle strength, and postural sway performance) demonstrate poorer driving simulator performance (Gaspar et al., 2013).

Age-related changes in cognition (Ball et al., 1993; Clay et al., 2005; Cross et al., 2009; Goode et al., 1998; Haymes et al., 2007; Mathias & Lucas, 2009; Owsley et al., 1998; Rubin et al., 2007; Sims et al., 2000; Sims et al., 1998) and visual-perceptual abilities are also indicative of older driver safety outcomes. A meta-analysis revealed that poorer speed of processing for visual attention tasks (as measured by the Useful Field of View Test) is associated with negative driving outcomes (Cohen's $d = 0.945$) including state-recorded MVCs, on-road driving performance, and driving simulator performance. In addition, age-related changes in visual-perceptual abilities including declines in visuomotor speed and attention set-switching (e.g., Trail Making Test B; Classen et al., 2013; Emerson et al., 2012; Friedman et al., 2013; Mathias & Lucas, 2009), and visual perception (e.g., the Motor-Free Visual Perception Test; Ball et al., 2006) are also associated with driving safety among older adults. For example, poorer performance on Trail Making Test B is associated with on-road driving test failure (Classen et al., 2008) and a greater number of at-fault safety errors (e.g., erratic steering, unsafe intersection behavior) during an on-road driving task (Uc et al., 2006). Individuals with poorer Motor-Free Visual Perception performance are more likely to have a history of MVC involvement (Friedman et al., 2013) and are 2.1 times more likely to incur a future crash (Ball et al., 2006). Fortunately, such age-related changes in physical function (i.e., high falls risk), cognition, and visual-perceptual abilities indicative of driving safety risks can be targeted through intervention.

Interventions to Counter Age-Related Declines

Several types of older driver interventions that attempt to attenuate the aforementioned factors have been examined in the literature (Korner-Bitensky et al., 2009; Kua et al., 2007). These include (1) physical retraining/exercise (Marottoli, Allore, et al., 2007); (2) visual-perceptual training (Horswill, Kemala, Wetton, Scialfa, & Pachana, 2010); (3) cognitive training (Ball, Edwards, Ross, & McGwin, 2010; Roenker, Cissell, Ball, Wadley, & Edwards, 2003); (4) education (Eby, Molnar, Shope, Vivoda, & Fordyce, 2003; Gaines, Burke, Marx, Wagner, & Parrish, 2011; Owsley, McGwin Jr, et al., 2004; Owsley et al., 2003); and (5) combined approaches (Bédard et al., 2008; Marottoli, Van Hess, et al., 2007).

Based on evidence summarized in four published systematic reviews on older driver interventions, skill-specific training (e.g., physical retraining, visual-perceptual training) is a promising approach to improve driving safety (Golisz, 2014; Korner-Bitensky et al., 2009; Kua et al., 2007; Unsworth & Baker, 2014). Additionally, to our knowledge, there is one existing meta-analysis on older driver interventions to reduce crashes and improve driving performance (Desapriya et al., 2008). Given the aforementioned older driver trends of increased fatal MVCs and longevity of driving independence, updated evidence for the efficacy of driving interventions is warranted, particularly evidence that has surfaced since 2014. To this end, the efficacy of the aforementioned interventions (i.e., physical retraining, visual-perceptual training, cognitive training, education, and combined approaches) were examined and synthesized by conducting a systematic review and meta-analysis of older driver interventions targeting driving-related outcomes such as crashes (i.e., overall, at-fault, and injurious crashes), driving performance (i.e., on-road driving performance), driver-reported outcomes (e.g., self-reported crashes, self-reported driving errors), and/or driving simulator performance.

Method

Identification and Inclusion of Relevant Studies

A comprehensive review of the scientific literature was performed between January 22, 2019 and February 12, 2019. This systematic literature review and meta-analysis was prospectively registered with AsPredicted (#24322; see Appendix A). The *a priori* pre-registration specified that studies had to meet the following inclusion criteria: 1) examined older adult participants (55 years of age and older); 2) conducted a randomized controlled trial (RCT) that examined a driving intervention; and 3) published in a peer-reviewed journal. In addition, the studies included were required to examine one or more of the following driving-related outcomes: crashes, on-road driving performance, driver-reported outcomes (i.e., self-reported driving errors, self-reported crashes), or driving simulator performance. The PubMed, PsycINFO, Web of Science, and Cochrane Central Register for Controlled Trials databases were searched using the following combinations of terms relevant to the concepts of older adults, older driver interventions, and driving-related outcomes (driver safety, driving performance, driver-reported outcomes, and driving simulator performance) (see Table 1 for comprehensive list of search terms).

The number of articles identified and selected for inclusion in analyses are detailed in Figure 1 per Preferred Reporting Items for Systematic Reviews and Meta-Analyses (a.k.a., PRISMA) guidelines. Of the 4,268 records screened, 4,074 were excluded based on title and abstract alone. Four additional records were identified through other sources: one through citation alert (Urlings et al., 2019) and three through other review articles (Laurie, Fisher, & Glaser, 1999; McCoy, Tarawneh, Bishu, Ashman, & Foster, 1993; Ostrow, Shaffron, & McPherson, 1992). The author (BF) and a doctoral student rater (PA) screened the resulting 198 full-text articles for inclusion and reviewed the full-text articles for eligibility. Of these, 172 articles were excluded: 128 were not RCTs; 33 did not examine older adults; one declined to send data; and 10 were RCTs but did not assess the driving safety outcomes of interest (i.e., crashes, on-road driving performance, driver-reported outcomes [self-reported driving errors, self-reported crashes], or driving simulator performance). Specifically, four examined driving mobility (Coxon et al., 2017; Edwards, Myers, et al., 2009; Jones, Cho, Abendschoen-Milani, & Gielen, 2011; Ross et al., 2016); two examined driving cessation (Edwards, Delahunt, & Mahncke, 2009; Ross, Freed, Edwards, Phillips, & Ball, 2017); two examined driving knowledge and safety behaviors (e.g., "How often do you wear a seat belt?") (Jones et al., 2012; Uribe-Leitz et al., 2015); one examined self-regulatory driving practices and avoidance (Owsley et al., 2003); and one examined hazard perception response time (Horswill, Falconer, Pachana, Wetton, & Hill, 2015`) and were thus excluded from analyses.

Nineteen of the 70 RCTs published in peer-reviewed journals considered older drivers as 50 years of age and older. Thus, in order to be more inclusive, the criteria were changed to consider studies that examined adults 50 years of age and older. Twenty-six full-text articles met inclusion criteria.

A subsequent search of the grey literature was conducted with the guidance of a qualified librarian (CD) to identify conference proceedings, theses, dissertations, and ongoing or unpublished trials. The following sources were searched for grey literature using the same search terms in Table 1: Clinical Trials (www.clinicaltrials.gov), Open Grey (http://www.opengrey.eu), ProQuest (https://pqdtopen.proquest.com/), and the AgeLine database (https://health.ebsco.com/products/ageline). The grey literature search yielded five additional sources (three doctoral dissertations, one conference proceeding, and one technical report) described in qualitative synthesis only.

The PEDro scale (de Morton, 2009) was implemented to rate the quality of the 26 included studies on an 11-point scale by two independent raters (BF and PA). The PEDro Scale provides a rating indicating the internal validity and methodological quality of the study with one point allocated for each of the following: 1) specification of inclusion criteria; 2) randomization; 3) concealed allocation; 4) baseline comparability of experimental and control groups on prognostic indicators; 5) blinding of participants; 6) blinding of therapists who administered the intervention; 7) blinding of assessors who measured at least one key outcome; 8) whether key outcomes were obtained from at least 85% of subjects; 9) whether intention-to-treat analysis was performed; 10) whether the results of between-group statistical comparisons are reported for at least one key outcome; and 11) whether the study provides both point measures and measures of variability for at least one key outcome (see Appendix B). PEDro results were interpreted following Foley and colleague's quality assessment (N. C. Foley, Teasell, Bhogal, & Speechley, 2003) where studies below 4 are considered "poor," 4 to 5 "fair," 6 to 8 considered "good," and scoring 9 and above are considered methodologically "excellent." Table 2 details the list of included studies including study sample size and characteristics, intervention type(s), outcome measures, and PEDro ratings of both raters. If discrepancies in category arose (e.g., BF rating of "good" and PA rating of "poor"), the study was re-reviewed to reach a consensus rating. Two studies were re-reviewed by the raters following category discrepancy with 100% agreement after re-review. The interrater reliability between the two raters was .92 with an average rating of 8.00 (*SD* = 1.68) across included studies.

Measures

Crashes. In order to understand the ecologically valid impact of driving interventions, crashes are of great relevance, especially at-fault crashes (Owsley et al., 2015). However, crashes in general are rare events and at-fault crashes are even rarer, prompting some investigators to use overall crashes as the outcome measure (Owsley et al., 2015). Thus, at-fault crashes and overall crashes (at-fault and no-fault crashes combined) were considered as outcomes. In addition, crashes can be quantified as injurious crashes, crashes in which anyone in the involved accident sustained an injury. Two studies examined the effects of an intervention on crashes, one on the effects of an educational program to reduce overall crashes (Owsley, McGwin, Phillips, McNeal, & Stalvey, 2004) and the other on three cognitive training approaches (speed of processing, reasoning, memory) to reduce at-fault crashes (Ball et al., 2010).

Driving performance. To examine whether interventions improved the task of driving, outcomes for driving performance were considered. On-road driving performance can be measured in several ways including using instrumented vehicles (e.g., with multiple censors and cameras in the vehicle to detect driver behavior and vehicle kinematics); naturalistic driving techniques to measure performance in the context of one's everyday activities; and in a personal vehicle on a closed-road circuit or on-road circuit. Eighteen studies examined on-road driving performance as outcomes (Anstey, Eramudugolla, Kiely, & Price, 2018; Bédard, Isherwood, Moore, Gibbons, & Lindstrom, 2004; Bédard et al., 2008; Casutt, Theill, Martin, Keller, &

Jäncke, 2014; Crotty & George, 2009; Hay, Adam, Bocca, & Gabaude, 2016; Jacobs et al., 1997; Lavallière, Simoneau, Tremblay, Laurendeau, & Teasdale, 2012; Marottoli, Allore, et al., 2007; Marottoli, Van Hess, et al., 2007; Mazer et al., 2015; Mazer et al., 2003; McCoy et al., 1993; Nozawa et al., 2015; Ostrow et al., 1992; Porter, 2013; Roenker et al., 2003; Sawula et al., 2018).

Driver-reported outcomes. Self-reported crashes and self-reported driving errors (e.g., violations, citations, risky driving behavior such as speeding, near-misses) were included to assess the effect of interventions on subjective driving safety. One study used self-reported crashes (Anstey et al., 2018). Stowe et al. (2015) used the Manchester Driving Behavior Questionnaire (LaJunen, Parker, & Summala, 2004), a 27-item measure of self-reported driving errors. Another study (Gaines et al., 2011) used a variant of the Manchester Driving Behavior Questionnaire called the Driving Questionnaire, a 26-item measure of self-reported driving errors (Eby, Molnar, Nation, Shope, & Kostyniuk, 2006).

Driving simulator performance. Driving simulators involve a virtual reality road test (Owsley et al., 2015). Performance metrics can be programmed into the simulator for automatic data collection on the simulated drive such as lane deviations, mean driving speed, mean following distance, and crashes. Four studies assessed driving simulator performance (Cuenen et al., 2016; Pope et al., 2018; Roge, Ndiaye, & Vienne, 2014; Urlings et al., 2019).

Statistical Analysis

Correlations, means, and standard deviations, odds ratios, rate ratios, and/or sample sizes for the intervention and control groups as well as *p* values were extracted from included studies and entered into Comprehensive Meta-Analysis (CMA) version 3.0 (Biostat, Englewood, NJ). If data could not be extracted from publications, the publication author was contacted to obtain the raw summary data.

To synthesize findings, intervention programs were grouped and examined by content types: (1) physical retraining/exercise; (2) visual-perceptual training; (3) cognitive training; (4) education; and (5) combined approaches as well as the aforementioned primary outcome domains (crashes, driving performance, self-reported driving outcomes, and driving simulator performance). The interventions were classified according to previous systematic reviews (Golisz, 2014; Korner-Bitensky et al., 2009; Kua et al., 2007).

Physical retraining/exercise interventions may involve a regimen including but not limited to conditioning, strength, coordination, flexibility, balance, aerobic fitness, and/or anaerobic fitness. Visual-perceptual approaches may involve repeated exposure to stimuli to discriminate features such as orientation, direction of motion, and spatial frequency (McMains & Kastner, 2011). Visual-perceptual training is considered to tap into bottom-up, stimulus-driven demands in the environment (Gold & Watanabe, 2010). Examples of such training might be exercises to help improve figure-ground discrimination. Visual-perceptual training may be in the form of paper- and pencil workbooks or computerized programs.

In contrast, cognitive training involves top-down, goal-oriented processing of stimuli in the environment and may be categorized as strategy-based (e.g., learning mnemonics to support recall) or process-based (e.g., training speed of processing for visual attention tasks through adaptive exercises; Lustig, Shah, Seidler, & Reuter-Lorenz, 2009). Education approaches may consist of web- or classroom-based lectures of driving topics such as road rules (e.g., AARP[1] Smart Driver™) or car demonstrations to show optimal hand positioning on steering wheel and distance of driver to steering wheel (e.g., CarFit[2]). Combined training approaches incorporate two or more components such as physical retraining plus education.

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[1] American Association of Retired Persons; https://www.aarpdriversafety.org/
[2] https://www.car-fit.org/

Context-specific skills training (i.e., simulator training, on-road training) emerged ad hoc as an additional intervention type during the systematic review. Context-specific skills training may take place on the road in an instrumented car, on a closed road circuit, on a driving simulator platform (e.g., NADS[3] miniSim™), or on a personal computer. The context-specific training provides an environment similar to that of the actual driving environment. An example of context-specific training is rearview and blind spot inspection training in a driving simulator (Lavallière et al., 2012).

If possible, Cohen's *d* effect sizes and forest plots were calculated and depicted, respectively, for each intervention type (physical retraining/exercise, visual-perceptual training, cognitive training, education, context-specific skills training, combined approaches) on each outcome domain (crashes, driving performance, driver-reported outcomes, driving simulator performance) relative to the control group using random effects. Most studies included multiple metrics to assess an outcome. For example, simulator driving performance metrics within a study may include mean driving speed, mean following distance, and standard deviation of lane positioning. In such cases, effect sizes for the simulator driving performance outcome were averaged within study creating a composite measure.

If there were two studies on a particular intervention and outcome, an effect was calculated (Valentine, Pigott, & Rothstein, 2010). If an active control group and wait-list/no-contact control group were both used in a trial, the active control group was used as a comparison to the intervention group. If studies presented data using both young and older adults, only data from the older adult group was extracted and analyzed. Cohen's *d* effect sizes were categorized as small (d = 0.2), medium (d = 0.5), or large (d = 0.8) (Cohen, 1988). If effect

[3] National Advanced Driving Simulator

sizes could not be calculated due to too few studies (e.g., only one study examined education on crashes), then the effect was described narratively in qualitative analyses.

Publication bias was determined by inspection of funnel plots and calculation of Egger's regression. Funnel plots and Egger's regression could only be calculated if there were three or more studies included in the analysis of a particular intervention on outcome (e.g., if there are three or more studies of physical retraining/exercise approaches on driving performance, the funnel plot and Egger's regression can be produced). If the funnel plot indicated asymmetry and/or if Egger's regression coefficient was significant ($p < .05$) indicating publication bias, Duval and Tweedie's trim and fill correction was used to adjust effect sizes (i.e., to estimate the number of missing studies from the funnel plot; Duval & Tweedie, 2000). In such cases, both unadjusted and adjusted effect sizes were reported. Each outcome domain was assessed for heterogeneity using Cochran's *Q*-statistic as well as the I^2-statistic. If the *Q*-statistic was significant, therefore indicating heterogeneity of the studies, the I^2-statistic was also examined using values of 25% (low heterogeneity), 50% (medium heterogeneity) and 75% (high heterogeneity). If possible, fail-safe *N*s (N_{fs}) were reported for each intervention by outcome analysis to depict how many studies with null results would be needed to render a significant effect non-significant.

Results

To be included in quantitative meta-analyses, studies had to 1) examine a driving intervention in a 2) randomized controlled trial among 3) older adult participants (50 years of age and older) and 4) be published in a peer-reviewed journal. We included 26 studies involving a total of 1,676 participants (training $n = 805$; control = 871) that examined the efficacy of physical retraining/exercise ($k = 3$), visual-perceptual training ($k = 2$), cognitive training ($k = 9$), education (k = 7), context-specific training (k = 5), and/or combined training approaches (k = 7). Some studies examined the effects of more than one intervention compared to a control group in which case intervention versus control comparisons were considered unique (e.g., Nozawa et al., 2015, in-vehicle cognitive training versus cognitive stimulation and computer-based cognitive training versus cognitive stimulation were considered separate effect sizes).

To be included in qualitative analyses, studies had to meet the aforementioned criteria except for being published in a peer-reviewed journal. Thus, unpublished doctoral dissertations, conference proceedings, and technical/government reports were considered. In addition to the 26 studies included in meta-analyses (see Table 2), five additional studies were identified via grey literature search and are described qualitatively and synthesized with quantitative findings (Belchior, 2007; Chattha, 2010; Gaspar, Neider, Simons, McCarley, & Kramer, 2012; Lindstrom, 2009; Seidler et al., 2010). Grey literature studies were not added to quantitative analyses as there are no established guidelines to incorporate grey literature into reviews (Mahood, Van Eerd, & Irvin, 2014). However, grey studies may still be synthesized qualitatively to provide a more comprehensive view of the available literature (Mahood et al., 2014). Results are reported quantitatively for included peer-reviewed studies and synthesized qualitatively with any grey literature studies by outcome below.

Crashes

No studies examined physical retraining/exercise, visual-perceptual training, context-specific training or combined approaches on crashes as the outcome.

Cognitive training. One study examined the efficacy of three types of cognitive training relative to a no contact control group to reduce at-fault crashes and thus, the effects of each training type (i.e., speed of processing training, memory training, reasoning training) were entered in analyses as three separate studies (Ball et al., 2010). The funnel plot (see Figure 2) and Egger's regression, p = .319, did not reveal evidence of publication bias. Results indicated low heterogeneity, $I^2 < 0.001$, $Q(2) = 1.846$, p = .397 and medium, significant effects of cognitive training to reduce at-fault crashes, $OR = 0.729$, p = .026, $N_{fs} = 2$ (see Figure 3 for forest plot).

Speed of processing training involved repeated practice of exercises to identity and locate stimuli in increasingly difficult displays. The reasoning training group worked on pattern recognition and everyday problem solving. Memory training consisted of teaching methods of support later recall (e.g., mnemonic strategies to remember word lists). Participants completed ten 60-minute training sessions of their assigned intervention two times a week for five weeks or underwent an equivalent no contact period. Results from Ball et al. (2010) showed only speed of processing training significantly reduced at-fault crash involvement per person-year and person-mile across six years both before and after controlling for age, sex, race, education, depression, self-rated health, mental status, vision, and site by almost 50%. Reasoning training significantly reduced at-fault crashes only after covariate adjustment, $RR = 0.440$, 95% CI [0.240, 0.820], $p <$ .050. Memory training did not result in lower rates at-fault crashes as compared to the no contact control group.

Education. Only one study examined the efficacy of education to reduce crashes and is thus described qualitatively (Owsley, McGwin, et al., 2004). Older drivers with slowed visual speed of processing were randomized to either an educational curriculum led by a health educator to promote self-awareness of visual impairments plus usual care or a usual-care control group (N = 403). At two-year follow-up, the education group did not differ significantly from the control group in overall crash rates per person-years, *RR* = 1.080, 95% CI [0.710, 1.640], $p >$ .050 or per person-mile of travel, *RR* = 1.400, 95% CI [0.920-2.120], $p > .050$.

Driving Performance

Physical retraining/exercise. Three studies examined the effects of physical retraining/exercise interventions for on-road driving performance (Marottoli, Allore, et al., 2007; McCoy et al., 1993; Ostrow et al., 1992). Visual inspection of the funnel plot and calculation of Egger's regression, $p = .295$, did not indicate publication bias (see Figure 4 for funnel plot). There was no significant heterogeneity in the on-road driving performance outcome: $I^2 = 45.484$, $Q(2) = 3.669$, $p = .160$. Results showed a significant medium improvement indicating that those who completed physical retraining/exercise interventions had better on-road driving performance than controls, $d = 0.567$, $p = .017$, $N_{fs} = 8$ (see Figure 5 for forest plot).

Visual-perceptual training. Two studies examined whether visual-perceptual training improved on-road driving performance. Funnel plots, Egger's regression, and N_{fs} could not be calculated with only two included studies. Overall, those who completed visual-perceptual training outperformed controls by a magnitude of $d = 1.061$, $p = .002$ and there was not significant heterogeneity, $I^2 < 0.001$, $Q(1) = 0.948$, $p = .330$ (see Figure 6 for forest plot).

Crotty and George (2009) examined the efficacy of a type of visual-perceptual training using Dynavision ($n = 13$) to improve on-road driving performance as compared to a wait-list control group ($n = 13$) among older adults with a history of stroke. The Dynavision training involved self-paced 40-minute sessions facilitated by an occupational therapist held three times a week for six weeks. Participants had to respond as quickly and accurately as possible by pressing an illuminated button among 64 buttons arranged in five concentric rings. As performance on this task improved, the amount of time to locate the illuminated button and respond decreased. The outcome was a pass or fail rating on a standardized on-road driving assessment by a driving instructor and occupational therapist conducted in a dual-controlled vehicle. Results showed no significant difference in passing versus failing the on-road driving assessment between groups, $d = 0.749$, $p = .233$, but the effect size favored improvement following visual-perceptual training.

McCoy et al. (1993) examined the efficacy of a self-administered home-based training workbook of visual-perceptual training exercises among community-dwelling older adults. Exercises included figure-ground discrimination, visual closure, and spatial relationship tasks. The training group was instructed to work on the exercises 20 minutes per day, four times a week for eight weeks. The control group was a no-contact control group. The outcome measure was performance on a standardized 19-km on-road driving route adjudicated by a certified driving education expert on a scale of 0 (lowest) to 21 (highest) points. The training group demonstrated better post on-road driving performance as compared to the control group, $d = 1.435$, $p = .007$. Despite methodological heterogeneity, these studies combined showed an overall improvement of on-road driving performance as compared to the control groups.

