

Seniors face serious driving safety and mobility issues.



Select Physical Performance Measures and Driving Outcomes in Older Adults

A LongROAD Study

March 2016



Title

Select Physical Performance Measures and Driving Outcomes in Older Adults: A LongROAD Study. (*March 2016*)

Authors

Thelma J. Mielenz¹, PT, PhD, OCS, Laura Durbin¹, MPH, Jodi A. Cisewski¹, MPH, Jack M. Guralnik², MD, PhD, Guohua Li³, MD, MPH

¹ Columbia University Mailman School of Public Health, Department of Epidemiology

² University of Maryland, Department of Epidemiology & Public Health

³ M. Finster Professor of Epidemiology and Anesthesiology, Director of the Center for Injury Epidemiology and Prevention at Columbia University

About the Sponsor

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

Founded in 1947, the AAA Foundation in Washington, D.C. is a not-for-profit, publicly supported charitable research and education organization dedicated to saving lives by preventing traffic crashes and reducing injuries when crashes occur. Funding for this report was provided by voluntary contributions from AAA/CAA and their affiliated motor clubs, from individual members, from AAA-affiliated insurance companies, as well as from other organizations or sources.

This publication is distributed by the AAA Foundation for Traffic Safety at no charge, as a public service. It may not be resold or used for commercial purposes without the explicit permission of the Foundation. It may, however, be copied in whole or in part and distributed for free via any medium, provided the AAA Foundation is given appropriate credit as the source of the material. The AAA Foundation for Traffic Safety assumes no liability for the use or misuse of any information, opinions, findings, conclusions, or recommendations contained in this report.

If trade or manufacturer's names are mentioned, it is only because they are considered essential to the object of this report and their mention should not be construed as an endorsement. The AAA Foundation for Traffic Safety does not endorse products or manufacturers.

©2016, AAA Foundation for Traffic Safety

About LongROAD

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

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

Abstract

Importance

Driving exposure (driving distance and trips taken), driving cessation, crashes, citations, and poor driving ability are all factors that can have significant implications for safety and health among older adults, and so identifying measures associated with these is important for preventing negative driving outcomes. In current aging research, only one well-validated and reliable physical functioning battery (the Short Physical Performance Battery [SPPB]) is being used consistently, although there are multiple stand-alone measures that are regularly employed, including the Timed Up and Go Test (TUG) and the Rapid Pace Walk (RPW).

Objectives

This systematic review assesses the evidence in the research literature on the association between three well-validated lower extremity physical functioning measures (SPPB, TUG, and the RPW) with driving outcomes in older adults.

Methods

Studies published between 1994 and 2015 that included the SPPB, the TUG, or the RPW as a measure of physical functioning, included a driving-related outcome, and were conducted in adults aged 50 years and older were identified through a comprehensive search of bibliographic databases and were reviewed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Results

Thirteen studies involving 5,313 older adults met all of the inclusion criteria. Of them, three included the SPPB, two included the TUG, and eight included the RPW. Lower SPPB scores were associated with reduced driving exposure and increased cessation in all three studies. Specifically, average frequency of trips per week made by driving a car decreased from 5.1 for older adults with high SPPB scores (10-12) to 2.5 for those with intermediate SPPB scores (7-9) and to 1.0 for those with low SPPB scores (<7), (ANOVA, $p < .001$, Davis et al., 2011); and the odds of driving cessation increased progressively with lower SPPB scores (adjusted odds ratio (OR) for each point reduction in SPPB scores 1.16, 95% confidence interval (CI) 1.05-1.28, Sims et al., 2007; adjusted HR 1.35, 95% CI 0.81–2.26 for intermediate SPPB scores (7-9) and 2.20, 95% CI 1.32-3.68 for low SPPB scores (4-6), relative to high SPPB scores (10-12), Gill et al., 2012). TUG was not associated with an increased rate of negative driving outcomes (cessation, ability, crashes, and citations) in either of the two studies. Poorer RPW scores were associated with decreased driving ability in two studies (moderate correlation between RPW (higher score is worse) and driving ability (Global Rating Score – lower score is worse), $r = -.454$, $p < .001$, Stav et al., 2008; adjusted OR for each one-unit increase in RPW completion time 1.45, 95% CI 1.05-2.00, Classen et al., 2013) and with reduced driving exposure in one study (relative risk ratio (RR) of low mileage drivers compared to high mileage drivers 1.30, 95% CI 1.08-1.55, Langford et al., 2013) but was not associated with decreased driving ability, increased crashes, increased citations, or increased cessation in the remaining five studies.

Conclusions

Lower SPPB scores are associated with reduced driving exposure and increased cessation, poorer RPW scores are associated with decreased driving ability in some studies and reduced driving exposure in one study, and TUG scores are not associated with any driving outcomes. The TUG measure does not appear to be a useful measure of physical functioning for the driving outcomes that were included here, although the studies were limited. The RPW may be useful in studies related to driving ability and exposure. More driving studies should consider using the SPPB to determine if there is an association between SPPB scores and driving outcomes that have not been studied with this battery, and the SPPB may be useful as a risk factor assessment for identifying individuals at risk of reducing their driving exposure and driving cessation.

Introduction

Driving a motor vehicle is an important component of the lives of most older adults in the United States, and this transportation activity allows older adults to maintain their independence and mobility. According to Barr (2002), due to the “suburbanization” of the United States, driving is often the only feasible way for older adults to reach the locations that they need to travel to for recreational purposes and for necessities. Reducing the amount of car trips taken each week or ceasing driving entirely can have serious consequences for the well-being of older adults. Even after adjusting for the influence of sociodemographic and health-related factors, driving cessation among older adults is strongly associated with decreased out-of-home activity levels (Marottoli et al., 2000). A review by Oxley and Whelan (2007) states that the evidence is clear that quality of life is reduced for older adults when they cease driving and that certain vulnerable populations, such as women and financially disadvantaged individuals, will suffer the most from giving up their mobility in the form of driving a private vehicle.

Despite the benefits of continued driving, there are also legitimate concerns regarding the ability of older drivers to continue driving safely. Although older adults actually have lower crash involvement rates per capita since they are licensed less often and drive fewer miles (Federal Highway Administration, 1997), older adults are more likely to be involved in certain types of crashes including right turn, left turn, intersections, and angle collisions (Lyman, Ferguson, & Williams, 2002; Abdel-Aty, Chen, & Radwan, 1999; Caird & Hancock, 2002). Despite fatality rates among older drivers declining in recent years, older adults still have a higher risk of being involved in fatal crashes than middle aged drivers, due in part to their higher likelihood of being involved in a police-reported crash per vehicle miles traveled and to their greater odds of dying when a crash occurs (Cicchino, 2015; Cicchino & McCartt, 2014; Li, Braver, & Chen, 2003).

The objective of this review is to assess the evidence in the research literature on the association of three validated lower extremity strength and balance physical functioning measures and driving outcomes in older adults, including: driving exposure, cessation, crashes, citations, and ability. These three measures include one battery and two stand-alone measures: the Short Physical Performance Battery (SPPB), the Timed Up-and-Go Test (TUG), and the Rapid Pace Walk (RPW).

Driving Outcomes

Driving outcomes contain many subdomains of the overarching domain of driving. Here are some examples of driving outcomes included in the LongROAD (Longitudinal Research on Aging Drivers) Study baseline self-report assessment, as an indication of the breadth of driving outcomes that exist in current research: driving exposure, driving ability, driving space, alternative modes of transportation, driving importance, self-regulation of driving, driving lapses, driving errors, driving violations, driving history, vehicle factors, crashes, and citations (From: www.longroadstudy.org; Accessed December 2015). The driving outcomes that are discussed below are those that were included in articles that met our eligibility criteria and were acquired in full-text.

Driving Exposure and Cessation Among Older Adults

Research suggests that there can actually be serious consequences from reduced driving exposure and increased driving cessation among older adults. Fonda, Wallace, and Herzog (2001) note that older adults who reduce or cease driving are at a greater risk for worsening depressive symptoms, even when they have a spouse who is able to drive them instead.

Windsor, Anstey, Butterworth, Luszcz, and Andrews (2007), after finding the same increase in depressive symptoms in their study, also determined that this result was at least in part explained by a decreased sense of control among those who cease driving. It is even possible that driving cessation increases an individual's risk of entering long-term care. A study by Freeman, Gange, Munoz, and West (2006) indicated that after adjusting for demographic and health variables, older adults who were former or never drivers had higher hazards of entering long-term care than drivers. This may be a real finding or may be due to residual confounding by factors related to poorer health and driving cessation that were not captured by the health variables used in the analysis.

Older adults cease driving for a variety of reasons, which range from financial, vehicle access, and psychosocial reasons to various age-related medical concerns (Marottoli et al. 1993; Choi, Mezuk, & Rebok, 2012; Dugan & Lee, 2013; Choi, Mezuk, Lohman, Edwards, & Rebok, 2012; Anstey, Windsor, Luszcz, & Andrews, 2006; Edwards et al., 2008; Freeman, Munoz, Turano, & West, 2005; Carr, Flood, Steger-May, Schechtman, & Binder, 2006; Sims, Ahmed, Sawyer, & Allman, 2007; Dellinger, Sehgal, Sleet, & Barrett-Connor, 2001). Medical concerns that impact driving decisions among older adults include problems such as with vision, Parkinson's disease, stroke-related residual paralysis or weakness, syncope, diabetes, stroke, depression, neurologic disease, congestive heart failure, arthritis, and taking sedating medications (Ragland, Satariano, & MacLeod, 2004; Campbell, Bush, & Hale, 1993; Freeman et al., 2005; Marottoli et al., 1993; Edwards et al., 2008; Carr et al., 2006).