Cognitive training. Five studies examined the effects of cognitive training on driving performance (see Table 2 for individual study details; Casutt et al., 2014; Mazer et al., 2003; Nozawa et al., 2015 [a. in-vehicle cognitive training and b. computer-based cognitive training]; Roenker et al., 2003). Cognitive training types were varied including attention training (Casutt et al., 2014), speed of processing training (Mazer et al., 2003; Roenker et al., 2003), and in-vehicle and computer-based training on combined speed, executive control, and working memory training (Nozawa et al., 2015). There was no evidence of publication bias according to the funnel plot (see Figure 7) or Egger's regression, $p = .547$. There was no significant heterogeneity, $I^2 = 16.099$, $Q(4) = 4.768$, $p = .312$ or effects of cognitive training on on-road driving performance, $d = -0.150$, $p = .330$, $N_{fs} = 0$ (see Figure 8 for forest plot).

Education. Four studies examined the effects of education on on-road driving performance (Bédard et al., 2004; Jacobs et al., 1997; McCoy et al., 1993; Porter, 2013). Egger's regression, $p = .511$ and funnel plot did not indicate publication bias (see Figure 9 for funnel plot). There was not significant heterogeneity, $I^2 = 36.700$, $Q(3) = 4.739$, $p = .192$. Meta-analyses revealed no significant effect of education on the outcome of driving performance, $d = 0.381$, $p = .148$, $N_{fs} = 0$ (see Figure 10 for forest plot), but effect size was in favor of improvement.

Context-specific training. Four studies examined context-specific training on driving performance (Casutt et al., 2014; Jacobs et al., 1997; Mazer et al., 2015; Roenker et al., 2003). Egger's regression, $p = .341$, and the funnel plot did not show evidence of publication bias (see Figure 11 for funnel plot). There was significant heterogeneity, $I^2 = 68.429$, $Q(3) = 9.502$, $p = .023$ and no effect of context-specific training on driving performance, $d = 0.217$, $p = .510$, $N_{fs} = 0$ (see Figure 12 for forest plot).

Combined training approaches. Ten studies examined the effects of combined training approaches on driving performance (Anstey et al., 2018 [a. education & on-road training, b. education, simulator training, & on-road training] ; Bédard et al., 2008; Hay et al., 2016; Lavallière et al., 2012; Marottoli, Van Hess, et al., 2007; McCoy et al., 1993 [a. education & physical retraining/exercise, b. education & visual-perceptual training]; Porter, 2013; Sawula et al., 2018 [a. education & on-road training, b. education, simulator training, & on-road training]) and showed significant, large improvements relative to control conditions, $d = 0.842$, $p < .001$, $N_{fs} = 153$. The funnel plot and Egger's regression, $p = .041$ reflected publication bias (see Figure

13 for funnel plot). Thus, Duval and Tweedie's trim and fill correction was applied after estimating one study was missing from the funnel plot. After correction, combined training approaches showed significant, medium-sized improvements relative to control conditions, d = 0.784, $p < .001$ (see Figure 14 for forest plot and details of combined interventions).

Across studies that employed combined training approaches, there was significant heterogeneity, $I^2 = 64.481$, $Q(9) = 25.339$, $p = .003$. This heterogeneity was further investigated by the following subgroup analyses: nature of the intervention (context-specific plus other training vs. skill-specific plus other training), quality of the study (excellent vs. good or below), type of control condition (active vs. no contact control), and type of outcome (calculated composite vs. holistic driving performance measure).

Effects of combined approaches were quantified by studies that used context-specific (e.g., on-road training) plus other training (e.g., education) ($k = 7$) and by studies that used skill-specific (e.g., physical retraining/exercise) plus other training (e.g., education) ($k = 3$). Among studies using context-specific plus other training, there was not significant heterogeneity, $I^2 = 51.578$, $Q(6) = 12.391$, $p = .054$. There were significant medium improvements of context-specific plus other training, $d = 0.793$, $p < .001$. Among studies using skill-specific plus other training, there was high heterogeneity, $I^2 = 84.249$, $Q(2) = 12.698$, $p = .002$. There were not significant, large improvements of skill-specific plus other training on driving performance, d = 1.044, $p = .074$ (see Figure 15 for forest plot).

Another aspect that may account for heterogeneity in combined training effects on driving performance is the methodological quality of included studies. Studies were grouped by excellent quality (i.e., PEDro score 9 or greater) vs. good to poor quality (e.g., PEDro score 8 or below). Studies with excellent quality ($k = 3$) showed no significant heterogeneity, $I^2 < 0.001$,

$Q(2) = 0.678$, $p = .712$ and small significant improvements on driving performance, $d = 0.423$, $p = .029$. Studies with good quality or below ($k = 7$) showed significant medium heterogeneity, $I^2 = 72.371$, $Q(6) = 21.716$, $p = .001$ and significant large improvements on driving performance, $d = 1.048$, $p < .001$ (see Figure 16 for forest plot).

Studies with combined approaches were also quantified by the type of control condition (active control group vs. no contact control group). There was significant heterogeneity among studies with active control groups ($k = 7$), $I^2 = 65.285$, $Q(6) = 17.284$, $p = .008$. Studies with active control groups showed medium-sized, significant improvements on driving performance, $d = 0.722$, $p < .001$. Studies with no contact control groups ($k = 3$) indicated not significant heterogeneity, $I^2 = 59.317$, $Q(2) = 4.916$, $p = .086$ and significant large improvements on driving performance, $d = 1.206$, $p = .004$ (see Figure 17 for forest plot).

Some studies ($k = 5$) reported multiple related outcomes which were combined for this meta-analysis into a single calculated composite and other studies reported only a holistic driving performance measure (i.e., overall driving performance, $k = 5$); thus, effects were quantified for calculated composites vs. holistic driving performance outcomes. For example, a study may report multiple metrics such as average driving speed, standard deviation of lane position, and mean following distance in which case the performances for all three metrics would be combined to calculate an effect size using CMA software. This would constitute a calculated composite of driving performance. In contrast, a holistic driving performance score is a single measure reported in the included study that captures overall performance. For studies with a calculated composite of driving performance, there was medium but not significant heterogeneity, $I^2 = 53.168$, $Q(4) = 8.541$, $p = .074$. There were significant medium improvements for studies employing calculated composites, $d = 0.505$, $p = .035$. For studies with holistic driving performance measures, there was also medium but not significant heterogeneity, $I^2 = 53.502$, $Q(4) = 8.602$, $p = .072$. Studies with holistic driving performance measures indicated significant large improvements, $d = 1.095$, $p < .001$ (see Figure 18 for forest plot).

Driver-Reported Outcomes

No studies examined physical retraining/exercise, visual-perceptual training, cognitive training, or context-specific training driver-reported outcomes (i.e., self-reported crashes, self-reported driving errors).

Education. Funnel plots, Egger's regression, and N_{fs} could not be calculated with only two included studies for education on driver-reported outcomes analyses. There was not significant heterogeneity, $I^2 = 6.935$, $Q(1) = 1.075$, $p = .300$ or significant effects of education on driver-reported outcomes, $d = 0.140$, $p = .341$ (see Figure 19 for forest plot).

One doctoral dissertation examined the efficacy of education to improve driver-reported outcomes (Lindstrom, 2009) and demonstrated findings consistent with quantitative analyses (no education effect on driver-reported outcomes). The Safety Awareness for Elderly Drivers, a group-based education intervention on driving safety topics conducted in two 2-hour sessions by a researcher, was compared to a control group that received a publicly available "Roadsense for Drivers" handbook. Before and after training, participants completed questionnaires on their driving habits and behaviors. For the outcome of interest, driver-reported outcomes included self-reported vehicular incidents (including crashes and near-misses) in the past month at baseline and post-test. Those in the education group did not show differential reduction from baseline to post-test in number of vehicular incidents as compared to the control group, $F(1, 42) = 2.30$, $p = .140$. Effect size was not reported.

Combined training approaches. Only one study (Anstey et al., 2018) examined combined training approaches to improve driver-reported outcomes. Anstey et al. (2018) examined a combined training approach of education plus context-specific training to improve driver-reported outcomes (i.e., self-reported crashes/incidents).

Community-dwelling older adults were randomized to either a) an intervention group involving a two-hour road education course with two tailored on-road driving lessons or b) a control group involving only the road education course. Following training, participants completed six months of driving diaries and were asked to indicate any crashes, significant incidents or near misses. The training group reported significantly fewer self-reported events overall across six-month follow-up (11 in training vs. 20 control), $OR = 0.275$, 95% CI [0.086, 0.884], $p = .030$.

Driving Simulator Performance

No studies examined the effects of education on driving simulator performance.

Physical retraining/exercise. One doctoral dissertation (Chattha, 2010) examined the efficacy a 12-week fitness program of aerobic and anaerobic exercise led by certified fitness instructors ($n = 16$) to reduce the number of collisions or non-collision errors in a driving simulator relative to wait-list controls ($n = 13$). Results showed a significant group effect on simulator errors and collisions, $F(3, 9) = 4.739$, $p = .030$, partial $\eta^2 = .612$. Further analyses showed that the control group committed significantly fewer errors from pre- to post-test as compared to the intervention group that had no significant changes in errors. Interestingly, however, the intervention group completed the driving scenarios significantly more quickly at post-test relative to baseline whereas control participants did not differ in completion times across sessions. The author postulated that the intervention may have reduced behavioral slowing (as indicated by faster simulator scenario completion times) at the expense of behavioral accuracy.

Visual-perceptual training. One study (Roge et al., 2014) examined the effects of a visual-perceptual training on driving simulator performance. Participants were randomized to either a visual-perceptual training aimed at increasing useful visual field size (n = 15) or a control condition (car-following task; n = 16). Before and after the intervention period, both groups underwent simulator testing in which they had to identify vulnerable road users from a distance. There was a significant time by training group interaction, $F(1, 27) = 12.290$, p = 0.001, d = 3.514 such that the training group experienced greater visibility distance gains to detect vulnerable road users from baseline to post-test as compared to the control group.

Cognitive training. Three studies examined the effect of cognitive training on driving simulator performance. The funnel plot (see Figure 20) and Egger's regression, p = .715, did not indicate publication bias. There was not significant heterogeneity, $I^2 = 43.952$, $Q(2) = 3.568$, p = .168 and no significant effect of cognitive training on driving simulator performance, d = 0.122, p = .681, $N_{fs} = 0$ (see Figure 21 for forest plot).

Three additional studies were identified through grey literature search which examined cognitive training on driving simulator performance (Belchior, 2007; Gaspar et al., 2012; Seidler et al., 2010). These grey literature studies report findings consistent with the quantitative analyses of cognitive training on driving simulator performance.

One doctoral dissertation study examined the effects of three intervention groups (Medal of Honor [video game training], Useful Field of View (UFOV) [cognitive training], or Tetris [cognitive stimulation]) versus a no-contact control group on driving simulator performance among community-dwelling older adults (Belchior, 2007). Participants in the intervention groups completed six 90-minute sessions (nine hours) of their assigned training. None of the three intervention groups, including the UFOV cognitive training, training of interest in these qualitative analyses, significantly improved their driving simulator scores (brake reaction distance, lane maintenance score, accuracy score) from baseline to post-test relative to the no-contact control group, (brake reaction distance, partial $\eta^2 = 0.040$, $p = .107$; lane maintenance score, partial $\eta^2 = 0.040$, $p = .503$, detection accuracy score, partial $\eta^2 = 0.008$, $p = .939$.

Similarly, a conference proceedings paper examined the efficacy of a commercially available brain training program, the CogniFit Senior Driver program, which targeted 14 cognitive abilities (e.g., working memory, visual scanning, etc.) to improve driving simulator performance (Gaspar et al., 2012). Participants in the intervention group completed 16 hours of CogniFit. The intervention group did not demonstrate differential improvement on simulator performance including following behavior, partial $\eta^2 = 0.080$, $p = .140$, lane changing headway, partial $\eta^2 < 0.001$, $p = .140$ or lane changing tailway, partial $\eta^2 = 0.007$, $p = .150$ relative to a computer card game active control group.

A technical report examined the efficacy of working memory training to improve driving simulator performance as compared to a knowledge training group (i.e., vocabulary and general trivia knowledge; Seidler et al., 2010). The working memory training did not differentially improve driving simulator performance as measured by a composite of lane deviations, number of collisions, and maintaining appropriate speed. No effect sizes were reported.

Context-specific training. One study (Urlings et al., 2019) examined two types of context-specific training to improve driving simulator performance and is described in more detail qualitatively. Egger's regression, N_{fs} and the funnel plot could not be generated. There was not significant heterogeneity, $I^2 < 0.001$, $Q(1) = 0.001$, $p = .979$ and no effect of context-specific training on driving simulator performance, *d* = -0.183, *p* =.565 (see Figure 22 for forest plot).

Participants were randomized to a) computer-based context-specific training (*n* = 10) ; b) simulator-based context-specific training (*n* = 11) ; or c) an active control group (*n* = 10). Participants in the computer-based group viewed six first-person, driver's point of view videos of unexpected road events (e.g., yielding for a sudden cross traffic from the right with obstructed view). Participants then responded on the touch-screen monitor by touching the location that required attention. Regardless of whether their response was correct, participants were provided feedback regarding their correct or incorrect responses and information as to how to react in this unexpected situation. Then, they viewed the same video again and were asked to locate the point that required attention.

The simulator-based training involved participants driving through scenarios that were identical to the videos in the computer-based training. Participants reacted according to the unexpected events and regardless of their action, were given feedback on how to maneuver this situation before driving the same scenario again. The control group viewed the computer videos and drove the same simulator scenarios but were not given any feedback in either situation. Regardless of the type of training, the Test Ride for Investigating Practical fitness to drive score, average speed, and response time to an unexpected event improved from baseline to post-test. No other scores significantly improved from baseline to post-test and neither intervention group outperformed the active control group. The net effect was a single-session of context-specific training, either computer-based, *d* = -0.174, *p* = .704, or simulator-based, *d* = -0.191, *p* = .565 did not improve driving simulator performance.

Combined training approaches. One study investigated transcranial direct current stimulation combined with cognitive training (i.e., UFOV cognitive training) to improve driving simulator performance (Pope et al., 2018). Participants were randomized to 10 one-hour sessions of either transcranial direct current stimulation with UFOV cognitive training (n = 15) or sham transcranial direct current stimulation with cognitive training (n = 15). There was a significant training effect for only average driving speed (those in combined transcranial direct current stimulation and cognitive training exhibited greater reduction in average driving speed as compared to the control group), partial η^2 = 0.191, p = .020. When combining all metrics of driving simulator performance in a single outcome, however, there was no effect of this combined approach on driving simulator performance, d = 0.221, p = .511.

Discussion

This systematic review and meta-analysis of 26 published studies and five studies from the grey literature showed skill-specific training approaches (i.e., physical retraining/exercise, visual-perceptual training, cognitive training) and combined approaches improved driving performance and driving safety among older adults. Specifically, quantitative analyses revealed medium-sized effects of physical retraining/exercise on driving performance, d = 0.564. Visual-perceptual training demonstrated large effects on driving performance, d = 1.061. Overall, cognitive training reduced at-fault crash involvement by 27.1%, OR = 0.729, 95% CI [0.553–0.962). Combined approaches showed a medium-sized improvement on driving performance, d = 0.784, although this overall effect was attenuated by higher study quality, combining skill-specific training plus other training (as opposed to context-specific training plus other), employing active controls, and using a calculated composite outcome (as opposed to a single overall performance score). Neither education nor context-specific training reduced crashes or improved driving performance, driver-reported outcomes, or driving simulator performance.

The present findings extend the results of prior reviews that reported tentative but promising evidence for skill-specific training to improve driving performance (Golisz, 2014; Korner-Bitensky et al., 2009; Kua et al., 2007; Unsworth & Baker, 2014). The current study showed that skill-specific training (physical retraining/exercise, visual-perceptual, cognitive) improved on-road driving performance, driving simulator performance, and reduced crashes. Regarding physical retraining/exercise, older drivers benefitted from range of motion, coordination, dexterity, strength, and flexibility exercises across three published RCTs; however, the N_{fs} was relatively small (8). Thus, the current review lends further evidence that physical retraining/exercise improves driving performance, particularly anaerobic exercises, but more research is warranted.

Regarding visual-perceptual techniques, driving performance improved among those trained in two RCTs (Crotty & George, 2009; McCoy et al., 1993). Publication bias and N_{fs} are unknown due to only two included studies in meta-analysis. Forthcoming research may provide more conclusive evidence of the efficacy of visual-perceptual training.

Although cognitive training approaches overall reduced at-fault crashes per person-year and per person-time combined by almost 30% ($N_{fs} = 3$), only one specific cognitive training, Useful Field of View cognitive training, showed significant at-fault crash reductions (Ball et al., 2010). Useful Field of View cognitive training targets speed of processing for visual attention tasks. The other types of cognitive training (i.e., reasoning and memory training) did not demonstrate differential reductions of at-fault crashes as compared to a no-contact control group. This finding is consistent with a prior review which reported that Useful Field of View cognitive training reduced adverse driving events (e.g., dangerous driving maneuvers) by almost 50% (N_{fs} = 9) and is the only intervention to date to reduce at-fault crash involvement among older drivers (Edwards, Fausto, Tetlow, Corona, & Valdés, 2018).

The present analyses showed that cognitive training approaches did not improve other driving outcomes including on-road driving performance or driving simulator performance. In addition, there were no studies that examined the efficacy of cognitive training to improve driver-reported outcomes (self-reported driving errors, self-reported crashes), warranting further research. However, the ecologically valid impact and meaningfulness of interventions may be better assessed by crashes, particularly at-fault crashes, rather than the other driving safety outcomes of interest. The finding that Useful Field of View cognitive training reduces at-fault crashes is of utmost practical value as the cost of crashes in terms of human lives and dollars should not be ignored (Edwards et al., 2018).

Prior research states that reviews should not equate approaches as each cognitive training type has unique effects (Edwards et al., 2018); however, the current study combined the varied cognitive training types. The types of cognitive training that were analyzed for the current study were indeed varied in terms of cognitive domain targeted, duration, dosage, frequency, and whether they were considered strategy- vs. process-based (see Table 2). Combining cognitive training approaches was warranted given that the only existing previous meta-analysis by Desapriya et al. (2008) combined all driver-related interventions (i.e., physical retraining/exercise, cognition, education, visual-perceptual, context-specific) on outcomes of crashes and on-road driving performance. The current study aimed to further tease apart the varied driver-related interventions combined in Desapriya et al. (2008) by specific intervention types. As the literature continues to mature, a future review should examine the unique effects of cognitive training approaches on driving safety.

Education approaches did not reduce crashes nor improve driver-reported outcomes and driving performance. These findings are consistent with other evidence that self-regulation does not mitigate crash risk and may even increase risks (Ross et al., 2009). Although education may improve knowledge of risks (Eby et al., 2003), this knowledge does not translate to improved driving safety (Owsley, McGwin, et al., 2004; Owsley et al., 2003). Across pre-post studies (Nasvadi & Vavrik, 2007), RCTs (Bédard et al., 2004; Gaines et al., 2011; Owsley, McGwin, et al., 2004), and reviews (Desapriya et al., 2008; Golisz, 2014; Korner-Bitensky et al., 2009; Kua et al., 2007; Unsworth & Baker, 2014), including the current systematic review and meta-analysis, education does not improve driving safety among older adults.

Similarly, context-specific training (on-road, simulator, or computer-based training using videos of traffic situations) did not differentially improve driving performance or driving simulator performance among those trained. The effects of such interventions have not been examined on outcomes of crashes or driver-reported outcomes, but all four included studies used simulator training. Context-specific training involves a learning environment that is similar to the actual driving context (Urlings et al., 2019). Despite the apparent face validity however, results showed limited transfer to on-road driving skills or driving simulator performance, perhaps due to older drivers' long-term familiarity with driving.

Unlike skill-specific training (i.e., physical retraining, visual-perceptual, and cognitive training approaches), education and context-specific training do not target older drivers' functional declines indicative of driving safety risks. Licensed older drivers are experienced drivers largely familiar with road rules who have implicit, procedural knowledge of the driving task (Karthaus & Falkenstein, 2016). Thus, education approaches on road rules or context-specific training targeting blind spot checks are not efficacious as they do not target the source of older driver difficulties. Instead, targeting skills that decline with age that are associated with increased driving risks (e.g., crashes) is a more efficacious approach to improving older driver safety.

According to the current review, combined training approaches are promising avenues to improve on-road driving performance, but the included RCTs varied by combined training type implemented (context-specific training plus other vs. skill-specific training plus other), type of control condition, methodological quality, and outcome measure. Ten different combined training approaches were used across the eight included studies of which four examined education and on-road training. There was one study for each of the following unique combined approaches: cognitive training and simulator training; education, simulator, and feedback training; education and physical retraining/exercise; education and visual-perceptual training; education, video, and feedback; and education, simulator training, and on-road training. Overall, these combined approaches show promise to improve driving safety, but more research should be conducted to determine the effects of combined training on driver-reported outcomes, driving simulator performance and actual crash involvement. In addition, studies that employ factorial designs (i.e., interventions that employ multiple components that can be evaluated in combination and in isolation) should be pursued to help parse which component(s) of the combined training contributed to driving safety improvements (Sprague et al., 2019).

Conclusion

Based on available evidence, the most efficacious interventions to improve older driver safety remediate age-related declines in abilities such as visual-perceptual function, physical function, and cognition (skill-specific training) or combine multiple training approaches. It is recommended that occupational therapists and driving rehabilitation specialists employ interventions that target age-related functional declines and combine training approaches. Such approaches can have major public health impacts including keeping older drivers and fellow road users safe thereby lowering MVCs overall and improving driving safety in the general population. Importantly, these interventions balance the needs to maintain public health of road users overall and to help older drivers maintain their mobility and independence.