In addition to specific medical diagnoses, physical performance has also been shown to be a reliable health-related predictor of driving cessation (Sims et al., 2007; Ackerman, Edwards, Ross, Ball, & Lunsman, 2008; Edwards et al., 2008). Physical performance is operationally defined for this review as an objective performance measure of physical functioning. More specifically, these objective physical performance measures have individuals perform standardized tasks and performance on these tasks is evaluated according to predetermined criteria, which could include the timing of the activity or a counting of repetitions, depending on the type of task (Guralnik, Branch, Cummings, & Curb, 1989). Physical performance is measured in different ways in older adult driving cessation studies. For example, grip strength is one measure shown to be a significant risk factor for driving cessation; another is poor balance as measured by the Turn 360 test (Anstey et al., 2006; Edwards et al., 2008; Ackerman et al., 2008).

Crashes, Citations, and Ability Among Older Adults

Crashing is of course a concerning driving outcome for older adults, as crash outcomes are more often deadly for this population than for younger adults (Lyman et al., 2002). Crashes are an outcome that can arise from a general lack of driving ability. However, less severe outcomes (including errors that result in citations and driver errors that may go unnoticed)

can also indicate limited driving ability that should be addressed before crashes occur. In addition to errors that are clearly citation-worthy, other noteworthy errors may include failing to check the rear-view mirror, driving while distracted, or failing to brake when appropriate (Emerson et al., 2012). Such actions may result in near-crashes that could go unreported and are much more difficult to quantify, with near-crashes being defined as circumstances that require any vehicle, pedestrian, or other actor on the road to make an evasive maneuver in order to avoid crashing (Dingus et al., 2006).

Crashes and poor driving ability among older adults are frequently associated with medical or chronic health conditions including alcohol abuse and dependence, dementia, depression, schizophrenia, epilepsy, cardiovascular disease, diabetes mellitus, cerebrovascular disease/TBI, musculoskeletal disorders, obstructive sleep apnea, vision disorders, and the use of certain medications (Marshall, 2008). However, using these diagnoses alone to determine fitness-to-drive would overly restrict safe drivers, as these conditions are only slightly to moderately associated with an increased crash risk, and so other factors must be considered such as the presence of multiple medical conditions and varying levels of disease severity (Marshall, 2008).

Physical performance measures could be informative of an individual's fitness to drive since they tend to be relatively inexpensive and can be easy to administer. Moreover, longstanding research supports physical functioning improvement (i.e., gait velocity and muscle strength) with exercise training at any age, indicating that physical functioning, as a modifiable risk factor, could be a promising focus for future interventions to assist older adults in maintaining safe driving (Nelson et al., 1994; Fiatarone et al., 1994).

Physical Performance Measures

The Short Physical Performance Battery

The Short Physical Performance Battery (SPPB) was created by Guralnik et al. (1994) and is used to assess balance and physical functioning, specifically lower extremity function. The researchers adapted previously used measures with the aim that one trained lay interviewer with limited unobstructed space and limited time (10-15 minutes) available would be able to conduct the SPPB, while ensuring the safety of the participants. There are three major components of the SPPB: standing balance (standing with feet together in three positions of increasing difficulty: side-by-side, semi-tandem, and tandem), walking speed (usual speed on a four-meter course), and ability to rise from a chair (time to rise five times from a chair with arms folded across the chest). Scores of zero (inability to carry out task) to four (best performance possible) are assigned for each of the three tasks, and these are summed to create a final SPPB score (range zero to 12). Lower overall scores indicate poorer physical functioning. Previous research has suggested that a cut-off point of nine or less is acceptable for investigating associations between physical functioning (as measured by the SPPB) and mobility disability (Sink et al., 2015).

Guralnik et al. (1994) validated the SPPB in a study of more than 5,000 older adults who were aged 71 years and older. Each test and an overall SPPB score were strongly associated with self-report of disability. Both self-reported disability and SPPB scores were predictors of short-term mortality and nursing home admission; however, SPPB also provides

additional information that self-reported disability may lack. Individuals self-reporting themselves as high functioning were able to be placed on a gradient of risk for mortality and nursing home admission by using their SPPB scores. Guralnik, Ferrucci, Simonsick, Salive, and Wallace (1995) further determined that SPPB scores can predict onset of disability within a nondisabled older adult population.

Since the development of the SPPB, both its reliability and sensitivity to change have been confirmed, and it has become a widely used physical functioning measure in older adult research (Ostir, Volpato, Fried, Chaves, & Guralnik, 2002). Multiple population studies of aging have utilized the SPPB, including the Established Populations for Epidemiologic Studies of the Elderly (EPESE) Study, National Health and Aging Trends Study (NHATS), and the Lifestyle Interventions and Independence for Elders (LIFE) Study Randomized Clinical Trial (Guralnik et al., 1994; Kasper, Freedman, & Niefeld, 2012; Pahor et al., 2014). Studies have also confirmed a high validity for the SPPB as a measure of functional status and have reported that the SPPB can predict hospitalizations and length of hospital stay, identify patients who are at a higher risk of poor outcomes after being discharged from a hospitalization, and predict declines in function and health status (Penninx et al., 2000; Volpato et al., 2008; Volpato et al., 2011; Studenski et al., 2003). The SPPB is further a known predictor for mortality (Rolland et al., 2006; Cesari et al., 2008; Ostir, Kuo, Berges, Markides, & Ottenbacher, 2007).

The Timed Up-and-Go Test

The Timed Up-and-Go Test (TUG) is a timed derivative of the Get-Up-and-Go Test, which was created by Mathias, Nayak, and Isaacs (1986). In the TUG, participants are observed and timed as they rise from an arm chair, walk 3 meters, turn, walk back, and sit back down (Podsiadlo & Richardson, 1991). Podsiadlo & Richardson (1991) found that this timed measure was risk marker for an older adult's ability to go safely outside alone. The measure has content validation since it focuses on physical actions that are used in daily life and concurrent validation, as it correlates with other established measures of balance and functional ability including measures on Berg Balance Scale, gait speed, and measures from the Barthel Index of Daily Living Scale (Podsiadlo & Richardson, 1991; Bennie et al., 2003; Freter & Fruchter, 2000).

Since its creation, inter-rater and test-retest reliability of the TUG has been confirmed (Shumway-Cook, Brauer, & Woollacott, 2000; Noren, Bogren, Bolin, & Stenstrom, 2001). The TUG is used most often in falls-related research, and TUG scores have been found to be both sensitive and specific for identifying older adults prone to falling (Shumway-Cook et al., 2000). In the original study, older adults over 79 years old who were considered healthy took 7-10 seconds to perform the TUG, whereas older adults who were considered to be frail performed the task in 10-240 seconds (Podsiadlo & Richardson, 1991). Since then, some research has posited that healthy community-dwelling older adults should be able to perform the test in under 20 seconds without an assistive device, although a cutoff point of 12 seconds for predicting fall risk has also been suggested (Medley & Thompson, 1997; Bischoff et al., 2003). More recently, research has suggested that the cutoff value for the TUG used among community-dwelling older adults should be much lower than the 13.5 seconds recommended for older adults with impairments, although a review of 11 studies found that the cutoff time separating non-fallers and fallers can range from 10 to 32.6 seconds (Singh, Pillai, Tan, Tai, & Shahar, 2015; Beauchet et al., 2011). As the TUG can be

completed by most older adults and is a quick and easy-to-administer test, it is used frequently with older adult populations (Yim-Chiplis & Talbot, 2000). For example, it is part of the US Centers for Disease Control and Prevention tool kit for clinical screening of fall risk called STEADI (Stopping Elderly Accidents, Deaths, and Injuries) and is also part of the fall-focused physical examination for the Annual Medicare Wellness Visit (Phelan, Mahoney, Voit, & Stevens, 2015).

The Rapid Pace Walk

The Rapid Pace Walk (RPW) is a rapid version of the Usual Pace Walk, first appearing in the literature in an older adult driving-related study (Marottoli, Cooney, Wagner, Doucette, & Tinetti, 1994). Participants are asked to walk 10 feet away and back at the fastest pace at which the participants feel safe and comfortable (Marottoli et al., 1994). Since its first use, the RPW has been frequently used in driving studies and was recognized as a measure of note in the Physician's Guide to Assessing and Counseling Older Drivers, which was released by the National Highway Traffic Safety Administration (Carr, Schwartzberg, Manning, & Sempek, 2010). It is generally accepted that completing the task in longer than 9 seconds indicates a need for intervention (Carr et al., 2010).

The RPW is a measure included in the Assessment of Driving-Related Skills (ADReS), which is a test battery that consists of vision, cognition, and motor/somatosensory function measures that assess skills necessary for safe driving. The ADReS measures were selected by a panel of driving safety experts in conjunction with the American Medical Association, and were chosen based on factors such as ease of use, quality of information, and amount of time required (Carr et al., 2010). Many validity cut-offs exist around gait speed, but less information is available for the specific RPW protocol. It has been suggested that a normal gait speed of 0.8 m/s or 1.0 m/s may suggest healthier aging and better life expectancies, and that a slower fast gait speed and a faster decline in fast gait speed can predict incident disability (Studenski et al., 2003; Studenski et al., 2011; Abellan van Kan et al., 2009; Artaud et al., 2015). One study on the stability of physical assessment measures found that the RPW had a moderate relative reliability and low coefficients of variability (CV) values (Smith et al., 2013).