Table 1

Systematic Review Search Terms

	Concept 1	Concept 2	Concept 3
Key concepts	**Older driver**	**Interventions**	**Outcomes**
Free text terms / natural language terms (synonyms, UK/US terminology, medical/laymen's terms, acronyms/abbreviations, drug brands, more narrow search terms)	Older drivers Aged drivers Aging or Ageing/Agi?ng drivers Geriatric drivers Senior drivers	Intervention Training Trial Randomized clinical trial Randomised/Randomi?ed clinical trial	<u>Crashes</u> Crashes Motor vehicle crashes Motor vehicle collisions MVC Crash risk Crash rate <u>Driving performance</u> On-road driving Closed road circuit Road performance Driving performance Driving test <u>Driver-reported outcomes</u> Self-reported driving errors Self-reported crash <u>Driving simulator performance</u> Simulator performance Driving simulator

Note. Table adapted from https://utas.libguides.com/SystematicReviews/ControlledVocabularyTerms: "Template for Systematic Review Search".

Table 2

Summary of Included Articles and PEDro Ratings

Article #	Author/Year	Study Design	Study Sample Characteristics	Intervention Type	Intervention and Comparator/Control Group(s) Descriptions and Dosage	Outcome Measure(s)	Rater #1 (PA) PEDro Ratings	Rater #2 (BF) PEDro Ratings	Consensus Quality Rating
1	Anstey et al. (2018)	RCT	57 community-dwelling older adults, current drivers, ≥ 65 years old	Combined (Educational + Context-specific training [on-road])	Intervention group: Two-hour classroom instruction on road rules + two one-hour tailored driving lessons in dual-brake vehicle Control group: Two-hour classroom instruction on road rules only	On-road driving performance	9	10	Excellent
2	Ball et al. (2010)	RCT	908 community-dwelling older adults, ≥ 65 years old	Cognitive training	Intervention group: Ten ~70-min sessions of cognitive training for speed of processing, memory or reasoning Control group: No-contact control group	At-fault crashes	8	8	Good
3	Bédard et al. (2004)	RCT	72 community-dwelling older adults, current drivers, ≥ 55 years old	Educational	Intervention group: Two three-hour sessions of classroom instruction on driving topics Control group: Wait-list control group	On-road driving performance	10	9	Excellent
4	Bédard et al. (2008)	RCT	75 community-dwelling older adults, current drivers, ≥ 65 years old	Combined (Educational + Context-specific training [on-road])	Intervention group: Two three-hour sessions of classroom instruction on driving topics + two 40-min on-road driving lessons in dual-brake or personal vehicle Control group: Wait-list control group	On-road driving performance	11	9	Excellent
5	Casutt et al. (2014)	RCT	91 community-dwelling older adults, current drivers, range 62 – 87 years old	Context-specific training (simulator) Cognitive training	Intervention groups: Ten 40-min sessions of driving simulator training or attention training Control group: Wait-list control group	On-road driving performance	7	7	Good
6	Crotty and George (2009)	RCT	26 adults with stroke referred for driving assessment, 65.6±13.1 years old	Visual perceptual training	Intervention group: Three 40-min sessions over 6 weeks of Dynavision training Control group: Wait-list control group	On-road driving performance	10	9	Excellent
7	Cuenen et al. (2016)	RCT	56 community-dwelling older	Cognitive training	Intervention group: 25 sessions of adaptive working memory training	Driving simulator	7	7	Good

Table 2 (Continued)

			adults, current drivers, ≥ 70 years old		Control groups: Active control group-non-adaptive working memory training and passive control group-no contact control	performance			
8	Gaines et al. (2011)	RCT	195 community-dwelling older adults, current drivers, ≥ 60 years old	Educational	Intervention group: CarFit Control group: No treatment comparison group	Self-reported driving errors	8	6	Good
9	Hay et al. (2016)	RCT	106 older adults from Safe Move cohort, current drivers, ≥ 70 years old	Cognitive training Combined cognitive training and context-specific training (simulator)	Intervention group: 35 hours of computerized cognitive training over three months plus one hour of simulated driving Comparator: 36 hours of computerized cognitive training over three months	On-road driving performance	6	6	Good
10	Jacobs et al., 1997	RCT	21 older adults, current drivers, no prior driving re-education participation, ≥ 55 years old	Context-specific training (simulator) Educational	Intervention group(s): Two-hour driving simulator training or instruction through viewing simulator films in classroom Control group: No contact control group	On-road driving performance	7	7	Good
11	Lavallière et al. (2012)	RCT	22 older adults, current drivers, ≥ 65 years old	Combined educational and context-specific training (simulator)	Intervention group: Three training sessions with driver refresher course, driving simulator training, and driving specific feedback Control group: Three training sessions with driver refresher course and driving simulator training with no feedback	On-road driving performance	7	8	Good
12	Marottoli, Allore, et al. (2007)	RCT	178 community-dwelling older adults, current drivers, ≥ 70 years old	Physical retraining/exercise	Intervention group: Graduated exercise program by physical therapist for 12 weeks Control group: In-home education on home safety by trained research assistants	On-road driving performance	10	10	Excellent
13	Marottoli, Van Hess, et al. (2007)	RCT	126 community-dwelling older adults, current drivers, ≥ 70 years old	Combined educational and context-specific training (on-road)	Intervention group: 8 hours of classroom instruction on driving topics and 2 hours of on-road instruction Control group: In-home education on home safety by trained research assistants	On-road driving performance	8	7	Good
14	Mazer et al. (2003)	RCT	97 adults referred for driving	Cognitive training	Intervention group: Twenty 30-60 min sessions of speed of processing training	On-road driving performance	9	9	Excellent

Table 2 (Continued)

			evaluation after stroke, mean age for experimental group 65.5±11.4 and control group 66.5±8.9 years old		Control group: Twenty 30-60 min sessions of visuoperception-based games (e.g., Tetris)				
15	Mazer et al. (2015)	RCT	52 adults referred for driving evaluation after stroke, mean age for experimental group 66.3±15.0 and control group 68.6±8.6 years old	Context-specific training (simulator)	Intervention group: Sixteen 60 min sessions of simulator training Control group: No contact control group/usual care by post-stroke rehabilitation program	On-road driving performance	9	10	Excellent
16	McCoy et al. (1993)	RCT	105 community-dwelling older adults, current drivers, ≥ 75 years old	Physical retraining/exercise, visual perceptual training, educational	Intervention group(s): Self-administered physical therapy, perceptual therapy, education or traffic engineering improvements Control group: No contact control group	On-road driving performance	5	5	Fair
17	Nozawa et al. (2015)	RCT	37 community-dwelling older adults, current drivers, age range 60-75 years old	Cognitive training	Intervention group(s): In-vehicle cognitive training or PC-based cognitive training Control group: Crossword puzzle group	On-road driving performance	11	11	Excellent
18	Ostrow et al. (1992)	RCT	32 community-dwelling older adults, current drivers, age range 60-85 years old	Physical retraining/exercise	Intervention group: 8-week range-of-motion exercise training program Control group: No contact control group	On-road driving performance	5	4	Fair
19	Owsley, McGwin, et al. (2004)	RCT	403 community-dwelling older adults, current drivers, ≥ 60 years old, visual impairment, crash history	Educational	Intervention group: Usual care with eye examination by optometrist plus educational intervention Control group: Usual care with eye examination by optometrist only	Crashes	8	8	Good
20	Pope et al. (2018)	RCT	30 older adults, HIV+, ≥ 50 years old	Combined cognitive training and transcranial direct current stimulation	Intervention group: Ten 1-hr sessions of speed of processing training plus transcranial direct current stimulation Control group: Ten 1-hr sessions of speed of processing plus sham transcranial direct current stimulation	Driving simulator performance	7	8	Good

Table 2 (Continued)

21	Porter (2013)	RCT	54 community-dwelling older adults, current drivers, ≥ 70 years old	Educational	Intervention group(s): Two 4-hour in-class sessions on driving topics (55 Alive Mature Driving program) plus video and global positioning system feedback or 55 Alive only Control group: Wait-list control group	On-road driving performance	9	10	Excellent
22	Roenker et al. (2003)	RCT	95 community-dwelling older adults, current drivers, ≥ 55 years old	Cognitive training Context-specific training (simulator)	Intervention group(s): Speed of processing training or traditional driver training in simulator Control group: No-contact, low-risk reference group	On-road driving performance	8	8	Good
23	Roge et al. (2014)	RCT	31 community-dwelling older adults, current drivers, age range 63-78 years old	Visual perceptual training Context-specific training (simulator)	Intervention group: Three hours of useful visual field training Control group: Three hours of vehicle-following task in a driving simulator	Driving simulator performance	6	6	Good
24	Sawula et al. (2018)	RCT	78 older adults, current drivers, ≥ 65 years old	Combined: In-class, context-specific training (on-road) with feedback plus context-specific training (simulator)	Intervention group(s): Basic in-class instruction plus on-road training with feedback OR basic in-class instruction plus on-road training with feedback plus driving simulator training Control group: Basic in-class instruction	On-road driving performance	10	9	Good
25	Stowe et al. (2015)	RCT	39 older adults with impaired visual, cognitive or psychomotor function, current drivers, ≥ 60 years old	Educational	Intervention group: Two 75-min personalized planning sessions with peer counselor on transitioning from driving to non-driving Control group: No contact control group	Self-reported driving errors	6	8	Good
26	Urlings et al. (2019)	RCT	31 older adults referred for driving evaluation, current drivers, ≥ 70 years old	Context-specific training (simulator) Context-specific training (computer)	Intervention group(s): Simulator-based training with feedback provided OR computer-based training with feedback provided both related to responding to unanticipated events Control group: Practiced on simulator-based training and watched videos from computer-based training with NO feedback provided	Driving simulator performance	8	8	Good

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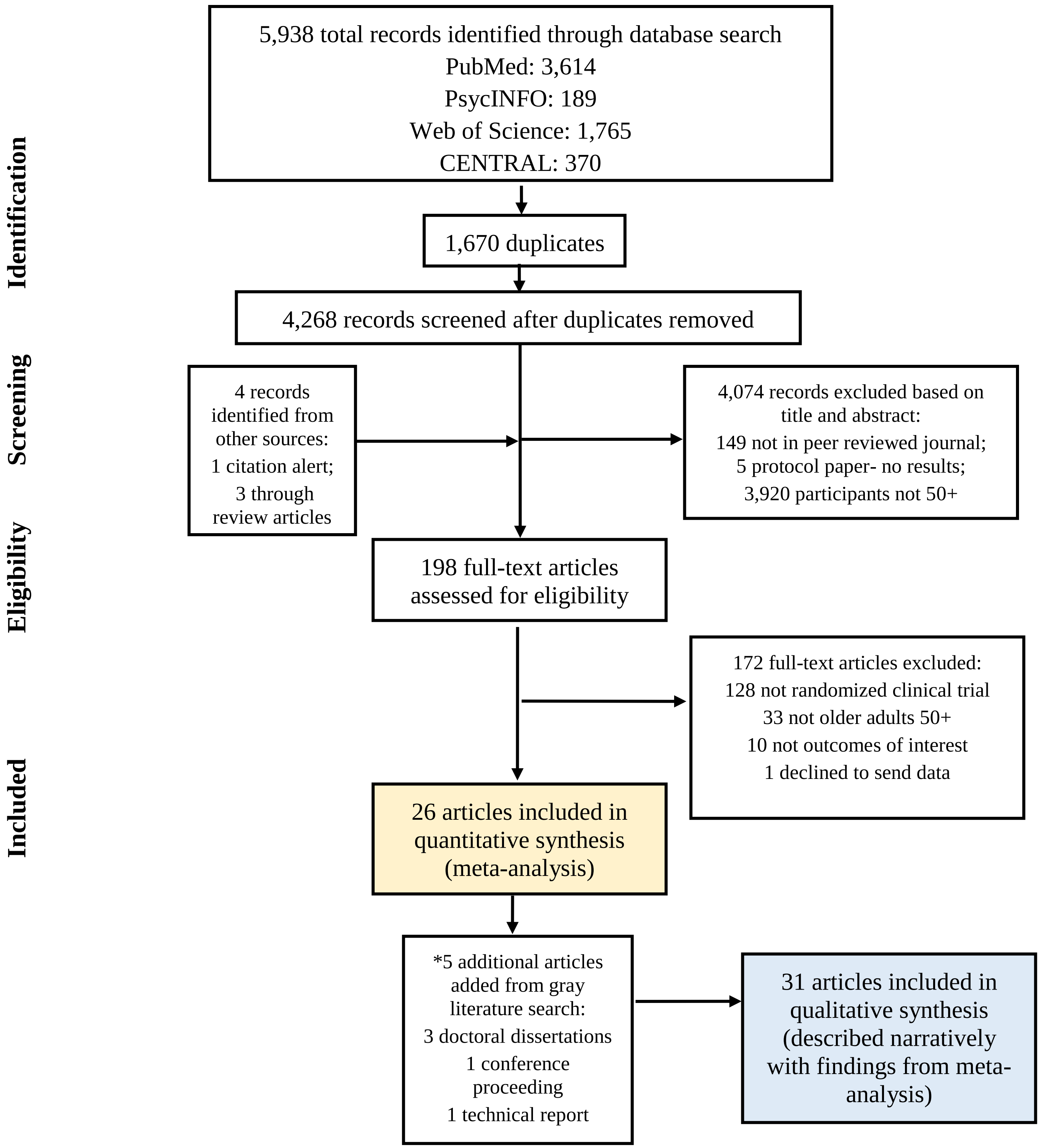

Figure 1. Records Identified Through Systematic Review. *A subsequent gray literature search yielded five articles included in qualitative synthesis only (Belchior, 2007; Chattha, 2010; Gaspar et al., 2012; Lindstrom, 2009; Seidler et al., 2010)

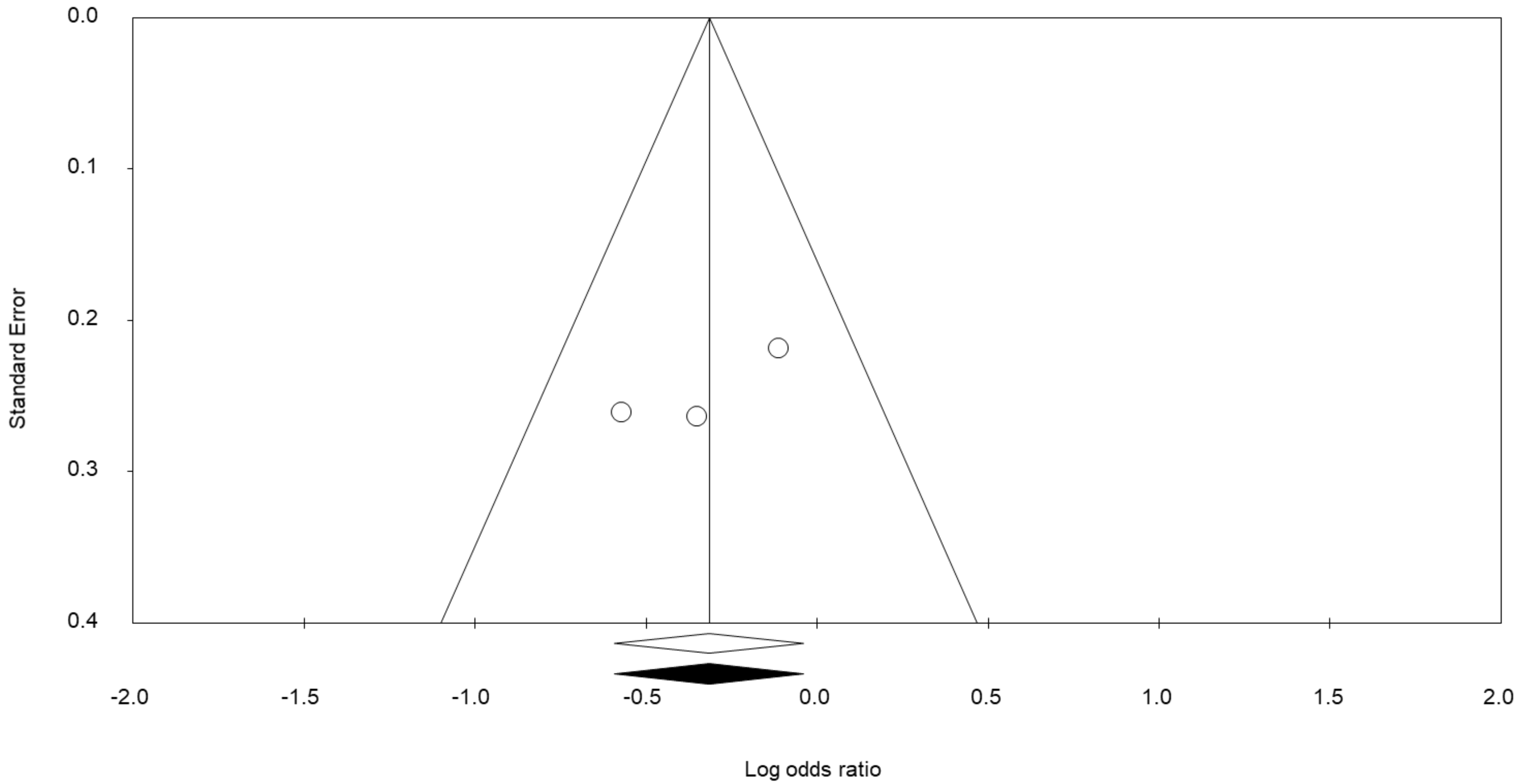

Figure 2. Funnel Plot of Standard Error by Log Odds Ratio for Cognitive Training on Crashes

Study name	Comparison	Intervention	Outcome	Statistics for each study				
				Odds Ratio	Lower limit	Upper limit	*Z*	*p*
Ball et al., 2010	No contact control group	Cognitive Training-Memory[1]	Combined[4]	0.894	0.582	1.374	-0.510	0.610
Ball et al., 2010	No contact control group	Cognitive Training-Reasoning[2]	Combined[4]	0.704	0.420	1.180	-1.331	0.183
Ball et al., 2010	No contact control group	Cognitive Training-Speed[3]	Combined[4]	0.565	0.339	0.942	-2.190	0.028
Overall odds ratio				0.729	0.553	0.962	-2.233	0.026

Odds ratio and 95% CI

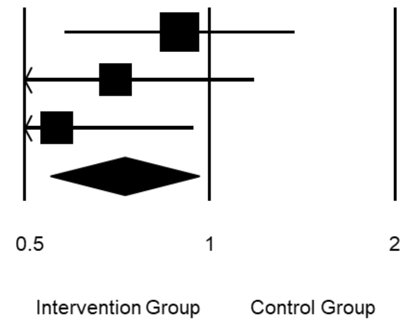

Figure 3. Forest Plot of Effect Sizes Using Random Effects for Cognitive Training on Crashes. Duval and Tweedie's trim and fill correction not needed. [1]Memory training (*N* = 584); [2]Reasoning training (*N* = 554); [3]Useful field of view training a.k.a., speed of processing training (*N* = 588); [4]Combined outcome = at-fault crashes per person time and at-fault crashes per person mile.

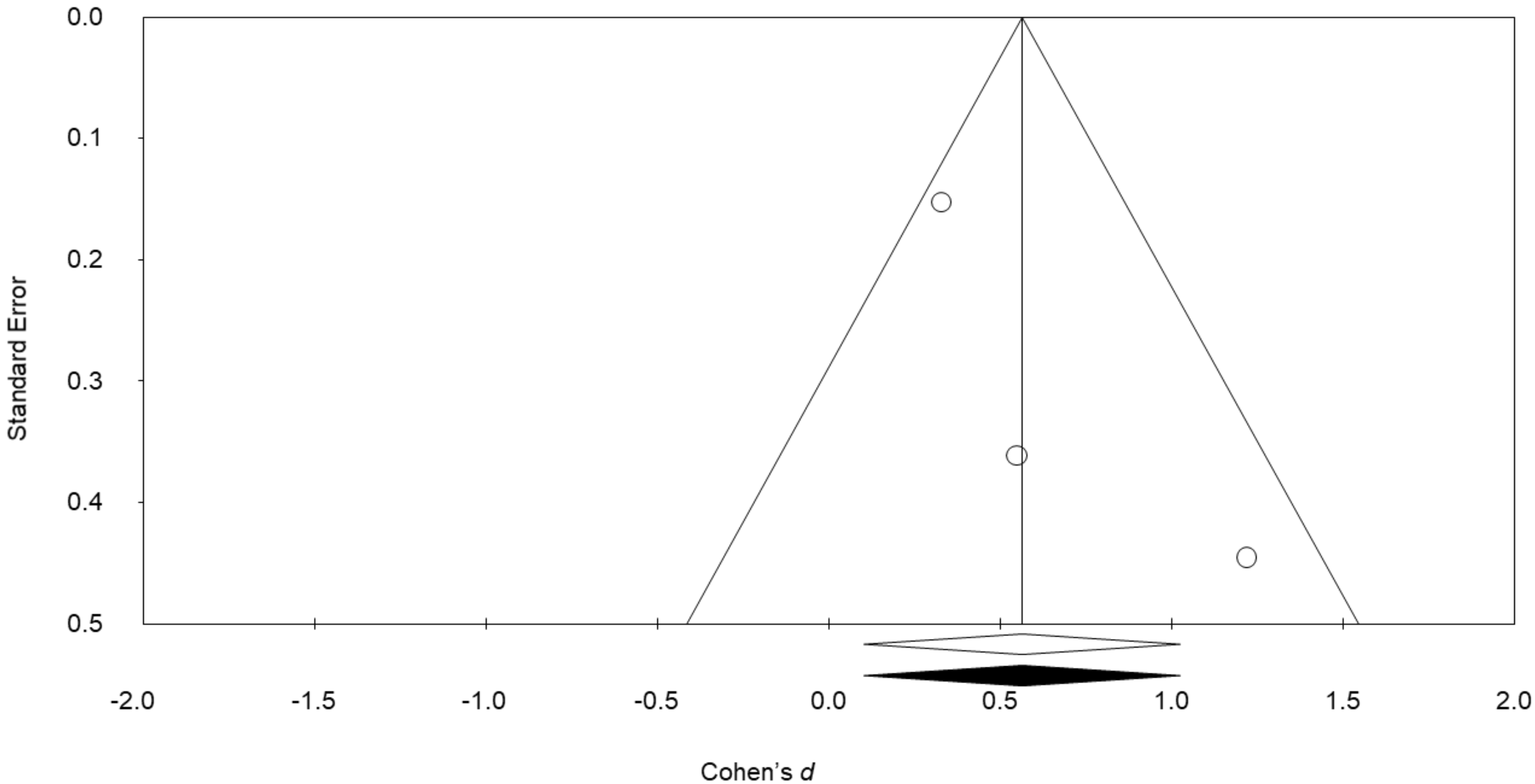

Figure 4. Funnel Plot of Standard Error by Cohen's *d* for Physical Retraining Exercise Interventions on On-Road Driving Performance

Study name	Comparison	Outcome	Statistics for each study					
			Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
Marottoli, Allore et al., 2007	Active control[1]	On-road driving performance	0.329	0.153	0.030	0.629	2.155	0.031
McCoy et al., 1993	No contact control group	On-road driving performance	1.218	0.446	0.345	2.091	2.735	0.006
Ostrow et al., 1992	No contact control group	Combined[2]	0.549	0.361	-0.160	1.257	1.518	0.129
Overall *d* effect size			0.564	0.235	0.103	1.025	2.397	0.017

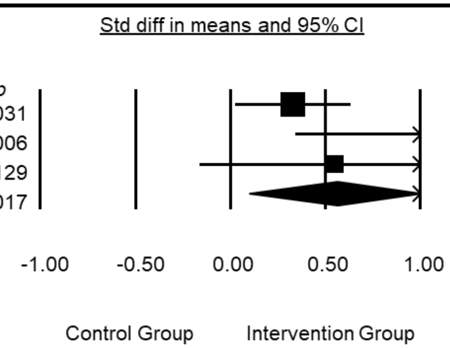

Figure 5. Forest Plot of Effect Sizes Using Random Effects for Physical Retraining/Exercise Interventions on On-Road Driving Performance. Duval and Tweedie's trim and fill correction not needed. [1]In-home safety education modules. [2]Combined outcomes included on-road driving performance metrics of vehicle handling, safe practices and observing scores.