Methods

This systematic literature review includes a narrative synthesis and adheres to reporting standards laid out in PRISMA guidelines (Moher et al. 2009; Beller et al. 2013).

Eligibility

Studies were eligible for inclusion in this systematic review if they: 1) included adults aged 50 years and older; 2) included at least one driving-related outcome; 3) used the full Short Physical Performance Battery (SPPB), the Timed Up-and-Go Test (TUG), or the Rapid Pace Walk (RPW), or a modified version of one of these measures, as an objective tool to measure physical functioning, and examined analytically a possible connection between the SPPB, TUG, or RPW and a driving outcome; 4) were published in the English language; 5) were published between the years 1994 and 2015, inclusive; and 6) used an epidemiological design (cross-sectional, cohort, or case-control). Acceptable studies were analytical in nature, and so all qualitative studies, patents, letters, commentaries, reviews, editorials, and opinion pieces were excluded.

Search Strategy, Data Sources and Extraction

A research librarian was consulted for constructing the search strategy and terms. All retained articles were pulled from the following electronic databases through a comprehensive search on November 11, 2015: American Psychological Association PsycINFO, EBSCO CINAHL, Medline OVID, PubMed, Scopus, and Transport Research International Documentation (TRID). One author (LD) screened all article titles and abstracts using the inclusion and exclusion criteria previously stated. Studies with unclear eligibility were reviewed in full-text using these criteria.

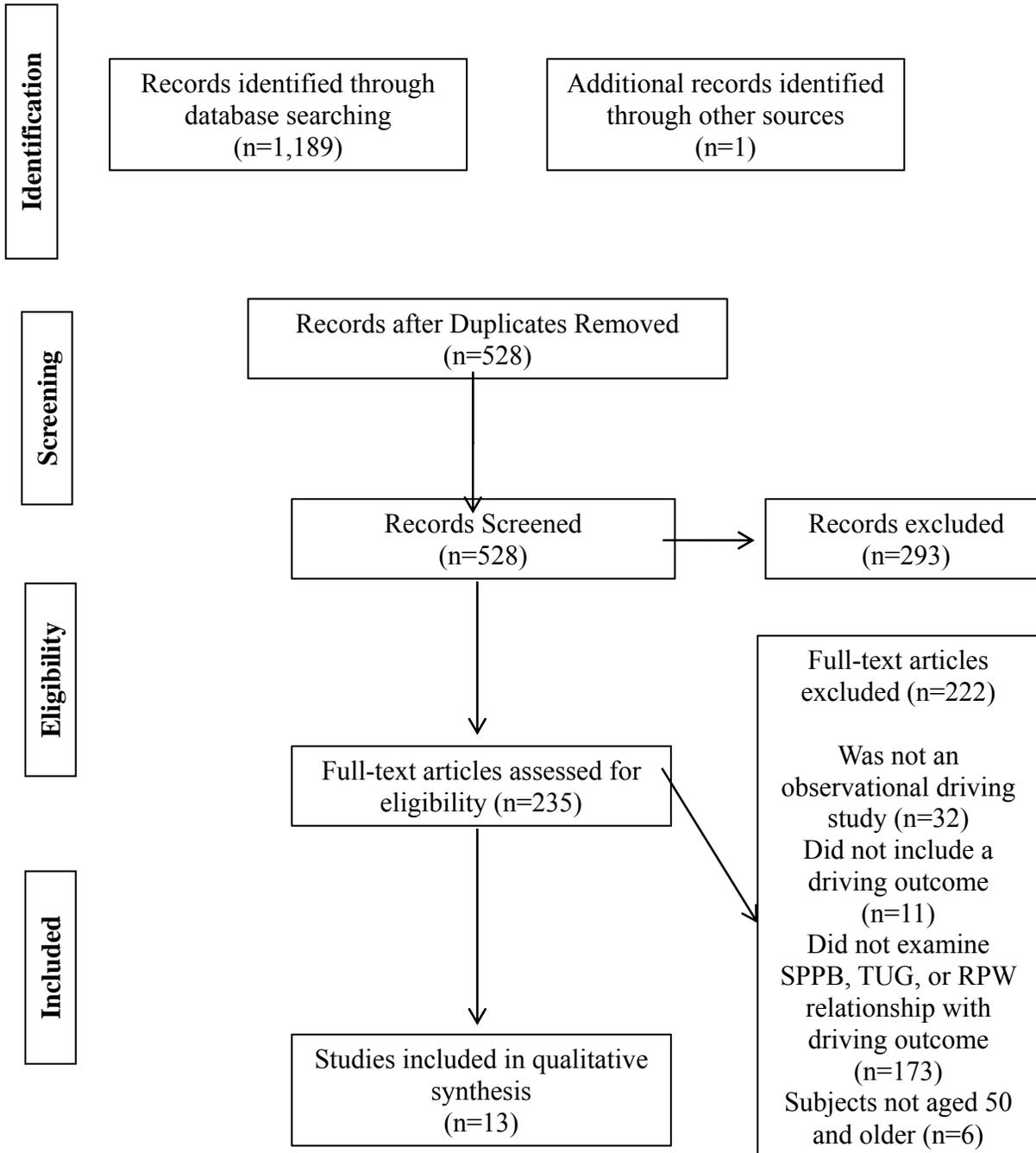
The MeSH (Medical Subject Heading) term “automobile driving” was used in conjunction with “Short Physical Performance Battery,” “Timed Up and Go,” and “Rapid Pace Walk,” as well as the abbreviated versions “SPPB,” “TUG,” and “RPW.” After examining the articles that were returned, the non-MeSH term “driving” was also used in conjunction with all of the preceding terms and abbreviations to determine if any articles had been previously overlooked with the specific MeSH term. In order to obtain any articles that were not captured with the specific physical performance terms, the term “geriatric assessment” was then used in conjunction with “automobile driving” and with “driving.” For most databases, the “all text” or “all fields” option was selected. For the Scopus database, due to its diverse scientific content, the “article title, abstract, keywords” option was selected.

Quality Assessment

The quality of included studies was evaluated using the Newcastle-Ottawa Quality Assessment Scale (Wells et al., 1999). The scale is only directly applicable to case-control and cohort studies, so for cross-sectional studies the reviewers modified the scale to exclude consideration of the follow-up period and absence of outcome at the beginning of the study, which is a practice that has precedence in the literature (Chihuri et al., 2015). The best score possible depended on study design, with lower scores indicating poorer study quality.

Ten was the best possible score for cross-sectional studies, whereas nine was considered the best score for cohort studies.

Figure 1. Flow diagram of the study selection included in the systematic review of SPPB, TUG, and RPW predicting older adult driving outcomes.



Adapted From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-analyses: The PRISMA Statement. PLoS Med 6(6): e1000097.
doi:10.1371/journal.pmed1000097

Results

Across the six databases, 1,189 results were returned. One additional resource that was identified was Marottoli et al. (1994), which is the first study in which the RPW measure is mentioned. A total of 662 results were removed for being duplicates, leaving 528 citations to be screened. Studies were then excluded that clearly did not meet eligibility criteria and 235 articles were assessed for full-text eligibility. Thirteen studies from the remaining citations met the eligibility criteria and were retained to be included in the systematic review (Fig. 1). No studies were excluded for reporting negative findings. At this point, it was determined that a meta-analysis would not be appropriate to include in this report as the thirteen studies included five varied driving outcomes.

Study Characteristics

Ten studies were conducted in the United States (Alabama, Connecticut, Florida, Iowa, Maryland, and Missouri), one in the UK (Bristol), and two in Canada (British Columbia), Australia (Queensland), and New Zealand (Wellington) (Tables 1a-c). Two publications reported outcomes from the same sample in Iowa City, Iowa (Dawson et al., 2010; Emerson et al., 2012), and two publications reported outcomes from the same Maryland Older Drivers Project (Ball et al., 2006; Edwards et al., 2010). All thirteen studies included both men and women and the participants in all studies were at least 52 years old. Ten of these studies only included participants that were at least 65 years old. Participant recruitment for each study is reported in Tables 1a-c. The study types varied, including five cross-sectional studies and eight cohort studies. One of the cohort studies included only baseline data, which were analyzed cross-sectionally (Langford et al., 2013). All studies used either a full or modified form of the SPPB, the TUG, or the RPW as a measure of physical functioning. Only one study (Gill et al., 2012) included a modified measure, and details of this modification are included when the study is introduced. The studies in this review had various socio-demographic covariates in their analyses, which included age, sex, education, and race (Tables 2a-c).

Study Quality

Study quality was assessed via the Newcastle-Ottawa Quality Assessment Scale. Six of the seven cohort studies were deemed to be high quality, with an average assessment score of 8.1 out of 9 (range 7-9). The six cross-sectional studies varied in quality, with an average score of 7.3 out of 10 (range 6-8) (Tables 3a-b).

Summary of Findings

Below is a description of driving outcomes that were included in studies examining the physical functioning measure listed in the header. The driving outcomes that were obtained in conjunction with at least one physical functioning measure included: driving exposure, cessation, crashes, citations, and ability. When there were no results returned in the systematic search for a physical functioning measure and one of these aforementioned outcomes, this is indicated.