Study name	Comparison	Outcome	Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
Crotty & George, 2009	No contact control group	On-road driving performance	0.749	0.475	-0.183	1.680	1.576	0.115
McCoy et al., 1993	No contact control group	On-road driving performance	1.435	0.520	0.416	2.453	2.760	0.006
Overall *d* effect size			1.061	0.351	0.374	1.748	3.025	0.002

Statistics for each study

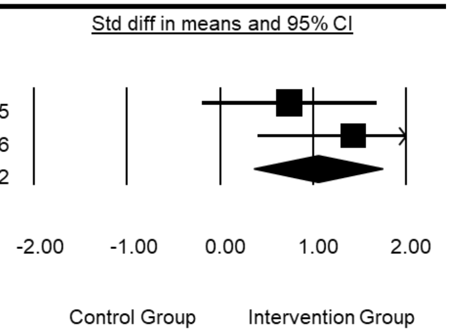

Figure 6. Forest Plot of Effect Sizes Using Random Effects for Visual-Perceptual Training on On-Road Driving Performance. Duval and Tweedie's trim and fill correction not needed.

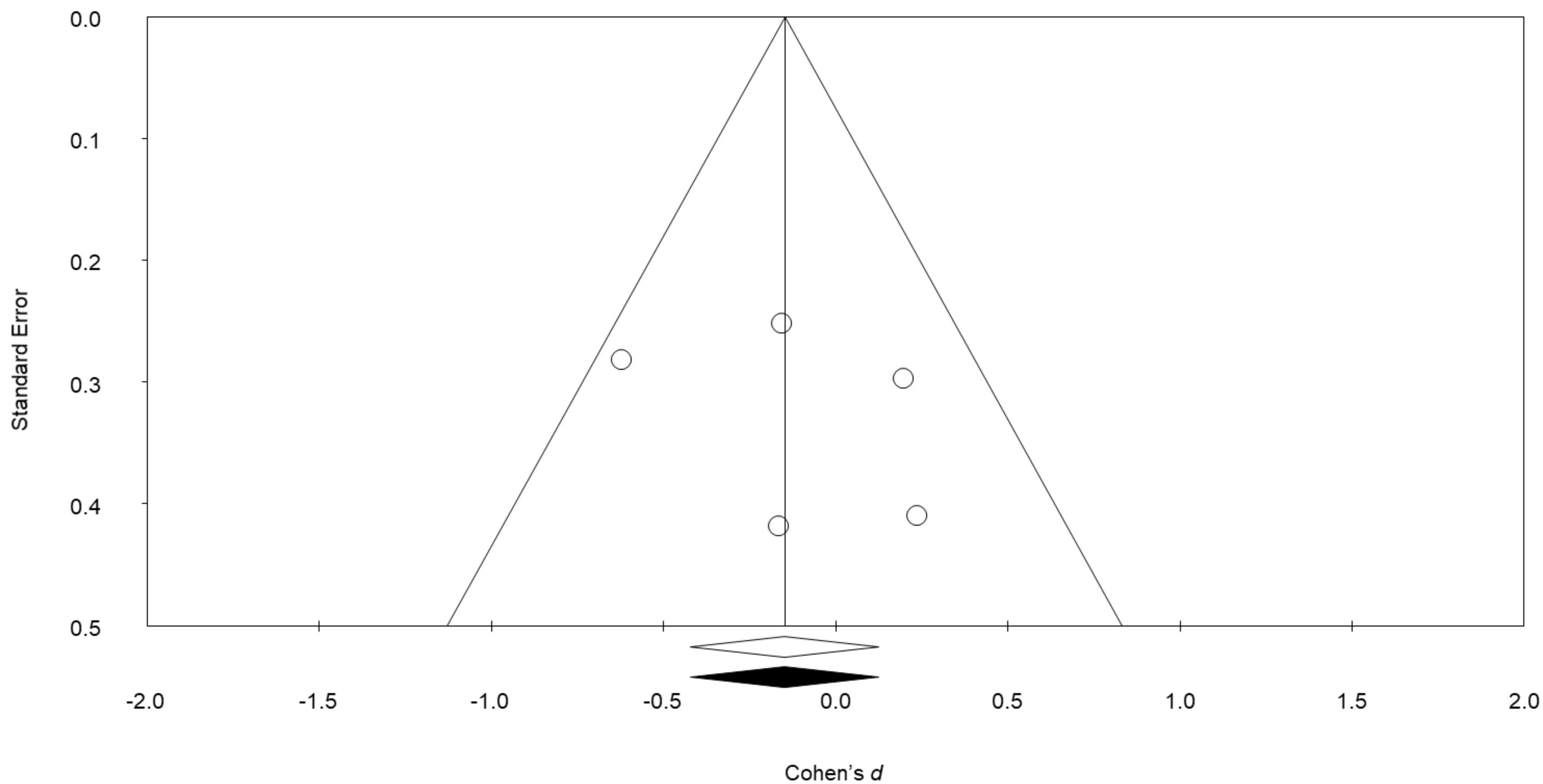

Figure 7. Funnel Plot of Standard Error by Cohen's *d* for Cognitive Training on Driving Performance

Study name	Comparison	Outcome	Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
			Statistics for each study					
Casutt et al., 2014[1]	Active control group[8]	On-road driving performance	-0.622	0.282	-1.174	0.070	-2.209	0.027
Mazer et al., 2003[2]	Active control group[6]	On-road driving performance	-0.155	0.252	-0.649	0.338	-0.618	0.537
Nozawa et al., 2015[3]	Active control group[7]	On-road driving performance	0.237	0.410	-0.566	1.040	0.579	0.562
Nozawa et al., 2015[4]	Active control group[7]	On-road driving performance	-0.166	0.418	-0.985	0.654	-0.397	0.691
Roenker et al., 2003[5]	Active control group[8]	Combined[9]	0.156	0.297	-0.426	0.738	0.526	0.599
Overall *d* effect size			-0.150	0.154	-0.453	0.152	-0.975	0.330

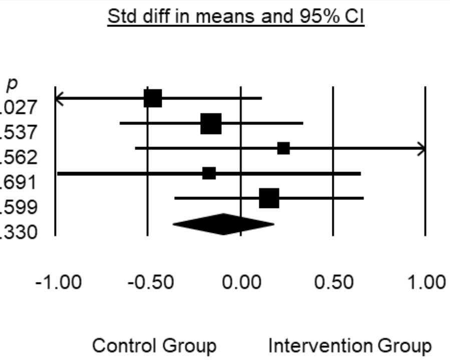

Figure 8. Forest Plot of Effect Sizes Using Random Effects for Cognitive Training on Driving Performance. Duval and Tweedie's trim and fill correction not needed. [1]Attention training consisting of phasic and tonic alertness and vigilance; [2]Useful field of view cognitive training; [3]In-vehicle cognitive training targeting speed of processing, executive control, divided attention, and working memory; [4]Computer-based cognitive training targeting speed of processing, executive control, divided attention, and working memory; [5]Useful field of view cognitive training; [6]Traditional visual-perceptual training for stroke clients; [7]Crossword puzzles; [8]Simulator training; [9]Combined outcome of on-road driving performance = global rating, dangerous driving maneuvers, signals, turning, changing lanes, position in traffic, stop position, speed, and tracking performance at post-test and 18 months.

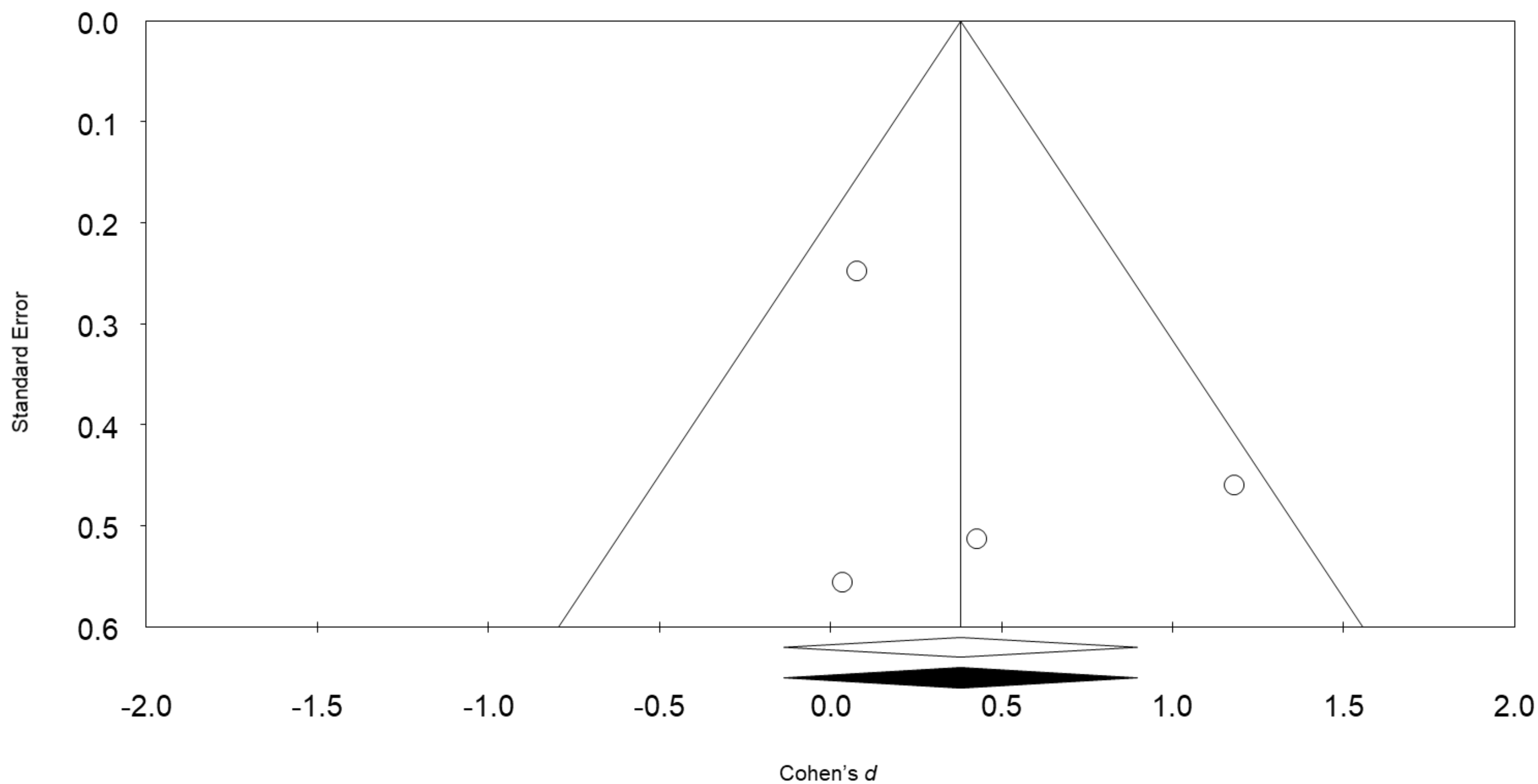

Figure 9. Funnel Plot of Standard Error by Cohen's *d* for Education on Driving Performance

Study name	Comparison	Outcome	Statistics for each study					
			Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
Bédard et al., 2004	No contact control group	On-road driving performance	0.079	0.248	-0.407	0.566	0.320	0.749
Jacobs et al., 1997	No contact control group	On-road driving performance	0.036	0.556	-1.054	1.127	0.065	0.948
McCoy et al., 1993	No contact control group	On-road driving performance	1.181	0.460	0.279	2.083	2.566	0.010
Porter (2013)	No contact control group	Combined[1]	0.427	0.513	-0.578	1.433	0.833	0.405
Overall *d* effect size			0.381	0.263	-0.135	0.897	1.446	0.148

Std diff in means and 95% CI

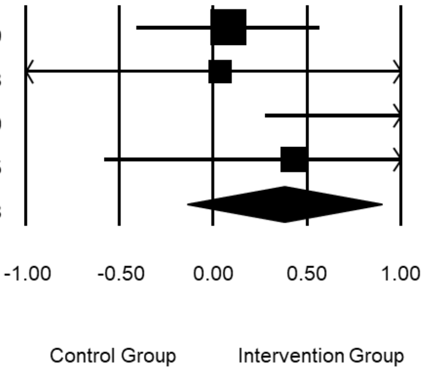

Figure 10. Forest Plot of Effect Sizes Using Random Effects for Education on Driving Performance. Duval and Tweedie's trim and fill correction not needed.

[1]Combined outcome for driving performance: Total errors and number of participants in each group with improved safety category scores (unsafe, marginal, safe).

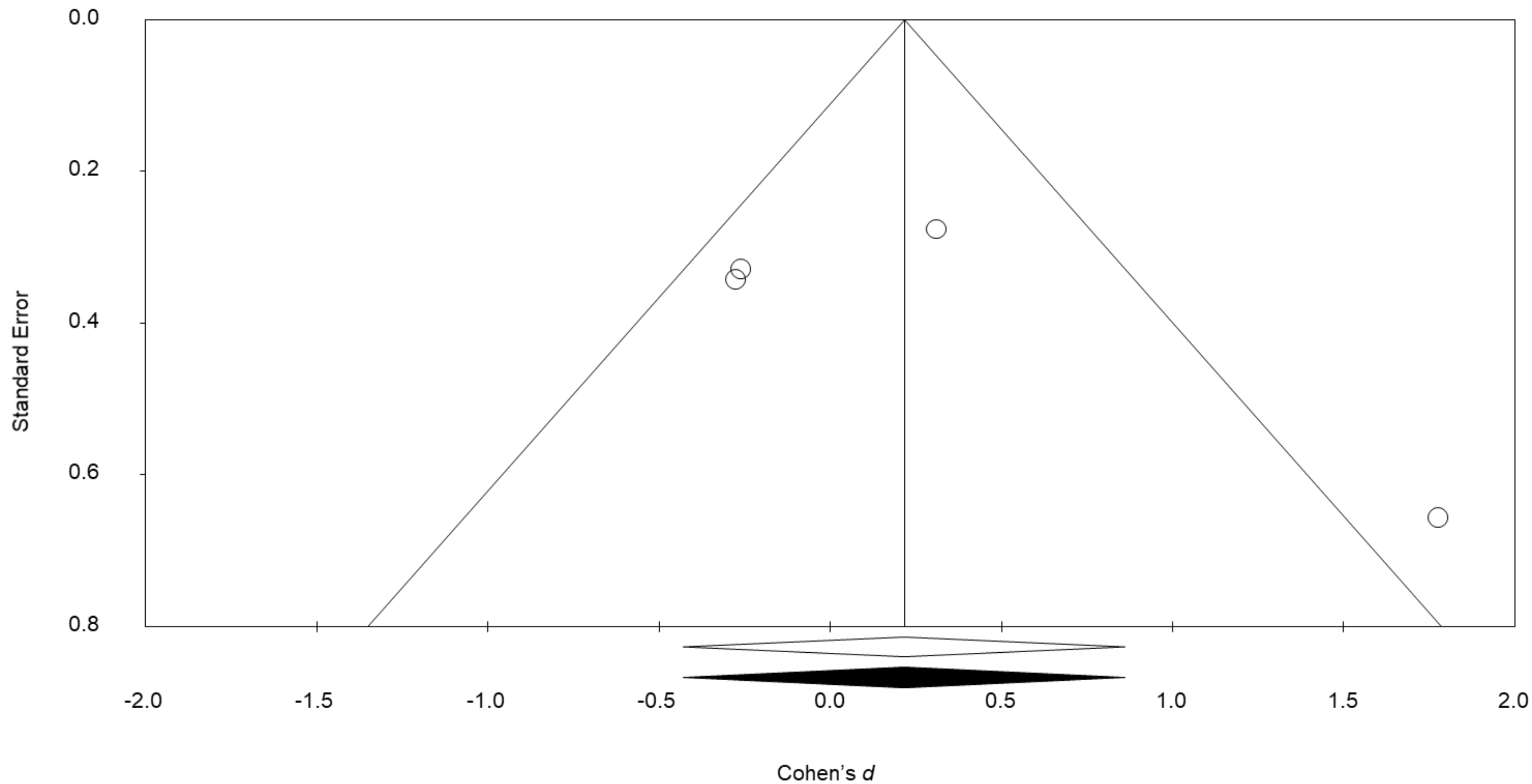

Figure 11. Funnel Plot of Standard Error by Cohen's *d* for Context-Specific Training on Driving Performance

Study name	Comparison	Outcome	Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
Casutt et al., 2014[1]	No contact control group	On-road driving performance	0.311	0.277	-0.231	0.854	1.124	0.261
Jacobs et al., 1997[1]	Active control group[2]	On-road driving performance	1.777	0.657	0.490	3.064	2.707	0.007
Mazer et al., 2015[1]	No contact control group	On-road driving performance	-0.276	0.343	-0.947	0.396	-0.804	0.421
Roenker et al., 2003[1]	Low risk reference group	Combined[3]	-0.260	0.330	-0.907	0.386	-0.789	0.430
Overall d effect size			0.217	0.329	-0.428	0.861	0.659	0.510

Statistics for each study

Std diff in means and 95% CI

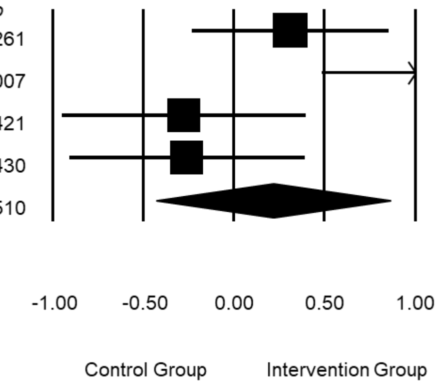

Figure 12. Forest Plot of Effect Sizes Using Random Effects for Context-Specific Training on Driving Performance. Duval and Tweedie's trim and fill correction not needed. [1]Simulator training; [2]Active control group = education; [3]Combined outcome of on-road driving performance = global rating, dangerous driving maneuvers, signals, turning, changing lanes, position in traffic, stop position, speed, and tracking performance at post-test and 18 months.

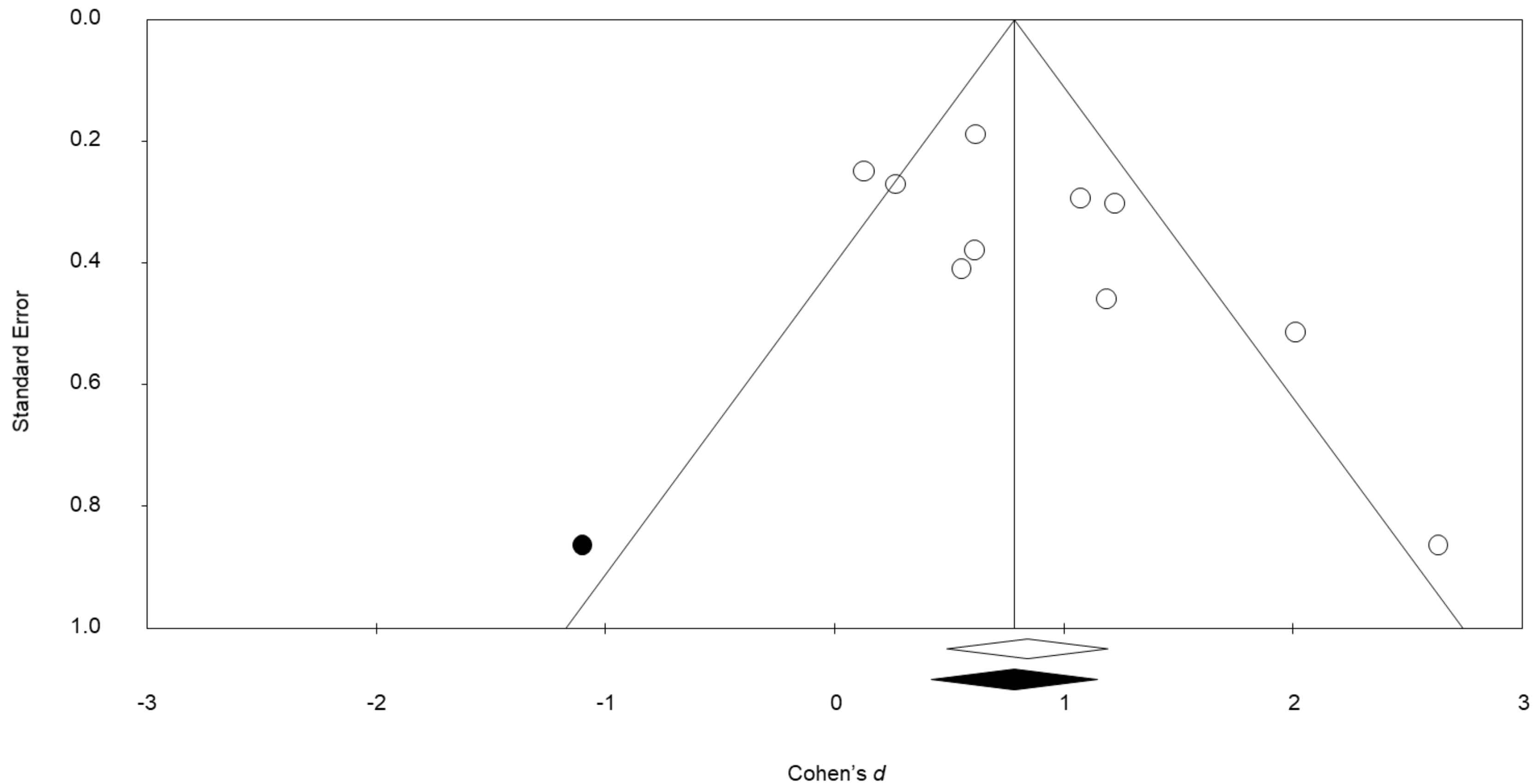

Figure 13. Funnel Plot of Standard Error by Cohen's *d* for Combined Training Approaches on Driving Performance. One study imputed due to publication bias.

Study	Comparison	Outcome	Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
1	Active control group	Combined[a]	0.269	0.271	-0.262	0.800	0.991	0.322
2	No contact control group	Combined[b]	0.554	0.411	-0.251	1.359	1.349	0.177
3	Active control group	Combined[c]	0.129	0.250	-0.360	0.618	0.517	0.605
4	Active control group	Combined[d]	2.636	0.865	0.941	4.331	3.048	0.002
5	Active control group	On-road driving performance	0.617	0.189	0.247	0.988	3.264	0.001
6	No contact control group	On-road driving performance	1.186	0.460	0.283	2.088	2.576	0.010
7	No contact control group	On-road driving performance	2.012	0.515	1.004	3.021	3.910	0.000
8	Active control group	Combined[e]	0.613	0.379	-0.130	1.355	1.618	0.106
9	Active control group	On-road driving performance	1.222	0.302	0.629	1.814	4.042	0.000
10	Active control group	On-road driving performance	1.072	0.294	0.496	1.648	3.650	0.000
Overall *d* effect size			0.842	0.179	0.491	1.193	4.705	0.000
Overall *d* effect size with Duval and Tweedie's trim and fill correction			0.784	0.179	0.420	1.148	4.705	0.000

Statistics for each study

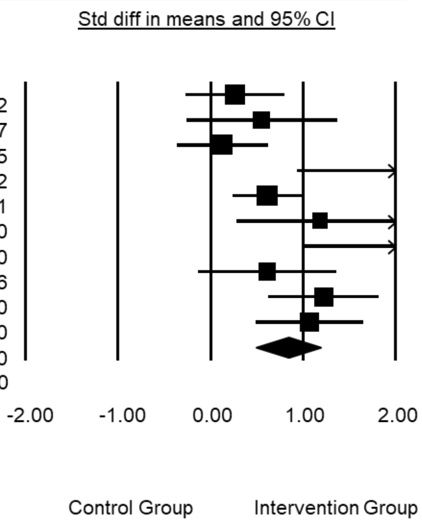

Figure 14. Forest Plot of Effect Sizes Using Random Effects for Combined Training Approaches on Driving Performance. Duval and Tweedie's trim and fill correction applied for one missing study. [1]Anstey et al., 2018 (N = 55), Education & On-Road Training; [2]Bédard et al., 2008 (N = 29), Education & On-Road Training; [3]Hay et al., 2016 (N = 67), Cognitive Training & Simulator Training; [4]Lavallière et al., 2012 (N = 22), Education, Simulator Training, & Feedback; [5]Marottoli, Van Hess et al., 2007 (N = 118), Education & On-Road Training; [6]McCoy et al., 1993 (N = 25), Education & Physical Retraining/Exercise; [7]McCoy et al., 1993 (N = 25), Education & Visual-Perceptual Training; [8]Porter, 2013 (N = 35), Education, Video, & Feedback; [9]Sawula et al., 2018 (N = 52), Education & On-Road Training; [10]Sawula et al., 2018 (N = 53), Education, Simulator Training, & On-Road Training; [a]Combined outcome = Driver safety rating and total driving errors; [b]Combined outcome = Thunder Bay and Winnipeg driving performance; [c]Combined outcome = Test Ride for Investigating Practical Fitness to Drive score, Behavioral Observation score, Operational Sub-score, Tactical Sub-score, and Tactical Compensation Sub-sosre; [d]Combined outcome = Frequency of blind spot, external mirrors, and rearview mirror inspection; [e]Combined outcome = driving performance errors and overall rating.

Study	Comparison	Outcome	Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
1	Active control group	Combined[a]	0.269	0.271	-0.262	0.800	0.991	0.322
2	No contact control group	Combined[b]	0.554	0.411	-0.251	1.359	1.349	0.177
3	Active control group	Combined[c]	2.636	0.865	0.941	4.331	3.048	0.002
4	Active control group	On-road driving performance	0.617	0.189	0.247	0.988	3.264	0.001
5	Active control group	Combined[d]	0.613	0.379	-0.130	1.355	1.618	0.106
6	Active control group	On-road driving performance	1.222	0.302	0.629	1.814	4.042	0.000
7	Active control group	On-road driving performance	1.072	0.294	0.496	1.648	3.650	0.000
Subgroup *d* effect size for context-specific training with other training			0.793	0.176	0.447	1.139	4.494	0.000
8	Active control group	Combined[e]	0.129	0.250	-0.360	0.618	0.517	0.605
9	No contact control group	On-road driving performance	1.186	0.460	0.283	2.088	2.576	0.010
10	No contact control group	On-road driving performance	2.012	0.515	1.004	3.021	3.910	0.000
Subgroup *d* effect size for skill-specific training with other training			1.044	0.584	-0.101	2.189	1.787	0.074
Overall *d* effect size			0.814	0.169	0.483	1.145	4.819	0.000

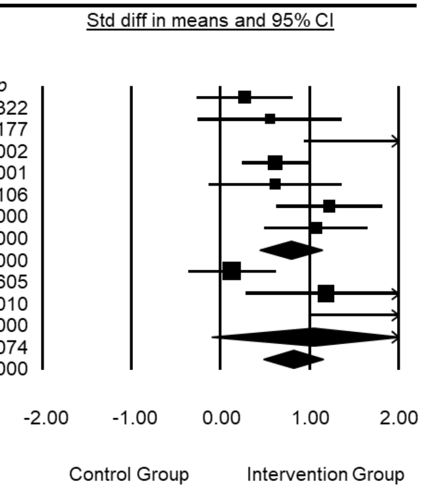

Figure 15. Forest Plot of Effect Sizes Using Random Effects for Combined Training Approaches on Driving Performance: Context-Specific vs. Skill-Specific Training. [1]Anstey et al., 2018 (N = 55), Education & On-Road Training; [2]Bédard et al., 2008 (N = 29), Education & On-Road Training; [3]Lavallière et al., 2012 (N = 22), Education, Simulator Training, & Feedback; [4]Marottoli, Van Hess et al., 2007 (N = 118), Education & On-Road Training; [5]Porter, 2013 (N = 35), Education, Video, & Feedback; [6]Sawula et al., 2018 (N = 52), Education & On-Road Training; [7]Sawula et al., 2018 (N = 53), Education, Simulator Training, & On-Road Training; [8]Hay et al., 2016 (N = 67), Cognitive Training & Simulator Training; [9]McCoy et al., 1993 (N = 25), Education & Physical Retraining/Exercise; [10]McCoy et al., 1993 (N = 25), Education & Visual-Perceptual Training; [a]Combined outcome = Driver safety rating and total driving errors; [b]Combined outcome = Thunder Bay and Winnipeg driving performance; [c]Combined outcome = Frequency of blind spot, external mirrors, and rearview mirror inspection; [d]Combined outcome = driving performance errors and overall rating. [e]Combined outcome = Test Ride for Investigating Practical Fitness to Drive score, Behavioral Observation score, Operational Sub-score, Tactical Sub-score, and Tactical Compensation Sub-score.

Study	Comparison	Outcome	Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
1	Active control group	Combined[a]	0.269	0.271	-0.262	0.800	0.991	0.322
2	No contact control group	Combined[b]	0.554	0.411	-0.251	1.359	1.349	0.177
3	Active control group	Combined[c]	0.613	0.379	-0.130	1.355	1.618	0.106
Subgroup *d* effect size for excellent quality studies			0.423	0.194	0.042	0.804	2.178	0.029
4	Active control group	Combined[d]	0.129	0.250	-0.360	0.618	0.517	0.605
5	Active control group	Combined[e]	2.636	0.865	0.941	4.331	3.048	0.002
6	Active control group	On-road driving performance	0.617	0.189	0.247	0.988	3.264	0.001
7	No contact control group	On-road driving performance	1.186	0.460	0.283	2.088	2.576	0.010
8	No contact control group	On-road driving performance	2.012	0.515	1.004	3.021	3.910	0.000
9	Active control group	On-road driving performance	1.222	0.302	0.629	1.814	4.042	0.000
10	Active control group	On-road driving performance	1.072	0.294	0.496	1.648	3.650	0.000
Subgroup *d* effect size for ≤ good quality studies			1.048	0.243	0.572	1.525	4.313	0.000
Overall *d* effect size			0.667	0.152	0.369	0.964	4.393	0.000

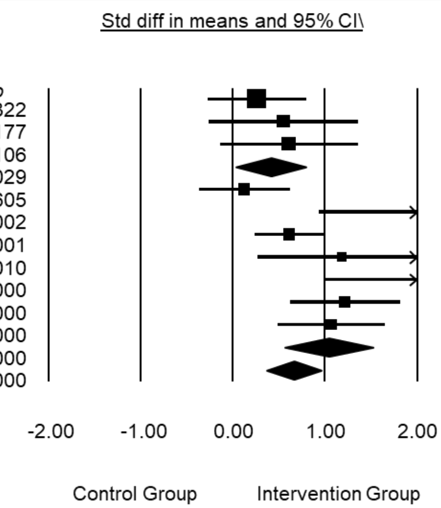

Figure 16. Forest Plot of Effect Sizes Using Random Effects for Combined Training Approaches on Driving Performance: Excellent vs. Good or Below Quality. [1]Anstey et al., 2018 (N = 55), Education & On-Road Training; [2]Bédard et al., 2008 (N = 29), Education & On-Road Training; [3]Porter, 2013 (N = 35), Education, Video, & Feedback; [4]Hay et al., 2016 (N = 67), Cognitive Training & Simulator Training; [5]Lavallière et al., 2012 (N = 22), Education, Simulator Training, & Feedback; [6]Marottoli, Van Hess et al., 2007 (N = 118), Education & On-Road Training; [7]McCoy et al., 1993 (N = 25), Education & Physical Retraining/Exercise; [8]McCoy et al., 1993 (N = 25), Education & Visual-Perceptual Training; [9]Sawula et al., 2018 (N = 52), Education & On-Road Training; [10]Sawula et al., 2018 (N = 53), Education, Simulator Training, & On-Road Training; [a]Combined outcome = Driver safety rating and total driving errors; [b]Combined outcome = Thunder Bay and Winnipeg driving performance; [c]Combined outcome = driving performance errors and overall rating; [d]Combined outcome = Test Ride for Investigating Practical Fitness to Drive score, Behavioral Observation score, Operational Sub-score, Tactical Sub-score, and Tactical Compensation Sub-score. [e]Combined outcome = Frequency of blind spot, external mirrors, and rearview mirror inspection.

Study	Comparison	Outcome	Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
1	Active control group	Combined[a]	0.269	0.271	-0.262	0.800	0.991	0.322
2	Active control group	Combined[b]	0.129	0.250	-0.360	0.618	0.517	0.605
3	Active control group	Combined[c]	2.636	0.865	0.941	4.331	3.048	0.002
4	Active control group	On-road driving performance	0.617	0.189	0.247	0.988	3.264	0.001
5	Active control group	Combined[d]	0.613	0.379	-0.130	1.355	1.618	0.106
6	Active control group	On-road driving performance	1.222	0.302	0.629	1.814	4.042	0.000
7	Active control group	On-road driving performance	1.072	0.294	0.496	1.648	3.650	0.000
Subgroup *d* effect size for active control group comparison			0.722	0.194	0.341	1.103	3.716	0.000
8	No contact control group	Combined[e]	0.554	0.411	-0.251	1.359	1.349	0.177
9	No contact control group	On-road driving performance	1.186	0.460	0.283	2.088	2.576	0.010
10	No contact control group	On-road driving performance	2.012	0.515	1.004	3.021	3.910	0.000
Subgroup *d* effect size for no contact control group comparison			1.206	0.417	0.390	2.023	2.895	0.004
Overall *d* effect size			0.809	0.176	0.463	1.154	4.592	0.000

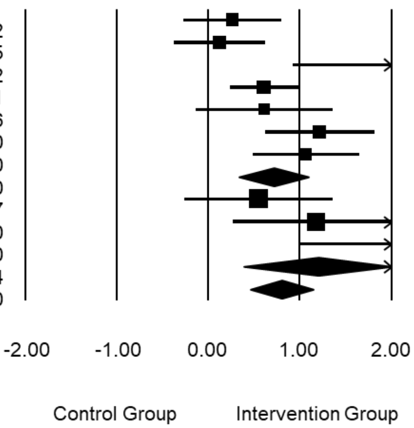

Figure 17. Forest Plot of Effect Sizes Using Random Effects for Combined Training Approaches on Driving Performance: Active vs. No Contact Control Groups. [1]Anstey et al., 2018 (N = 55), Education & On-Road Training vs. Education; [2]Hay et al., 2016 (N = 67), Cognitive Training & Simulator Training vs. Cognitive Training; [3]Lavallière et al., 2012 (N = 22), Education, Simulator Training, & Feedback vs. Simulator Training; [4]Marottoli, Van Hess et al., 2007 (N = 118), Education & On-Road Training vs. Home and Safety Training; [5]Porter, 2013 (N = 35), Education, Video, & Feedback vs. Education; [6]Sawula et al., 2018 (N = 52), Education & On-Road Training vs. Education; [7]Sawula et al., 2018 (N = 53), Education, Simulator Training, & On-Road Training vs. Education; [8]Bédard et al., 2008 (N = 29), Education & On-Road Training vs. No Contact Control Group; [9]McCoy et al., 1993 (N = 25), Education & Physical Retraining/Exercise vs. No Contact Control Group; [10]McCoy et al., 1993 (N = 25), Education & Visual-Perceptual Training vs. No Contact Control Group; [a]Combined outcome = Driver safety rating and total driving errors; [b]Combined outcome = Test Ride for Investigating Practical Fitness to Drive score, Behavioral Observation score, Operational Sub-score, Tactical Sub-score, and Tactical Compensation Sub-score; [c]Combined outcome = Frequency of blind spot, external mirrors, and rearview mirror inspection; [d]Combined outcome = driving performance errors and overall rating; [e]Combined outcome = Thunder Bay and Winnipeg driving performance.

Study name	Comparison	Outcome	Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
1	Active control group	Combined[a]	0.269	0.271	-0.262	0.800	0.991	0.322
2	No contact control group	Combined[b]	0.554	0.411	-0.251	1.359	1.349	0.177
3	Active control group	Combined[c]	0.129	0.250	-0.360	0.618	0.517	0.605
4	Active control group	Combined[d]	2.636	0.865	0.941	4.331	3.048	0.002
5	Active control group	Combined[e]	0.613	0.379	-0.130	1.355	1.618	0.106
Subgroup *d* effect size for combined driving performance outcome			0.505	0.240	0.034	0.976	2.103	0.035
6	Active control group	On-road driving performance	0.617	0.189	0.247	0.988	3.264	0.001
7	No contact control group	On-road driving performance	1.186	0.460	0.283	2.088	2.576	0.010
8	No contact control group	On-road driving performance	2.012	0.515	1.004	3.021	3.910	0.000
9	Active control group	On-road driving performance	1.222	0.302	0.629	1.814	4.042	0.000
10	Active control group	On-road driving performance	1.072	0.294	0.496	1.648	3.650	0.000
Subgroup *d* effect size for holistic driving performance outcome			1.095	0.211	0.681	1.509	5.180	0.000
Overall *d* effect size			0.837	0.159	0.526	1.148	5.277	0.000

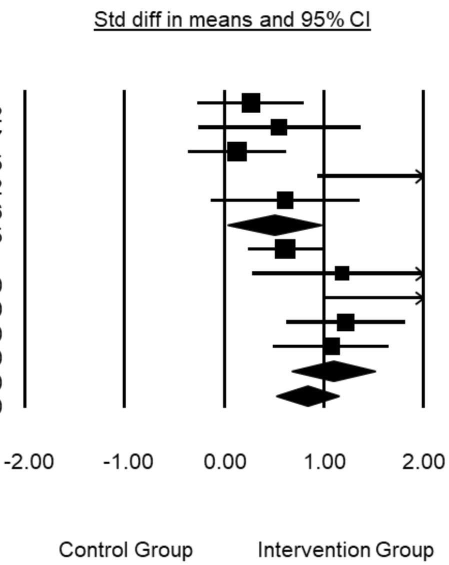

Figure 18. Forest Plot of Effect Sizes Using Random Effects for Combined Training Approaches on Driving Performance: Calculated Composite vs. Holistic Driving Performance Measures. [1]Anstey et al., 2018 (N = 55), Education & On-Road Training; [2]Bédard et al., 2008 (N = 29), Education & On-Road Training; [3]Hay et al., 2016 (N = 67), Cognitive Training & Simulator Training; [4]Lavallière et al., 2012 (N = 22), Education, Simulator Training, & Feedback; [5]Porter, 2013 (N = 35), Education, Video, & Feedback; [6]Marottoli, Van Hess et al., 2007 (N = 118), Education & On-Road Training; [7]McCoy et al., 1993 (N = 25), Education & Physical Retraining/Exercise; [8]McCoy et al., 1993 (N = 25), Education & Visual-Perceptual Training; [9]Sawula et al., 2018 (N = 52), Education & On-Road Training; [10]Sawula et al., 2018 (N = 53), Education, Simulator Training, & On-Road Training; [a]Combined outcome = Driver safety rating and total driving errors; [b]Combined outcome = Thunder Bay and Winnipeg driving performance; [c]Combined outcome = Test Ride for Investigating Practical Fitness to Drive score, Behavioral Observation score, Operational Sub-score, Tactical Sub-score, and Tactical Compensation Sub-score; [d]Combined outcome = Frequency of blind spot, external mirrors, and rearview mirror inspection. [e]Combined outcome = driving performance errors and overall rating.

Study name	Comparison	Outcome	Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
Gaines et al., 2011[1]	No contact control group	Driver-reported outcomes[a]	0.208	0.145	-0.077	0.493	1.432	0.152
Stowe et al., 2015[2]	No contact control group	Driver-reported outcomes[b]	-0.175	0.340	-0.842	0.491	-0.516	0.606
Overall *d* effect size			0.140	0.147	-0.148	0.427	0.952	0.341

Statistics for each study

Std diff in means and 95% CI

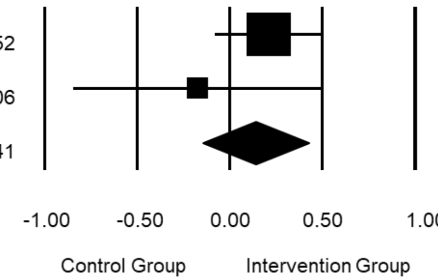

Figure 19. Forest Plot of Effect Sizes Using Random Effects for Education on Driver-Reported Outcomes. [1]CarFit intervention (N = 195); [2]Crash injury prevention intervention (N = 39); [a]Outcome = Driving Behaviors subscale to assess frequency of 26 safety-related driving behaviors at 6-month follow-up; [b]Outcome = Manchester Driving Behavior Questionnaire to assess the frequency of 27 safety-related driving behaviors combined at 1- and 6-month follow-up.