Short Physical Performance Battery

Driving exposure

In a study of 214 participants, Davis et al. (2011) focused on reduced driving exposure as their driving outcome, specifically measured as the number of car trips that were made each week by an individual as a driver. Physical function was assessed using the original, unmodified SPPB. In this cross-sectional study, trips that individuals made per week declined significantly with SPPB scoring categories: 5.1 trips for older adults with high SPPB scores (10-12), 2.5 for those with intermediate SPPB scores (7-9), and 1.0 for those with low SPPB scores (<7) (ANOVA, $p < .001$), indicating that SPPB scores are associated with reduced driving exposure although individual t-tests were not reported.

Driving cessation

Two SPPB studies (Gill et al., 2012; Sims et al., 2007) focused on driving cessation as a final outcome, although Gill et al. (2012) specifically termed the outcome “long-term disability in driving a car,” which was indicated by not driving in the past six months. Both studies were prospective cohort studies, which had follow-up periods of two years (Sims et al., 2007) and 12 years (Gill et al., 2012). Both also included large sample sizes of 507 (Gill et al., 2012) and 649 participants (Sims et al., 2007). Sims et al. (2007) used an unmodified version of the SPPB, whereas Gill et al. (2012) used a slightly modified version of the SPPB, which substituted three timed chair stands for the usual five and used a timed rapid gait measure instead of timed usual gait.

Both studies concluded that lower SPPB scores were associated significantly with increased driving cessation. Gill et al. (2012) found that there were eight risk factors independently associated with the rate of increased driving disability, but low scores (4-6) relative to high scores (10-12) on the SPPB was one of the strongest of these risk factors (adjusted HR 2.20, 95% CI 1.32-3.68), with adjustment for age, sex, living with others, chronic conditions, visual impairment, weight loss, cognitive impairment, physical activity, lower-extremity weakness, gross motor coordination, peak expiratory flow, hospitalization, and restricted activity. Intermediate SPPB scores (7-9) relative to high SPPB scores (10-12) was not a significant risk factor for increased driving disability rate (adjusted HR 1.35, 95% CI 0.81-2.26). Sims et al. (2007) similarly found that every one-point decline in SPPB scores was associated with a 16% increased odds of driving cessation (adjusted OR 1.16, 95% CI 1.05-1.28), with adjustment for age, sex, race, education, rural residence, self-rated health, visual acuity, Mini-Mental State Examination scores, Geriatric Depression Scale scores, and Charlson Comorbidity Index scores.

Driving crashes, citations, and ability

No studies were found that utilized the SPPB and included driving crashes, citations, or ability as outcome measures.

Timed Up-and-Go Test

Driving cessation

One prospective cohort TUG study with 100 older adult drivers (Emerson et al., 2012) included time to driving cessation as an outcome, although time to driving citations and crashes were also additional outcomes measured. The follow-up period ranged from three to eight years, due to rolling induction. The researchers called the TUG measure by the original name “Get-Up and Go,” but specified that “time to completion” was the measurement used. Older adult participants completed two trials of the TUG and the average of these times was the variable included. In this prospective cohort study, twenty of the older adult drivers (20%) ceased driving during the follow-up period. A one standard deviation (2.7 seconds) increase in TUG completion time (a worse performance) was not significantly associated with an increased rate of driving cessation (adjusted HR 1.29, 95% CI 0.88-1.90), after adjustment for age, gender, education, and baseline mileage driven per week.

Driving crashes

The study recently discussed, Emerson et al. (2012), also included a measure of time to driving crash (fault not determined) as an outcome. This outcome measure was available for 98 of the 100 total participants, and 34 of the older adult drivers (34.7%) were involved in a crash during the follow-up period. A one standard deviation (2.7 seconds) increase in TUG completion time was again not significantly associated with an increased rate of driving crashes (adjusted HR 1.29, 95% CI 0.96-1.72), with adjustment for age, gender, education, and baseline mileage driven per week.

Driving citations

A measure of time to receiving a citation was also included in the Emerson et al. (2012) study, which was available for 98 out of the total 100 participants. The researchers called the citations “moving violations,” and this measure only included citations that occurred when the car was in motion, not paperwork or parking violations. Twenty-seven of the older adult drivers (27.6%) were issued a moving citation during the follow-up period. A one standard deviation increase (2.7 seconds) in TUG completion time was not significantly associated with an increased rate of driving citations (adjusted HR 1.01, 95% CI 0.66-1.53), with adjustment for age, gender, education, and baseline mileage driven per week.

Driving ability

One TUG study (Dawson et al., 2010) focused on driving ability as a final outcome and found negative results. Dawson et al.’s (2010) cross-sectional study included 111 older adult drivers. Driving ability was based on the number of driving errors made on a 35-mile route. The researchers called the TUG measure by the original name “Get-Up and Go,” but specified that “time to completion” was the measurement used. A one standard deviation increase in TUG completion time resulted in .46 less safety errors, which was not a significant change (multiple linear regression coefficient adjusted for age, education, and sex, Standard Error (SE)=1.27, p=.72).