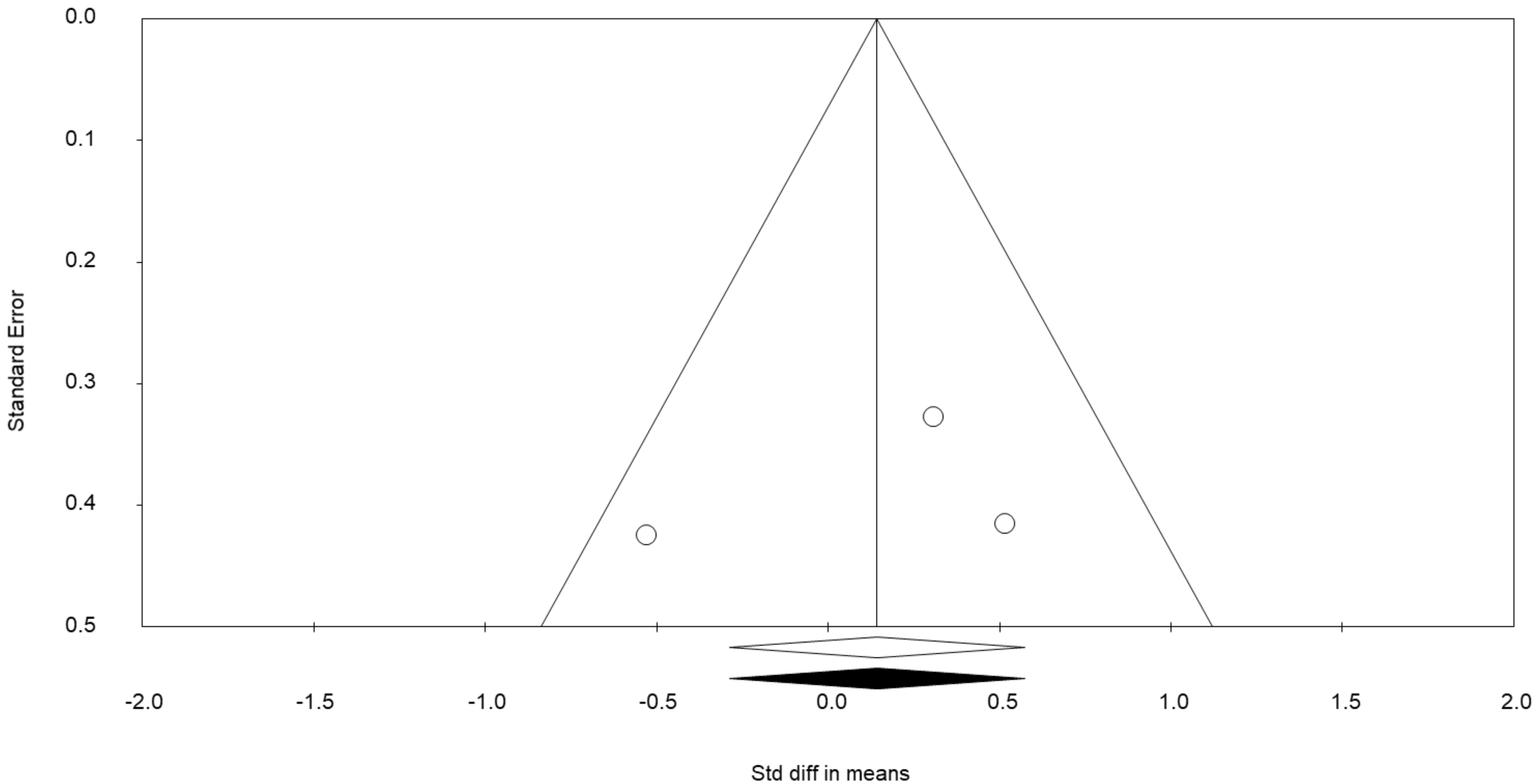

Figure 20. Funnel Plot of Standard Error by Cohen's *d* for Cognitive Training on Driving Simulator Performance

Study name	Comparison	Outcome	Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
			Statistics for each study					
Cuenen et al., 2016[1]	Active control group[4]	Combined[6]	0.308	0.327	-0.333	0.949	0.942	0.346
Nozawa et al., 2015[2]	Active control group[5]	Simulator performance	0.517	0.415	-0.297	1.330	1.245	0.213
Nozawa et al., 2015[3]	Active control group[5]	Simulator performance	-0.529	0.425	-1.361	0.303	-1.246	0.213
Overall *d* effect size			0.122	0.298	-0.461	0.706	0.411	0.681

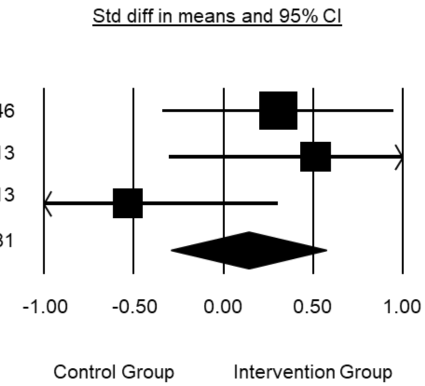

Figure 21. Forest Plot of Effect Sizes Using Random Effects for Cognitive Training on Driving Simulator Performance. Duval and Tweedie's trim and fill correction not needed. [1]Working memory training (N = 39); [2]In-vehicle cognitive training targeting speed of processing, executive control, divided attention, and working memory (N = 24); [3]Computer-based cognitive training targeting speed of processing, executive control, divided attention, and working memory (N = 23); [4]Non-adaptive working memory control group; [5]Crossword puzzles; [6]Combined outcome = simulator performance on crashes, driving speed, gap acceptance, right of way, and standard deviation of lane position.

Study name	Comparison	Outcome	Cohen's *d*	Standard error	Lower limit	Upper limit	*Z*	*p*
Urlings et al., 2019[a]	Active control group[1]	Combined[2]	-0.174	0.458	-1.072	0.723	-0.380	0.704
Urlings et al., 2019[b]	Active control group[2]	Combined[2]	-0.191	0.442	-1.057	0.675	-0.432	0.666
Overall *d* effect size			-0.183	0.318	-0.806	0.440	-0.575	0.565

Std diff in means and 95% CI

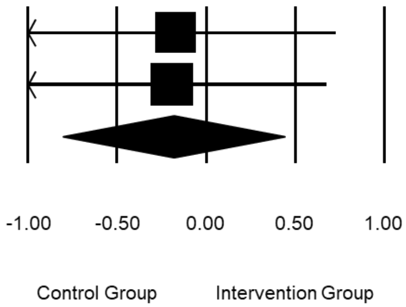

Figure 22. Forest Plot of Effect Sizes Using Random Effects for Context-Specific Interventions on Driving Simulator Performance. Duval and Tweedie's trim and fill correction not needed. [a]Computer-based context-specific training; [b]Simulator-based context-specific training; [1]Viewing simulator-based and computer-based scenarios with no feedback provided; [2]Combined outcome = overall driving simulator score ("TRIP"), speed, standard deviation of lane position, response time 2, gap 3, gap 4, and full stop 1.

CHAPTER THREE:

THE EFFECTIVENESS OF USEFUL FIELD OF VIEW COGNITIVE TRAINING TO REDUCE OLDER DRIVERS' AT-FAULT CRASH INVOLVEMENT

Introduction

Driving is an important component of quality of life and independence among older adults. Consequences associated with driving cessation are well-documented, ranging from increased social isolation (Curl et al., 2014), depressive symptomology (Marottoli et al., 1997) and risk for long-term care entry (Freeman et al., 2006). Some data show elevated crash rates among older adults (Hu et al., 2000; Insurance Institute for Highway Safety, 2017; S. Lyman et al., 2002). In addition, older drivers are more vulnerable to injuries and fatalities when involved in motor vehicle crashes (MVCs) (Li et al., 2003). These considerations support the development and implementation of interventions to promote older adults' safe driving mobility Such interventions should seek a balance between public safety concerns and older drivers' independence (Oxley & Whelan, 2008). One study and a review indicated Useful Field of View (UFOV®[4]) cognitive training may be an efficacious approach to reduce MVC involvement and reduce adverse driving events among older drivers relative to no contact controls (Ball et al., 2010; Edwards et al., 2018). However, the efficacy of such training to improve driving safety using adaptive techniques (i.e., the difficulty of the training exercises is tailored to the user's ongoing abilities) or relative to active controls across long periods of time has not been

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[4] UFOV® is a registered trademark licensed to Visual Awareness Research Group, Inc. http://www.visualawareness.com/Beta/privacy.htm

examined. Thus, the purpose of the current study was to examine the efficacy of adaptive Useful Field of View cognitive training to reduce older drivers' MVC involvement.

Predictors of MVC Involvement

Among older drivers, demographics, health, and functional factors impact one's driving safety (i.e., MVC involvement) (Anstey, Horswill, Wood, & Hatherly, 2012; Anstey et al., 2005; Cross et al., 2009; Karthaus & Falkenstein, 2016; Sims et al., 2000; Sims et al., 1998). Older age and non-white race are risk factors for prospective MVCs (Ball et al., 2006; Cross et al., 2009; Rubin et al., 2007). Males have higher rates of MVC involvement and are more likely to be involved in at-fault MVCs (Ball et al., 2006; Hu et al., 1998). A history of falls (Ball et al., 2006; Cross et al., 2009; Margolis et al., 2002) and fewer annual miles driven are associated with increased future crash involvement (Ball et al., 2006; Langford et al., 2013; Langford & Koppel, 2006; Margolis et al., 2002). For example, Margolis et al. (2002) reported that older drivers with a fall in the previous year had 1.53 times the risk of a MVC. Age-related changes in cognition as demonstrated by declines in speed of processing for visual attention tasks (e.g., Useful Field of View test; Ball et al., 1993; Clay et al., 2005; Cross et al., 2009; Goode et al., 1998; Haymes et al., 2007; Mathias & Lucas, 2009; Owsley et al., 1998; Rubin et al., 2007; Sims et al., 2000; Sims et al., 1998), visuomotor speed and attention set-switching (e.g., Trail Making Test B; Classen et al., 2008; Classen et al., 2013; Emerson et al., 2012; Friedman et al., 2013; Mathias & Lucas, 2009), and visual perception (e.g., the Motor-Free Visual Perception Test; Ball et al., 2006) are also predictive of MVCs. Overall, prospective risk factors of MVCs include older age, being male, not Caucasian, fewer annual miles driven, and age-related functional declines in physical health, visual perception, and cognition.

Of these risk factors, cognitive performance, particularly as measured by the UFOV test, is most strongly predictive of MVC involvement (for a review, see Clay et al., 2009). The UFOV test assesses speed of processing for visual attention tasks. To date, the divided attention subtest of the UFOV is the strongest predictor of prospective crashes in older adults, such that those who have a threshold of 353 ms or longer are 2.02 times as likely to incur an at-fault MVC (Ball et al., 2006). Across several prospective follow-up studies, UFOV remained a predictor of future MVCs after considering demographic and health factors (Ball et al., 2010; Cross et al., 2009; Owsley et al., 1998; Rubin et al., 2007; Sims et al., 2000).

UFOV Cognitive Training Reduces Future MVC Involvement

Given that UFOV performance is the strongest indicator of driving safety outcomes (Clay et al., 2005), it is not surprising that improving UFOV performance via cognitive training improves driving safety (Ball et al., 2010; Roenker et al., 2003). Longitudinal analysis from the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study examined the effects of three cognitive interventions on state-recorded at-fault crash involvement across six years (Ball et al., 2010). Participants were randomly assigned to one of four conditions: a no-contact control group or 10 one-hour sessions of memory training (i.e., learning mnenomic strategies), reasoning training (i.e., identifying patterns), or UFOV cognitive training (i.e., improving speed of processing for visual attention tasks). UFOV cognitive training reduced at-fault MVC rates per person-year and person-mile of driving exposure by almost 50% before and after controlling for covariates of age, sex, education, mental status, health, vision, depressive symptoms, and testing site. Reasoning training also demonstrated an approximate 50% reduction of at-fault MVCs after covariate adjustment only. The results indicated UFOV cognitive training and reasoning training reduced at-fault MVC rates as compared to the control condition.

Two studies have also examined the effects of UFOV cognitive training on indicators of driving safety other than crashes (American Automobile Association, 2016; Roenker et al., 2003). Among 7,000 older drivers insured by the American Automobile Association, there was a 30% reduction in collision claims in the subsequent six-months after completion of UFOV cognitive training. Roenker et al. (2003) examined the comparative efficacy of UFOV cognitive training versus a traditional driver training control group (i.e., driving simulator) and a low-risk reference group (who had intact UFOV performance at baseline) over an 18-month study period by assessing on-road driving performance. At baseline, the low-risk reference group demonstrated fewer dangerous maneuvers (defined as a maneuver in which, to avoid collision, other vehicles had to alter their course, or the driving instructor had to take control of the vehicle) than either the UFOV cognitive training or traditional driver training control groups. UFOV cognitive training and the traditional driver training did not differ from the low-risk reference group in number of hazardous maneuvers during the on-road driving evaluation at immediate post-training. Eighteen months later, UFOV cognitive training demonstrated significantly safer on-road driving (i.e., fewer hazardous maneuvers) than the low-risk reference or the traditional driver training groups.

Study Rationale

These studies provide evidence that UFOV cognitive training improves driving safety. Two longitudinal randomized trials are of particular relevance to the current study as they both utilized UFOV cognitive training: Staying Keen in Later Life (SKILL; Edwards, Wadley, Vance, Roenker, & Ball, 2005) and Accelerate (Vance et al., 2007). The SKILL and Accelerate studies found that UFOV cognitive training resulted in improved UFOV performance relative to an active control condition. Accelerate results indicated that such cognitive improvements endured over the subsequent two years. Results from Accelerate also showed immediate post-training improvements on the Starry Night Test, a measure of visual attention. Thus, both SKILL and Accelerate showed that UFOV cognitive training improved cognitive performance.

In addition, previous results from the SKILL study indicated improvements in everyday function including driving-related outcomes among those randomized to UFOV cognitive training (Edwards, Delahunt, et al., 2009; Edwards, Myers, et al., 2009; Edwards et al., 2005). SKILL reported transfer of UFOV cognitive training to improvements in everyday function, as indicated by Timed Instrumental Activities of Daily Living test performance (Edwards et al., 2005). Older drivers randomized to UFOV cognitive training self-reported fewer driving mobility declines and decreased driving difficulty after three years as compared to an active control group (Edwards, Myers, et al., 2009). Other analyses from SKILL revealed that older adults randomized to cognitive training were 40% less likely to cease driving over three years as compared to controls (Edwards, Delahunt, et al., 2009). Examination of the effects of UFOV cognitive training on MVCs from these two randomized trials is warranted. Thus far, the SKILL study has only examined self-reported driving-related outcomes. Driving outcomes have not been examined with Accelerate study data. Furthermore, SKILL and Accelerate had important methodological differences than the aforementioned ACTIVE study: SKILL and Accelerate both used adaptive training whereas ACTIVE used partially-adaptive training.

Adaptive training is a technique in which exercise difficulty adjusts to the participant’s ongoing performance (Lövdén, Backman, Lindenberger, Schaefer, & Schmiedek, 2010). In their model, Lövdén et al. (2010) purport that cognitive training programs utilizing adaptive techniques are more effective than non-adaptive training programs. Indeed, a recent meta-analysis indicates that as compared to controls, the effects of UFOV cognitive training on UFOV performance are larger for adaptive training versus non-adaptive or partially adaptive training (Edwards et al., 2018). In the ACTIVE study, UFOV cognitive training resulted in lower at-fault MVC involvement rates over six years relative to controls, but the first five sessions of training were non-adaptive, followed by five sessions of adaptive training. In SKILL and Accelerate, all 10 training sessions utilized adaptive techniques. Thus, given the transfer of training to lower MVC rates in the ACTIVE study, the adaptive training techniques used in SKILL and Accelerate may lend to larger reductions in MVC rates.

Purpose

The current study sought to determine the longitudinal impact of adaptive UFOV cognitive training on an objective measure of driving safety, at-fault MVCs per person-year of travel (primary outcome). The secondary outcome was at-fault MVCs per person-mile of travel. The primary outcome was chosen based on aforementioned results from the ACTIVE trial that UFOV cognitive training reduced at-fault crashes per person-year by almost 50% before and after covariate adjustment (Ball et al., 2010). At-fault MVCs per person-year was designated as the primary outcome as exposure was coded objectively (i.e., the years elapsed between date training completed, death or fixed follow-up date of crash records, January 18, 2017). The efficacy of UFOV cognitive training was determined by this primary outcome.

We also explored a secondary outcome, at-fault MVCs per person-mile (see Method section for more detail). Older driver research has called into question the accuracy of self-reported mileage driven (Staplin, Gish, & Joyce, 2008), with some reporting evidence that there is only moderate agreement between self-reported and actual driving behavior (Porter et al., 2015; Singletary et al., 2017) or no agreement (Thompson, Baldock, Mathias, & Wundersitz, 2016). Given the subjective and potentially less accurate information derived to calculate at-fault MVCs per person-mile, this outcome was designated as secondary. Despite the subjective nature of this measure of exposure, it is of interest to older driver researchers due to the issue of the "low mileage bias." The low mileage bias states that individuals who drive fewer miles per year have higher MVCs per person-mile, regardless of age (Hakamies-Blomqvist, 1998; Hakamies-Blomqvist, Raitanen, & O'Neill, 2002).

The hypothesis was that older drivers randomized to UFOV cognitive training would demonstrate lower at-fault MVC rates across 10 years as compared to the control condition. To address the study hypothesis, existing data from the SKILL (Edwards et al., 2005) and Accelerate (Vance et al., 2007) studies were combined with prospective state-reported crashes from the Alabama Department of Public Safety.

Method

Participants

The SKILL and Accelerate studies both examined the impact of cognitive training on cognitive abilities among older adults with impaired speed of processing for visual attention tasks (Edwards et al., 2005; Vance et al., 2007). To be included in training, participants were required to be at least 60 years old and have: a) a Mini-Mental State Examination score ≥ 23; b) far visual acuity of 20/80 or better with correction (if worn) for the SKILL study or far visual acuity of 20/40 or better with correction for the Accelerate study; c) contrast sensitivity ≥1.35 as measured by the Pelli-Robson Contrast Sensitivity Chart; and d) a processing speed impairment (as measured by UFOV subtest 2 score ≥ 150 ms or subtests 3 and 4 combined score ≥ 800 ms) (Edwards, Delahunt, et al., 2009; Edwards, Myers, et al., 2009; Edwards et al., 2005). Participants completed baseline and post-intervention assessments during which participants underwent sensory, cognitive, and everyday ability testing. Of the 1,052 participants who were screened for participation, 253 eligible participants were randomly assigned to 10 one-hour training sessions of either UFOV cognitive training or a social- and computer-contact control group. Those randomized who were current drivers at baseline were included in these analyses. Descriptive characteristics of the combined SKILL and Accelerate analytic sample by intervention group are displayed in Table 3. Further details of the SKILL and Accelerate studies can be found in prior publications (Edwards et al., 2005; Vance et al., 2007).

Measures

Intervention group. The independent variable, intervention group assignment (UFOV cognitive training or social and computer-contact control group), was examined as a predictor of subsequent at-fault MVC rates. Adherence (i.e., the mean number of sessions completed) is reported descriptively for both groups in Table 3.

Prospective state-reported crashes. The outcome variable was at-fault MVCs per person-year of travel, derived from the Alabama Department of Public Safety state records. The numerator for the rate outcome was the number of at-fault MVCs. We extracted fault status (fault or no-fault) using the "primary contributing unit" field from each record. Fault status was determined by the police officer on scene who gathered information regarding the circumstances surrounding the crash and all individuals involved.

The denominator (i.e., the exposure) for the primary outcome, person-years of travel, was calculated as the number of years elapsed between date training completed and date of death, driving cessation date, or January 18, 2017 (fixed follow-up date of crash records), whichever came first. Thus, the person-years exposure captured the possible number of years the participant could have driven during the follow-up period.

The denominator for the secondary outcome, person-miles of travel was calculated by multiplying each participants' person-years by their self-reported annual mileage at baseline. Annual mileage was derived from the question "How many miles do you drive in an average seven-day week?" (see Mobility Questionnaire below). Responses were multiplied by 52 weeks to obtain self-reported annual mileage during the follow-up period. The person-miles exposure was needed to reflect differences in opportunity to incur an at-fault MVC.

Mini-Mental State Examination (MMSE). The MMSE (Folstein, Folstein, & McHugh, 1975) is a measure of global mental status with scores ranging from 0 to 30 (higher scores indicate better performance). Participants were required to have a score of 23 or higher. The test-retest reliability of this measure ranges from .38 to .99 (Tombaugh & McIntyre, 1992).

Far visual acuity. A GoodLite Model 600A light box with ETDRS chart was used to measure binocular far visual acuity (with correction, if worn). The chart is designed to be read from a distance of ten feet and consists of nine increasingly smaller lines of letters (Good-Lite, 2007). Scores range from 0 (worst) to 90 (best) and can be converted to Snellen equivalents. Participants were required to have acuity of 20/80 or better for the SKILL study or 20/40 or better for Accelerate.

Contrast sensitivity. Visual contrast sensitivity was assessed binocularly (with correction, if worn) via the Pelli-Robson Contrast Sensitivity Chart (Pelli, Robson, & Wilkins, 1988). The chart contains eight rows of black letters on a white background that gradually decrease in contrast both from left to right and top to bottom. Each row consists of two sets of three letters. Scores were derived from the last set of triplets in which two letters were identified correctly, and the possible score range was 0.00 (poorest performance) to 2.25 $\log_{10}$ (best performance). Participants were required to have $\geq 1.35 \log_{10}$ contrast sensitivity.

UFOV test. The SKILL and Accelerate studies used the PC, touch, four-subtest version of the UFOV to measure cognitive speed of processing (Edwards et al., 2005). In each subtest, targets were displayed with durations ranging from 16.67 to 500 ms, and scores were the durations at which participants maintain 75% accuracy. The first subtest required participants to identify a central target (car or truck) that appeared in a fixation box. The second subtest required participants to identify the central target and simultaneously localize a peripheral target at one of eight radial locations. The third subtest mirrored the second subtest, except the peripheral target was embedded among visual distractors. The fourth and finals subtest involved the presentation of two objects in the central fixation box, and participants discriminated whether the two objects were the same or different. Total scores for the four-subtest UFOV ranged from 66.68 to 2000 ms. Inclusion criteria for UFOV were subtest 2 score $\geq$ 150 ms or subtests 3 and 4 combined score $\geq$ 800 ms.

Demographics. Age (Ball et al., 2006; Cross et al., 2009), sex (Ball et al., 2006), and race (Cross et al., 2009; Rubin et al., 2007) were considered as covariates as such factors are associated with MVC involvement rate.

Mobility Questionnaire. The Mobility Questionnaire was used to measure the extent of the participant's usual range of mobility, history of falls, and driving habits (Stalvey, Owsley, Sloane, & Ball, 1999). The Mobility Questionnaire was administered at baseline as well as three-year follow-up for the SKILL study. For the Accelerate study, the Mobility Questionnaire was administered at baseline as well as one- and two-year follow-up. This questionnaire provided self-reported baseline current driving status, driving cessation date, baseline driving exposure information, and history of falls at baseline.

Current driving status at baseline was assessed with the item, "For the purposes of our project, by current driver we mean someone who has driven a car within the last 12 months and someone who would drive a car today if they needed to. Using that definition, do you consider yourself a current driver?" with response choices yes (current driver) or no (not current driver). Date of driving cessation was calculated from this questionnaire using one- and two-year follow-up for Accelerate only and at three-year follow-up for SKILL by the item, "How long has it been since you last drove?" to which participants responded with number of years and/or months. Participants were deemed non-drivers at the follow-up date they reported "No" to current driver status and remained non-drivers for the rest of the study. For Accelerate, all participants who returned to one- (n = 57) or two-year (n = 44) follow-up remained current drivers. Given the self-reported nature of current driver status, participants may have reported "No" to current driver at one-year follow-up and then reported having resumed driving at two-year follow-up. However, no participants reported driving cessation at one-year follow-up and resumed driving at 2-year follow-up. For SKILL, five participants reported being non-drivers at three-year follow-up. Follow-up date minus the number of years/months since last driven was used as date of driving cessation. Two-week test-retest reliability for the current driver domain of the mobility questionnaire is r = .73 (Owsley et al., 1999). For either Accelerate or SKILL, those who did not attend the follow-up visits were considered to have remained current drivers.

Driving exposure, as defined as baseline mileage driven, was also extracted to calculate the secondary outcome as outlined earlier, at-fault MVCs per person-mile of travel (Langford et al., 2013; Langford & Koppel, 2006). At baseline, miles driven per week was determined by the question, "How many miles do you drive in an average seven-day week?" Test-retest reliability for the driving exposure domain is r = .83 (Owsley et al., 1999).

In addition, history of falls at baseline was determined by the question, "Have you had any falls in the last 2 months?" with response choices yes or no and was considered a covariate as a history of falls is related to increased MVC involvement rate (Ball et al., 2006; Cross et al., 2009; Margolis et al., 2002).

Trail Making Test B. The Trail Making Test B was used to assess visuomotor speed and attention set-switching (Tombaugh, 2004) and required the examinee to draw lines sequentially connecting 25 encircled numbers and letters in order (i.e., 1-A-2-B-3-C, etc.). Trail Making Test B performance was considered as a covariate in analyses given its potential to affect MVC involvement rate.

Study. Although the SKILL and Accelerate studies were conducted concurrently with overlapping inclusion measures and methods, study (SKILL = 0, Accelerate = 1) was considered as a covariate in analyses.

Analyses

Power analyses. A prior study of community-dwelling older adults found that UFOV cognitive training (n = 179) reduced at-fault crashes per person-year by 45% (rate ratio [*RR*] = 0.55) up to six years after study enrollment as compared to a no-contact control group (n = 409) (Ball et al., 2010). The no-contact control group had a base rate of .035 at-fault crashes per year. Using this base rate of at-fault crashes, the proposed sample size of 385 (n = 202 UFOV cognitive training, n = 183 social- and computer- contact control group) was sufficient to detect a *RR* of 0.44 with approximately seven years of data[5] and 90% power, according to G*Power (Faul, Erdefelder, Buchner, & Lang, 2009).

[5]Approximately seven years of crash data across the 10-year follow-up period for these analyses were available due to funding constraints.

Main analyses. To address the study hypothesis that older drivers randomized to UFOV cognitive training would demonstrate lower at-fault MVC rates per person-year of travel across 10 years as compared to the control condition, we followed established analytic techniques as in Ball et al. (2010). Thus, Poisson regression models using generalized estimating equations were carried out to calculate crude and adjusted *RR*s and 95% confidence intervals (CIs) for the association between intervention group (UFOV cognitive training or active control group) and at-fault MVC rates per person-year of travel. Variances were estimated using the robust variance estimator (Hardin & Hilbe, 2007).

First, at-fault MVC rates were calculated using per person-year of travel as the denominator i.e., the number of years elapsed between date of training completed and death, driving cessation date, or January 18, 2017 (fixed follow-up date of crash records), whichever came first. This measure of exposure captured the years each participant could have driven in the follow-up period.

We conducted *t*-tests for continuous variables and chi-square tests for categorical variables to identify any significant baseline group differences ($p < .05$) between randomized conditions on the following: age (Ball et al., 2006; Cross et al., 2009); sex (male) (Ball et al., 2006); race (Cross et al., 2009; Rubin et al., 2007); history of falls (Ball et al., 2006; Cross et al., 2009; Margolis et al., 2002); and Trail Making Test B performance (Classen et al., 2008; Classen et al., 2013; Emerson et al., 2012; Friedman et al., 2013; Mathias & Lucas, 2009) as such variables are associated with increased prospective MVC rates.

For the crude *RR*s, group assignment (UFOV cognitive training or social and computer-contact control group) was the independent variable and at-fault MVCs per person-year of travel, the dependent variable. This was the primary outcome.

For the adjusted *RR*s, the following steps were used for covariate selection in Poisson regression analyses: Step 1 included group assignment as the only predictor using the enter method in the Poisson regression model. Step 2 included any of the aforementioned variables (i.e., age, sex, race, history of falls, and Trail Making Test B) that significantly differed by group at baseline using the enter method. Step 3 added any of the following variables that were not entered in step 2: age, sex, race, history of falls, Trail Making Test B, and study site. A stepwise procedure was applied to the multivariate model either adding or deleting one variable at a time based on stepping criteria (i.e., $p < .05$ to enter and $p > .10$ to delete).

This hierarchical regression process was repeated using the at-fault MVCs per person-mile of travel as the dependent variable (i.e., the secondary outcome).

Sensitivity analyses were performed to examine the relationship between group assignment and the primary outcome, at-fault MVCs per person-year of travel, across seven- and five-year follow-up.

Analyses detailed above were pre-registered in Open Science Framework (https://osf.io/mejs3/?view_only=e182e3cbe3ec48a9aa2f5c444dc626fa).

Results

Of the 253 total SKILL and Accelerate participants who were current drivers at baseline and randomized, seven participants were excluded from analyses. Five participants were excluded due to missing data: one participant was missing race data and four participants were missing Trail Making Test B performance. An additional two participants quit driving before training completion date and were excluded from analyses. Analyses included 246 participants. There were no baseline differences between intervention groups on age (p =.198), sex (p = .755), race (p = .603), history of falls (p = .767), or Trail Making Test B performance (p = .105).

Descriptive statistics of the analytic sample by intervention group are reported in Table 3. A chi square-test of independence indicated no association between group assignment (UFOV cognitive training or social and computer-contact control group) and having an at-fault crash (yes or no), $\chi^2(1, N = 246) = 0.126, p = .723$.

Primary Outcome: At-Fault MVC Rates per Person-Year of Travel

A Poisson regression model using generalized estimating equations to account for clustering of repeated MVC events within study participants was conducted to calculate crude and adjusted *RR*s and 95% CIs for the association between intervention group and the primary outcome, at-fault MVC rates per person-year of travel. In step one, intervention group was added as the only predictor to calculate the crude *RR*. There was no significant association of UFOV cognitive training and at-fault MVC rates per person-year of travel, $p = .281$. As there were no baseline differences between groups on known risk factors of MVC involvement (age, sex, race, history of falls, Trail Making Test B performance), no covariates were added in step two. In step three, the aforementioned MVC risk factors plus study (SKILL or Accelerate) were subjected to stepwise selection procedure ($p < .050$ to add and $p > .100$ to delete). The only covariate to remain in the model after stepwise procedure in step three was study site. Those participants in the Accelerate study had an approximately 69.3% lower rate of an at-fault MVC per person-year of travel than the SKILL cohort, $RR = 0.307$, 95% CI [0.132, 0.714], $p = .006$. The model for the association between intervention group and at-fault MVC rates per person-year of travel remained non-significant after adjusting for study, $p = .761$.

Table 4 includes the crude and adjusted *RR*s for the association between intervention group and at-fault MVC rate per person-year of travel (primary outcome).

Crashes by study. Sensitivity analyses were performed to examine the relationship between study and at-fault crashes per person-year of travel. A chi-square test of independence indicated study (SKILL or Accelerate) was unrelated to having an at-fault crash (yes or no), $\chi^2(1, N = 246) = 1.359$, $p = .244$. The at-fault crash rate per person-year of travel was .023 in SKILL and .015 in Accelerate.

Planned sensitivity analyses for seven- and five-year follow-up. Pre-registered sensitivity analyses were conducted. We examined the relationship between group assignment and at-fault MVCs per person-year across seven years using the same steps outlined in analyses. Results are reported in Table 5. In step one, intervention group was added as the only predictor to calculate the crude *RR*. There was no significant association between intervention group and at-fault MVCs per person-year, $p = .557$. No covariates were added in step two as there were no baseline differences between groups. In step three following stepwise selection, the only covariate to remain significantly related to the primary outcome was study. Participants in the Accelerate study had a 68.5% lower rate of at-fault MVCs per person-year than those in the SKILL study, $p = .006$. After adjusting for study, the relationship between intervention group and at-fault MVCs per person-year of travel remained non-significant, $p = .557$.

Given we did not find UFOV cognitive training to be efficacious across seven years, we conducted planned sensitivity analyses to determine the efficacy of UFOV cognitive training to reduce at-fault MVC rates across five years. Results are reported in Table 6. In step one, the relationship between intervention group and at-fault MVCs per person-year of travel was not significant, $p = .806$. Step two did not include any covariates as there were no baseline differences between intervention groups. Step three did not include any significant covariates after stepwise selection. Thus, the crude *RR* remained unadjusted and indicated no significant association between intervention group and at-fault MVCs across five years, *RR* = 0.903, 95% CI [0.399, 2.043], *p* = .806 (see Table 6).

Secondary Outcome: At-Fault MVC Rates per Person-Mile of Travel

A separate Poisson regression model using generalized estimating equations was conducted to examine the association between intervention group and the secondary outcome, at-fault MVC rates per person-mile of travel. Two additional participants of the *n* = 246 analytic sample used in primary outcome calculations were excluded due to missing data (2.7%). One participant reported driving zero miles per week at baseline despite reporting being a current driver. Another participant had missing baseline miles per week driven despite reporting being a current driver. Thus, the at-fault MVC rates per person-mile of travel could not be calculated for these two participants as the denominator was zero. The analytic sample for the secondary outcome included 244 participants. There were no baseline differences between intervention groups on age, sex, race, history of falls, or Trail Making Test B performance, *p*s > .050.

In step one, intervention group was added as the only predictor in the model to calculate the crude *RR* and 95% CI. There was no significant association of UFOV cognitive training and at-fault MVC rates per person-mile of travel, *p* = .816. As in primary outcome analyses, there were no baseline differences between groups on potential covariates (age, sex, race, history of fails, Trail Making Test B performance). Thus, no covariates were added in step two. In step three, all potential covariates plus study site were added and subjected to stepwise selection procedure. The only covariate to remain in the model after stepwise procedure in step three was sex. Females had more than three times the rate of at-fault MVCs per person-mile of travel as compared to males, *RR* = 3.183, 95% CI [1.603, 6.320], *p* = .001. The model for the association between intervention group and at-fault MVC rates per person-mile of travel remained unchanged after adjusting for sex, p = .958.

Table 7 displays the crude and adjusted *RR*s for the association between intervention group and at-fault MVC rate per person-mile of travel (secondary outcome).

Crashes by sex. Sensitivity analyses were performed to investigate the significant association between sex and at-fault crashes per person-mile of travel. Chi-square tests of independence indicated sex (male or female) was not related to having an at-fault crash (yes or no), $\chi^2(1, N = 244) = 1.634$, $p = .201$. The at-fault crash rate per person-mile of travel was .00000256 among males and .00000554 among females.

Crash Rates and Characteristics

Table 8 includes the number of MVCs, at-fault MVCs, person-years of travel, person-miles of travel, at-fault MVCs per person-year (primary outcome), and at-fault MVCs per person-mile (secondary outcome) by intervention group.

Twenty-eight participants had one at-fault crash, 11 had two at-fault crashes, and one participant had three at-fault crashes. The rate of at-fault MVCs per person-year of travel for the UFOV cognitive training group was .020 and social-and computer-contact control group was .021.

Discussion

This study examined the longitudinal impact of adaptive UFOV cognitive training on at-fault MVCs per person-year of travel (primary outcome) and per person-mile of travel (secondary outcome). The hypothesis that those randomized to UFOV cognitive training would demonstrate lower at-fault MVC rates across 10 years as compared to the control condition was not supported. Our results showed that older adults with processing speed impairments randomized to UFOV cognitive training did not demonstrate significantly lower at-fault crashes rates across 10 years, regardless of exposure metric used. However, the achieved power was .18 given an analytic sample of 246 and a base at-fault MVC rate of .021 (α = .05, two-tailed test).

This is the first study to examine objectively-measured driving outcomes for the SKILL and Accelerate trials, but this is not the first study to examine such outcomes in a cognitive training trial. In the ACTIVE trial, UFOV cognitive training (*n* = 179) resulted in approximately 50% lower at-fault MVCs per person-year than a no-contact control group (*n* = 409), before and after controlling for age, sex, race, education, Mini-Mental State Examination score, self-rated health status, vision, depression, and site (Ball et al., 2010). The ACTIVE trial reported a base rate of .035 at-fault MVCs per person-year.

The current study demonstrated that UFOV cognitive training (*n* = 129) resulted in 32% lower at-fault MVC rates as compared to a social- and computer-contact control group (*n* = 119) but this effect did not achieve statistical significance. After adjusting for study, UFOV cognitive training demonstrated an 11% lower rate as compared to the control group but again did not achieve statistical significance. The current study reported a base rate of at-fault MVCs per person-year of .020 which is lower than the base rate of .035 at-fault MVCs per person-year in the ACTIVE trial. Thus, although the results from the ACTIVE trial were not replicated in the SKILL and Accelerate combined sample, this is likely due to inadequate power and the relative rarity of prospective crashes.

Additionally, there are three notable methodological differences between the ACTIVE trial and the combined SKILL and Accelerate studies: sample, length of the follow-up period, and booster sessions. Whereas SKILL and Accelerate examined community-dwelling older adults with processing speed impairments (i.e., impaired UFOV performance), the ACTIVE trial included community-dwelling older adults with no processing speed impairments or suspected cognitive decline. Also, the analyses by Ball et al. (2010) using ACTIVE data included a follow-up period of six years versus the 10-year follow-up period in the current study. To address this methodological difference, sensitivity analyses in the current paper were conducted to determine if adaptive UFOV cognitive training was efficacious across shorter periods of follow-up (i.e., seven and five years). However, there remained no significant reduction of at-fault MVCs for either time interval. Given these methodological differences and disparate findings, it is possible that the durability of UFOV cognitive training effects depend on the baseline abilities of the sample and the length of the follow-up period.

In the ACTIVE study, booster sessions were implemented for a sub-sample of participants. The purpose of booster sessions was to prolong the durability of training. Although participants with booster sessions were not included in the analyses by Ball et al. (2010) nor were booster sessions part of SKILL and Accelerate methodology, there is evidence that additional sessions further enhanced UFOV performance and such gains were maintained at two-year follow-up in the original ACTIVE trial analyses (Ball et al., 2002). In subsequent ACTIVE sub-analyses, booster sessions were associated with greater transfer to everyday functioning (Ball, Ross, Roth, & Edwards, 2013) as well as lowered risk of dementia (Edwards et al., 2017). Given the importance of training dose, perhaps booster sessions could have enhanced the durability of training gains in the current study.

In another study, UFOV cognitive training improved driving safety across 18 months among individuals with processing speed impairments (Roenker et al., 2003). Roenker and colleagues (2003) examined the efficacy of UFOV cognitive training versus a driving simulator training (control group) to improve on-road driving performance. A low-risk reference group with no processing speed impairment was also included to serve as an additional comparison group. At immediate post-test, both training groups demonstrated decreases in dangerous driving maneuver frequency and did not differ from the low-risk reference group. At 18-month follow-up, UFOV cognitive training demonstrated significantly fewer dangerous driving maneuvers than either the low-risk reference group or the driving simulator training groups. Thus, UFOV cognitive training improves driving safety, but the durability of the benefits is unknown. It is possible that the benefits of UFOV cognitive training may dissipate across longer follow-up periods, given the findings of reduced at-fault crashes in the ACTIVE trial and fewer dangerous maneuvers in Roenker et al. (2003). A better powered study would be able to reconcile ACTIVE findings versus the SKILL/Accelerate findings reported here and also help clarify the durability of UFOV cognitive training effects.

For the primary outcome, study emerged as a significant covariate in analyses. That is, Accelerate participants had approximately 70% lower at-fault MVC rates than SKILL participants. These studies had overlapping inclusion criteria and measures which merited a combined dataset for the current analyses. However, one notable difference between studies was SKILL participants were required to have visual acuity of 20/80 or better while Accelerate required 20/40 or better. In Alabama where both studies were conducted, the visual acuity requirements to renew a non-restricted driver’s license is 20/40 with or without correction. If acuity is worse than 20/40, individuals must have a minimum of 20/60 or better with or without correction and are referred to a vision specialist (American Automobile Association Foundation for Traffic Safety, 2016). Perhaps the more conservative visual acuity criteria for Accelerate selected individuals who did not have driving restrictions, state- or self-imposed, while those who met SKILL criteria likely already had driving restrictions. Future clinical trials of driving interventions should consider state-specific licensing policies and how they impact the actual driving behavior of older adults.

For the secondary outcome, sex was a significant covariate such that females had more than three times the rate of males to incur an at-fault crash per person-mile. This is consistent with evidence stating that females have higher crash involvement per distance traveled as compared to males (Hu et al., 1998; Ryan, Legge, & Rosman, 1998). Older female drivers tend to drive fewer miles annually and have increased avoidance behaviors (Charlton et al., 2006). Because older female drivers have lower annual mileage than same-age males, there appears to be overinvolvement of females in non-fatal crashes when annual mileage driven is the exposure metric (Langford et al., 2013). The results in this study lend support for the low-mileage bias (Hakamies-Blomqvist et al., 2002; Hakamies-Blomqvist, Wiklund, & Henriksson, 2005; Staplin et al., 2008). That is, at-risk older drivers with self-imposed restrictions drive less and are likely to drive in riskier scenarios (urban settings instead of freeways), producing a higher crash risk per mile (Antin et al., 2017). By taking into account annual mileage, it is apparent that although females in the current study did have a higher number of at-fault crashes than males (36 for females; 25 for males), females also drove significantly fewer total miles across the 10-year follow-up period (6,503,861.54 miles for females and 9,784,590.93 miles for males which translates to about 4,169.14 miles driven per month for females and 7,152.48 miles driven per month for males).

Other known risk factors for at-fault crashes (i.e., older age, non-white race, history of falls, and poorer Trail Making Test B performance) were not prospectively predictive of at-fault crash rate per person-year or person-mile in this study. This may be attributable to SKILL and Accelerate study inclusion for randomization of only individuals with a processing speed impairment (as measured by UFOV subtest 2 score ≥ 150 ms or subtests 3 and 4 combined score ≥ 800 ms). Findings spanning large-scale epidemiological, cross-sectional, retrospective, prospective, and meta-analytic studies demonstrate a strong link between poorer UFOV performance and increased crash involvement (Ball et al., 2006; Clay et al., 2005; Cross et al., 2009; Friedman et al., 2013; Margolis et al., 2002; Owsley et al., 1998; Rubin et al., 2007; Sims et al., 2000; Sims et al., 1998). However, the majority of these studies were population-based. With data derived from two RCTs in the current study, only individuals with processing speed impairments were randomized to group (UFOV cognitive training or social- and computer-contact control group), effectively removing the influence of UFOV performance. That older age, non-white race, history of falls, and poorer Trail Making Test B performance were not associated with increased at-fault crash involvement suggests UFOV performance is the strongest predictor of at-fault crash involvement above and beyond demographic and other cognitive predictors.

The current study is limited by self-reported driving data, especially across a long follow-up period. Date of driving cessation could not be verified as only baseline and three-year follow-up data were available for SKILL and baseline, one- and two-year follow-up were available for Accelerate. Only five baseline drivers reported quitting driving for SKILL three-year follow-up. No baseline drivers in Accelerate reported having quit driving at one- or two-year follow-up. Thus, it is reasonable to question whether only five participants truly stopped driving from three-year follow-up through the fixed date of January 18, 2017. Another limitation was that mileage driven could only be extracted from baseline for secondary outcome calculations. However, high-risk individuals such as those in the current study likely decreased their annual mileage over time (Edwards, Myers, et al., 2009).

Conclusion

Overall, these results suggest that adaptive UFOV cognitive training has the potential to reduce at-fault crash rates over 10 years given the 32% reduction in at-fault crashes per person-year of travel. However, this study was limited by inadequate power and even proportionally fewer at-fault crashes than the ACTIVE trial. Sensitivity analyses did not reveal efficacy of adaptive UFOV cognitive training to reduce at-fault crashes across shorter periods of time. Future research should further explore the durability of adaptive UFOV cognitive training to reduce at-fault crashes, especially among those at risk for future crashes, across shorter follow-up periods, in a well-powered study. In addition, future longitudinal study design should consider the changes in mobility across time (i.e., annual mileage reported at subsequent follow-ups) as well as incorporate more naturalistic measures of driving exposure.

Table 3

Summary Statistics for Analytic Sample by Intervention Group (N = 246)

	UFOV Cognitive Training (*n* = 129)		Social- and Computer-Contact Control (*n* = 117)	
Measure	*M* (*n*)	*SD* (%)	*M* (*n*)	*SD* (%)
Age (years)	74.60	5.54	75.55	5.98
Sex (female)	(68)	(52.71)	(64)	(54.70)
Race (Caucasian)	(108)	(83.72)	(95)	(81.20)
Education (years)	13.88	2.51	13.68	2.48
Mini-Mental State Examination (23-30)	28.16	1.45	27.98	1.61
Far Visual Acuity (LogMAR)	70.41	13.56	69.62	13.05
Contrast Sensitivity (Log_{10} contrast)	1.65	0.14	1.64	0.12
Useful Field of View test (ms)	1107.63	204.25	1111.38	191.53
History of Falls (Yes)	(16)	(12.40)	(16)	(13.68)
Trails Making Test B (s)	146.55	86.30	165.68	97.94
Number of Training Sessions Completed	9.12	2.01	9.28	1.80

Note. No significant differences at *p*s < .05, .01, or .001. by intervention group as indicated by t-tests for continuous variables and chi-square tests for categorical variables.

Table 4

Association of Intervention Group and At-Fault Motor Vehicle Collision (MVC) Rate Per Person-Year of Travel (Primary Outcome) Across 10 Years

Variable	Rate Ratio (*RR*)	95% Confidence Interval
Step 1: Crude *RR*		
Intervention Group (UFOV cognitive training)[a]	0.67	0.33 – 1.39
Step 2: Addition of variables differing at baseline for		
Adjusted *RR*: No baseline differences		
Step 3: Stepwise selection of variables for Adjusted *RR*		
Intervention Group (UFOV cognitive training)[a]	0.89	0.40 – 1.99
Age	1.05	0.96 – 1.15
Sex (Female)[b]	1.15	0.51 – 2.56
Race (Other)[c]	1.18	0.37 – 3.75
History of Falls (No)[d]	0.53	0.15 – 1.84
Trail Making Test B	0.80	0.47 – 1.35
Study (Accelerate)[e]	0.35	0.15 – 0.79*
Adjusted *RR*		
Intervention Group (UFOV cognitive training)[a]	0.89	0.40 – 1.94
Study (Accelerate)[e]	0.31	0.13 – 0.71**

Note. [a]Social- and computer-contact control group = reference; [b]Male = reference; [c] = White/Caucasion = reference; [d] History of falls-Yes = reference; [e]Staying Keen in Later Life = reference. Analyses for primary outcome included 246 participants. $^{*}p < .05$, $^{**}p < .01$.

Table 5

Association of Intervention Group and At-Fault Motor Vehicle Collision (MVC) Rate Per Person-Year of Travel (Primary Outcome) Across Seven Years

Variable	Rate Ratio (*RR*)	95% Confidence Interval
Step 1: Crude *RR*		
Intervention Group (UFOV cognitive training)[a]	0.80	0.38 – 1.68
Step 2: Addition of variables differing at baseline for		
Adjusted *RR*: No baseline differences		
Step 3: Stepwise selection of variables for Adjusted *RR*		
Intervention Group (UFOV cognitive training)[a]	0.85	0.40 – 1.82
Age	0.98	0.92 – 1.05
Sex (Female)[b]	1.57	0.73 – 3.38
Race (Other)[c]	1.24	0.36 – 4.34
History of Falls (No)[d]	0.74	0.27 – 2.04
Trail Making Test B	0.89	0.53 – 1.50
Study (Accelerate)[e]	0.32	0.14 – 0.72**
Adjusted *RR*		
Intervention Group (UFOV cognitive training)[a]	0.80	0.38 – 1.68
Study (Accelerate)[e]	0.30	0.14 – 0.67**

Note. [a]Social- and computer-contact control group = reference; [b]Male = reference; [c] = White/Caucasion = reference; [d] History of falls-Yes = reference; [e]Staying Keen in Later Life = reference. Analyses for primary outcome included 246 participants. $^{*}p < .05$, $^{**}p < .01$.

Table 6

Association of Intervention Group and At-Fault Motor Vehicle Collision (MVC) Rate Per Person-Year of Travel (Primary Outcome) Across Five Years

Variable	Rate Ratio (*RR*)	95% Confidence Interval
Step 1: Crude *RR*		
Intervention Group (UFOV cognitive training)[a]	0.90	0.40-2.04
Step 2: Addition of variables differing at baseline for		
Adjusted *RR*: No baseline differences		
Step 3: Stepwise selection of variables for Adjusted *RR*		
Intervention Group (UFOV cognitive training)[a]	0.87	0.39-1.95
Age	0.99	0.93-1.05
Sex (Female)[b]	1.96	0.86-4.46
Race (Other)[c]	1.16	0.24-5.65
History of Falls (No)[d]	0.97	0.35-2.69
Trail Making Test B	0.82	0.45-1.50
Study (Accelerate)[e]	0.49	0.21-1.15
Adjusted *RR*		
Intervention Group (UFOV cognitive training)[a]	0.90	0.40-2.04

Note. [a]Social- and computer-contact control group = reference; [b]Male = reference; [c] = White/Caucasion = reference; [d] History of falls-Yes = reference; [e]Staying Keen in Later Life = reference. Analyses for primary outcome included 246 participants.

Table 7

Association of Intervention Group and At-Fault Motor Vehicle Collision (MVC) Rate Per Person-Mile of Travel (Secondary Outcome) Across 10 Years

Variable	Rate Ratio (*RR*)	95% Confidence Interval
Step 1: Crude *RR*		
Intervention Group (UFOV cognitive training)[a]	0.92	0.47 – 1.81
Step 2: Addition of variables differing at baseline for		
Adjusted *RR*: No baseline differences		
Step 3: Stepwise selection of variables for Adjusted *RR*		
Intervention Group (UFOV cognitive training)[a]	1.00	0.52 – 1.92
Age	0.99	0.92 – 1.06
Sex (Female)[b]	3.09	1.45 – 6.59**
Race (Other)[c]	1.26	0.40 – 3.96
History of Falls (No)[d]	0.76	0.24 – 2.43
Trail Making Test B	0.88	0.53 – 1.45
Study (Accelerate)[e]	0.95	0.51 – 1.78
Adjusted *RR*		
Intervention Group (UFOV cognitive training)[a]	0.93	0.51 – 1.89
Sex (Female)[e]	3.18	1.60 – 6.32**

Note. [a]Social- and computer-contact control group = reference; [b]Male = reference; [c] Race White/Caucasion = reference; [d] History of falls-Yes = reference; [e]Staying Keen in Later Life = reference. Analyses for secondary outcome included 244 participants. *$p < .05$, **$p < .01$.

Table 8

Number of MVCs, At-Fault MVCs, Person-Years of Travel, Person-Miles of Travel, At-Fault MVCs Per Person-Year (Primary Outcome), and At-Fault MVCs Per Person-Mile (Secondary Outcome) by Intervention Group

Factor	UFOV Cognitive Training (*n* = 129)	Social- and Computer-Contact Control (*n* = 117)
Total MVCs	49	41
Total At-Fault MVCs (A)	28	25
Total Person-Years of Travel (B)	1,386.13	1,175.72
Total Person-Miles of Travel (C)*	8,927,900.48	7,360,551.99
Primary Outcome: Total At-Fault MVCs/Person-Year (A/B)	0.020	0.021
Secondary Outcome: Total At-Fault MVCs/Person-Mile (A/C)*	0.00000314	0.00000340

Note. *Secondary outcome could not be calculated for two participants

CHAPTER FOUR:

OVERALL CONCLUSION

As the older adult population continues to burgeon and age-related functional declines pose increasing risk to driver safety, identifying efficacious interventions to improve safe driving mobility are of utmost public health importance (Windsor & Anstey, 2006). Some projections estimate that police-reported crashes will increase among older adults in the upcoming decades (Hu et al., 2000; S. Lyman et al., 2002). In addition, with increasing longevity, older adults are staying on the roads later in life than previous cohorts and are driving more miles annually (Coughlin, 2000). There is also evidence that after age 75 or older, older adults demonstrate excessive crash risk as well as increased fragility, making them more vulnerable to injury than their younger driver counterparts (Li et al., 2003). The findings from these two dissertation studies address some of these concerns by providing updated knowledge on older driver interventions to improve safety. Consistent with the aforementioned common cause theory of cognitive aging and the multifactorial model of enabling driving safety, this dissertation supported that age-related cognitive and non-cognitive declines (physical and sensory function) that impact everyday function (e.g., driving abilities and safety) can be targeted to help maintain older drivers' safety driving mobility. In other words, these simultaneous declines increase driving safety risks, but we can mitigate these risks through skill-specific remediation.

The first study was a systematic review and meta-analysis of randomized clinical trials that examined a driving intervention among older adults aged 50+. A handful of systematic reviews on this topic exist (Golisz, 2014; Korner-Bitensky et al., 2009; Kua et al., 2007;

Unsworth & Baker, 2014) and only one meta-analysis published in 2008 exists, to our knowledge (Desapriya et al., 2008). The results showed that physical retraining/exercise and visual-perceptual training improved driving performance. Cognitive training reduced crashes per person-time and person-mile by almost 30%. Combined training approaches resulted in better driving performance among those trained particularly those that incorporated physical retraining, visual-perceptual or cognitive training as a component. Context-specific training and educational approaches alone did not show differential improvement as compared to control groups. Overall, these results demonstrated that skill-specific training (physical retraining/exercise, visual-perceptual training, and cognitive training) and combined training are efficacious approaches to improve driving safety in older adults. Future research should use factorial intervention designs to determine which component(s) of combined training most saliently improve driving safety.

In the second study, we examined the longitudinal impact of adaptive UFOV cognitive training on at-fault crash involvement across 10 years. Data from the SKILL and Accelerate studies were combined with prospective state-reported crashes. This study sought to extend the ACTIVE trial results that UFOV cognitive training significantly reduced at-fault crashes up to six years by almost 50% as compared to the no contact control condition (Ball et al., 2010). Unlike the ACTIVE trial, the 10 sessions of UFOV cognitive training were all adaptive, such that the difficulty of the exercises adjusted to the participant's ongoing performance. Given evidence that adaptive training techniques are more effective than non-adaptive techniques, it was hypothesized that the effects of adaptive UFOV cognitive training used in SKILL and Accelerate would lead to larger reductions in at-fault crashes. Results from this study showed that adaptive UFOV cognitive training did not significantly reduce at-fault crash involvement per person-year or person-mile across ten years. Sensitivity analyses also did not show efficacy of UFOV cognitive training to reduce at-fault crashes across seven- or five-year follow-ups. However, these analyses were limited by inadequate power and even smaller base rates of at-fault crashes than the ACTIVE trial. Given the 32% reduction in at-fault MVCs per person-year in favor of UFOV cognitive training, these findings lend further evidence of the benefits and optimization of this training to help older drivers safe driving mobility and ultimately maintain their health, well-being and independence longer.

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APPENDIX A: ASPREDICTED PRE-REGISTRATION FOR A SYSTEMATIC REVIEW AND META-ANALYSIS OF OLDER DRIVER INTERVENTIONS

ASPREDICTED

CONFIDENTIAL - FOR PEER-REVIEW ONLY

A review and meta-analysis of older driver interventions (#24322)

Created: 06/03/2019 03:46 PM (PT)

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This pre-registration is not yet public. This anonymized copy (without author names) was created by the author(s) to use during peer-review. A non-anonymized version (containing author names) will become publicly available only if an author makes it public. Until that happens the contents of this pre-registration are confidential.

1) **Have any data been collected for this study already?**

   No, no data have been collected for this study yet.

2) **What's the main question being asked or hypothesis being tested in this study?**

   The overall goal is to summarize and quantify the efficacy of older driver interventions in a systematic review and meta-analysis.

3) **Describe the key dependent variable(s) specifying how they will be measured.**

   The following domains of driving-related outcomes i.e., dependent variables, that will be examined in this systematic review and meta-analysis are 1) crashes; 2) driving performance; 3) driver-reported outcomes; and 4) driving simulator performance. The outcome of crashes will be searched using the following terms: Crashes; Motor vehicle crashes; Motor vehicle collisions; MVC; Crash risk; and Crash rate. The outcome of driving performance will be searched using the following terms: On-road driving; Closed road circuit; Road performance; Driving performance; and Driving test. The outcome of driver-reported outcomes will be searched using the following terms: Self-reported driving errors and Self-reported crash. The outcome of driving simulator performance will be searched using the following terms: Simulator performance and Driving simulator.

4) **How many and which conditions will participants be assigned to?**

   Studies of older adults (55 years of age and older) that examined a driving intervention in a randomized clinical trial will be included. Thus, the driving intervention may be compared to one or more of the following conditions:

1) A no-contact control group- Older drivers receive no intervention
2) A wait-list control group- Older drivers receive the intervention only after the study period ends (e.g., after post-test)
3) An active control group- Older drivers receive instruction on a topic unrelated to driving safety

5) Specify exactly which analyses you will conduct to examine the main question/hypothesis.

Intervention programs will be grouped by the following content types: 1) physical exercise; 2) visual/perceptual training; 3) cognitive training; 4) education; and 5) combined approaches. The dependent variables will be grouped by 1) crashes; 2) driving performance; 3) driver-reported outcomes; and 4) driving simulator performance. Cohen's d effect sizes will be calculated for each intervention type on each outcome domain using random effects. Publication bias will be examined using funnel plots and Egger's regression. Duval and Tweedie's trim-and-fill analysis will be used in the case of publication bias. In addition, heterogeneity statistics including Cochran's Q-statistic and I2-statistic will be reported. Finally, fail safe Ns will be calculated to determine how many studies would be needed to render a significant difference no longer significant.

6) Describe exactly how outliers will be defined and handled, and your precise rule(s) for excluding observations.

This is a proposed systematic review and meta-analysis, thus handling/definition of outliers and exclusions of observations is not applicable.

7) How many observations will be collected or what will determine sample size? No need to justify decision, but be precise about exactly how the number will be determined.

The sample size will be determined by how many randomized clinical trials are identified in the systematic literature review search. If there are two studies on a particular intervention and outcome, an effect will be calculated.

8) Anything else you would like to pre-register? (e.g., secondary analyses, variables collected for exploratory purposes, unusual analyses planned?)

Nothing else to pre-register.

Verify authenticity: http://aspredicted.org/blind.php?x=c6mi2z

Version of AsPredicted Questions: 2.00

Wharton UNIVERSITY of PENNSYLVANIA CREDIBILITY LAB

APPENDIX B: PEDRO SCALE

1. Eligibility criteria were specified no yes where:

2. Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received) no yes where:

3. Allocation was concealed no yes where:

4. The groups were similar at baseline regarding the most important prognostic indicators no yes where:

5. There was blinding of all subjects no yes where:

6. There was blinding of all therapists who administered the therapy no yes where:

7. There was blinding of all assessors who measured at least one key outcome no yes where:

8. Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups no yes where:

9. All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by "intention to treat" no yes where:

10. The results of between-group statistical comparisons are reported for at least one key outcome no yes where:

11. The study provides both point measures and measures of variability for at least one key outcome no yes where:

APPENDIX C: OPEN SCIENCE FRAMEWORK PRE-REGISTRATION FOR PAPER #2: THE EFFECTIVENESS OF USEFUL FIELD OF VIEW COGNITIVE TRAINING TO REDUCE OLDER DRIVERS' CRASH INVOLVEMENT

Authors: Bernadette A. Fausto, MS, Jerri D. Edwards, PhD, Lesley A. Ross, PhD & Karlene K. Ball, PhD

This Pre-Registration can be viewed publicly online at the following link:

https://osf.io/mejs3/?view_only=e182e3cbe3ec48a9aa2f5c444dc626fa

1) **Data collection.** Have any data been collected for this study already?
    a. Yes, we already collected the data.
    b. No, no data have been collected for this study yet.
    c. It's complicated. We have already collected some data but explain in Question 8 why readers may consider this a valid pre-registration nevertheless.

    (Note: "Yes" is not an accepted answer.)

2) **Hypothesis.** What's the main question being asked or hypothesis being tested in this study?
    a. Useful Field of View cognitive training will result in lower at-fault motor vehicle crash rates of older drivers.

3) **Dependent variable.** Describe the key dependent variable(s) specifying how they will be measured.
    a. Primary Outcome
        i. The primary outcome will be at-fault motor vehicle crash (MVC) rates derived from the Alabama Department of Public Safety state records and the calculation of person-year of travel. Crash reports will be examined to determine at-fault or no-fault. Person-year of travel will be calculated as the number of years elapsed between date training completed and date of driving cessation, date of death, or January 18, 2017 (fixed date follow-up date of crash records), whichever came first. The primary outcome will be expressed as the following rate: at-fault motor vehicle crashes per-person year of travel. Efficacy of the intervention will be determined by this outcome.

b. Secondary Outcome:
    i. The secondary outcome will be at-fault MVC rates per person-mile of travel. Person-miles of travel will be calculated as the number of person-years during follow-up period multiplied by self-reported baseline annual mileage driven. Thus, for each participant, the rate for the secondary outcome will be number of at-fault motor vehicle crashes per person-mile. This information will be provided for driving researchers concerned about "low mileage bias" (Hakamies-Blomqvist, 1998; Hakamies-Blomqvist et al., 2002; Langford et al., 2013; Staplin et al., 2008).

4) **Conditions.** How many and which conditions will participants be assigned to?
    a. Participants were randomized to 10 one-hour training sessions of either:
        i. Useful Field of View cognitive training (a.k.a. speed of processing training)- Each session began with 10-15 minutes of discussion facilitated by the trainer on topics of mobility (e.g., falls, driving) and how Useful Field of View is related to these topics. The latter 45-50 minutes consisted of individual, adaptive computerized visual exercises that involved speed of processing, divided attention, and selective attention.
        ii. Social- and computer-contact control group- Each session began with 10-15 minutes of trainer-led discussion on a specific skill related to computer or internet use (e.g., acquiring and using an e-mail account) followed by 45-50 minutes of individual practice of the new skill.

5) **Analyses.** Specify exactly which analyses you will conduct to examine the main question/hypothesis.
    a. First, we will conduct t-tests for continuous variables and chi-square tests for categorical variables to identify any significant baseline group differences ($p < .05$) between randomized conditions on the following variables: age; sex (male); race; history of falls; and Trail Making Test B performance as such variables are associated with increased prospective MVC rates.
    b. Poisson regression models using generalized estimating equations (GEEs) will be used to calculate crude and adjusted rate ratios (RRs) and 95% confidence intervals for the association between intervention group (Useful Field of View cognitive training or social- and computer-contact control group) and at-fault motor vehicle crashes per person-year of travel (primary outcome).
    c. For the crude RRs, group assignment (UFOV cognitive training or social and computer-contact control group) will be the independent variable and at-fault MVCs per person-year of travel, the dependent variable.
    d. For the adjusted RRs, the following steps will be used to determine covariates in Poisson regression analyses:

Step 1 will include group assignment as the only predictor using the enter method in the Poisson regression model.

Step 2 will include any of the aforementioned variables (i.e., age, sex, race, history of falls, and Trail Making Test B) that significantly differ by group at baseline using the enter method.

Step 3 will add any of the following variables that were not entered in step 2: age, sex, race, history of falls, Trail Making Test B, and study site. A stepwise procedure will be applied to the multivariate model by either adding or deleting one variable at a time based on stepping criteria (i.e., $p < .05$ to enter and $p > .10$ to delete).

e. This hierarchical regression process will then be repeated using the at-fault MVCs per person-mile of travel as the dependent variable (i.e., the secondary outcome).

6) **Sample Size.** How many observations will be collected or what will determine sample size? No need to justify decision, but be precise about exactly how the number will be determined.
    a. The sample size will include participants who were randomized and were current drivers at baseline visit in the Staying Keen in Later Life and Accelerate study cohorts. Eligibility criteria included: a) 60 years of age or older and community-dwelling; b) far visual acuity of 20/80 or better for SKILL or 20/40 or better for Accelerate; c) contrast sensitivity 1.35 $\log_{10}$ or better; and d) processing speed impairment.

7) **Other.** Anything else you would like to pre-register? (e.g., secondary analyses, variables collected for exploratory purposes, unusual analyses planned?)
    a. These are secondary analyses from the Staying Keen in Later Life and Accelerate studies combined with public records of crash reports. No prior analysis of crash reports has been conducted for SKILL or Accelerate. Although the studies are completed, we have not coded the crash reports which were obtained recently from the Alabama Department of Public Safety.
    b. Power Analyses: A prior study of community-dwelling older adults found that UFOV cognitive training (n = 179) reduced at-fault crashes per person-year by 45% (RR = 0.55) up to six years after study enrollment as compared to a no-contact control group (n = 409) (Ball et al., 2010). The no-contact control group had a base rate of .035 at-fault crashes per year. Using this base rate of at-fault crashes, the proposed sample size of 385 (n = 202 UFOV cognitive training, n = 183 social- and computer- contact control group) will be sufficient to detect a RR

of 0.44 with 7 years of data and 90% power, according to G*Power (see output below; Faul, Erdefelder, Buchner, & Lang, 2009).

Analysis:	Post hoc: Compute achieved power		
	z tests - Poisson regression		
Options:	Large sample z-Test, Demidenko (2007) with var corr		
Analysis:	Sensitivity: Compute required effect size		
Input:			
	Tail(s)	=	Two
	Effect direction	=	$\beta 1 <= 0$
	α err prob	=	0.05
	Power (1-β err prob)	=	0.90
	Total sample size	=	385
	Base rate exp($\beta 0$)	=	0.035
	Mean exposure	=	7
	R^2 other X	=	0
	X distribution	=	Binomial
	X parm π	=	0.5
Output:			
	Critical z	=	-1.9599640
	Exp($\beta 1$)	=	0.4364046

c. Additional Analyses: Additional analyses will be conducted if UFOV cognitive training is not found to be efficacious to reduce at-fault crashes across the prospective follow-up period (10+ years).

   i. The durability of UFOV cognitive training to reduce at-fault crashes has yet to be determined. If there are not significant results, we will perform analyses as outlined in section 5 above to determine the durability of training to reduce at-fault crashes per person-year across 7.5 years.

   ii. If UFOV cognitive training is not found to be efficacious to reduce at-fault crashes across 7.5 years, we will perform analyses as outlined in section 5 to determine the durability of the training to reduce at-fault crashes per person-year across 5 years. Statistical power is likely to not be sufficient for significance testing. Thus, we will only examine effect sizes in this case.

   iii. We will also perform analyses to determine if the training significantly reduced at-fault crashes per person-year (primary outcome) as compared to a non-trained reference group (SKILL and Accelerate participants not randomized to training). Thus, we will conduct a Poisson regression analysis examining the association between group (social- and computer-contact control group, UFOV cognitive training group, or non-trained reference group) and at-fault crashes per person-year.

1. We would expect the UFOV cognitive training group and the non-trained reference group to demonstrate similar at-fault crash rates per person-year. We would expect the social- and computer contact control group to demonstrate more at-fault crashes as compared to the non-trained reference group.

8) **Name.** Give a title for this Open Science Framework pre-registration
   a. The Effectiveness of Useful Field of View Cognitive Training to Reduce Older Drivers' At-Fault Crash Involvement

9) **Finally.** For record keeping purposes, please tell us the type of study you are pre-registering.
   a. Class project or assignment
   b. Experiment
   c. Survey
   d. Observational/archival study
   e. Other: **Secondary analyses of data from randomized clinical trials combined with public records of crash reports**

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APPENDIX D. NOT HUMAN SUBJECTS DETERMINATION FOR IRB # PRO00038563: THE EFFECTIVENESS OF USEFUL FIELD OF VIEW COGNITIVE TRAINING TO REDUCE OLDER DRIVERS' AT-FAULT CRASH INVOLVEMENT

USF
UNIVERSITY OF SOUTH FLORIDA

RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
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January 16, 2019

Bernadette Fausto
School of Aging Studies
Tampa, FL 33612

RE: **Not Human Subjects Research Determination**

IRB#: Pro00038563

Title: The Effectiveness of Useful Field of View Cognitive Training to Reduce Older Drivers' At-Fault Crash Involvement

Dear Ms. Fausto:

The Institutional Review Board (IRB) has reviewed your application. The activities presented in the application involve methods of analysis of pre-existing de-identified data. As such, USF IRB approval and oversight are not required.

While not requiring USF IRB approval and oversight, your study activities should be conducted in a manner that is consistent with the ethical principles of your profession. If the scope of your project changes in the future, please contact the IRB for further guidance.

If you will be obtaining consent to conduct a program evaluation, quality improvement project, or needs assessment, please remove any references to "research" and do not include the assigned Protocol Number or USF IRB contact information.

If your study activities involve collection or use of health information, please note that there may be requirements under the HIPAA Privacy Rule that apply. For further information, please contact a HIPAA Program administrator at (813) 974-5638.

Sincerely,

Kristen Salomon, Ph.D.,
Chairperson USF Institutional
Review Board