Driving exposure

No studies were found that utilized the TUG and included driving exposure as an outcome measure.

Rapid Pace Walk

Driving crashes and citations

Three RPW studies (Marottoli et al., 1994; Ball et al., 2006; Woolnough et al., 2013) included driving crashes as an outcome, with primarily negative results. Marottoli et al. (1994) was the first study to introduce the RPW as a physical functioning measure, which the researchers acquired for 278 of the total 283 participants. The driving outcome in this prospective cohort study was actually a composite measure of driving crashes (fault not determined) and driving citations, including the self-report of being involved in a crash, receiving a moving violation, or being stopped by the police in the past year. Although in the unadjusted analyses worse performance on the RPW (completing the task in > 7 seconds compared to completing it in ≤ 7 seconds) had the strongest association with more adverse driving events (RR 2.0, 95% CI 1.0-3.8), when entered into a binomial relative risk model and with adjustment for driving frequency and housing type, poorer RPW scores were no longer associated with a higher risk for the composite driving outcome.

Ball et al. (2006) used the RPW in the Maryland Older Drivers Project, which was a prospective cohort study of 1,910 older adult participants. At-fault driving crashes during a follow-up period spanning between 4.18 and 5.13 years was the outcome studied. RPW data were missing for 25% of the subjects and so, since the RPW and Foot Tap measures were highly correlated for the subjects that had complete data on both, an estimated score was imputed for the missing RPW values using a linear regression equation. Noncrashers (n=1,808) averaged an RPW of 6.58 seconds and crashers (n=92) averaged an RPW of 6.83 seconds, which was neither an important nor significant difference (p=.32, based on a 2-sample t-test). The researchers did not specify cut-points for the RPW. For each 1-second increase on the RPW (worse performance), participants had 1.16 the odds of a driving crash (OR 1.16, 95% CI 0.96-1.39), with adjustment for annual miles driven; this finding was neither significant nor important.

Woolnough et al. (2013) used baseline data from the Candrive II/Ozcandrive prospective cohort study. Analyzing historical data from 1,230 participants in a retrospective analysis, Woolnough et al. found that in the prior two years to baseline assessment that 5.1% of the participants had been involved in a driving crash (at-fault or not at-fault). The researchers determined that poorer performance on any of the Assessment of Driving-Related Skills (ADReS) sub-tests (including the RPW using a 2-sample t-test) was not associated with increased crash involvement (p>.01). The mean participant completion time on the RPW test was 6.6 seconds for those involved in crashes (n=63) and also for those who were not (n=1167).

Driving ability

Three RPW studies (Stav et al., 2008; Classen et al., 2013; Carr et al., 2011) focused on driving ability as a primary outcome, although driving ability was measured in various ways.

In the cross-sectional study of 123 older adults by Stav et al. (2008) with the primary aim of a predictive model in order to identify useful assessment tools by, the driving ability measure consisted of a Global Rating Score of driving performance that was assigned during a road test. The researchers collected data on the RPW for 120 participants and found that the RPW was the motor performance measure that showed the strongest correlation with the Global Rating Score ($r=-.454$, $p<.001$). Regression models were built and the strongest model found that one of the risk markers that best accounted for the variability of poor driving ability was worse performance on the RPW (three additional risk markers accounted for 44% of the variability in the Global Rating Scale).

Classen et al. (2013) were primarily focused on gender differences in driving ability among older drivers and used a sample of 195 participants in their cross-sectional study. Driving ability was measured by a comprehensive driving evaluation, with the outcome consisting of passing or failing the test. The researchers did not specify their cut-points, but listed the RPW as a continuous variable in Table 1. We might assume that a one second increase in RPW completion time means worse performance, although in interpretation of the model they mention poorer PRW scores more generally. The RPW was associated with a 45% increased odds of failing the driving test (adjusted OR 1.45, 95% CI 1.05-2.00), with adjustment for various demographics, driving history, avoidance behaviors, and clinical tests. RPW was also reported to be a risk marker of the total number of errors in a similarly adjusted linear regression model; assuming a one second increase in the RPW then there results a 2.17 increase in the number of errors. However, we would like to note that although the p value was significant ($p=0.001$), the confidence interval included 1.00 (95% CI 0.89-3.46), therefore the reader should use discretion when interpreting these results.

Unlike the preceding studies, Carr et al. (2011) did not find an association between a higher RPW completion time and poorer driving ability. In a cross-sectional study of 99 participants who had all been diagnosed with dementia, driving ability was assessed by determining if an individual passed or failed the Washington University Road Test. Individuals who passed the road test ($n=34$) averaged a score of 7.5 seconds on the RPW, whereas those who failed the test ($n=65$) averaged a score of 8.3 seconds, which was not a significant difference ($p=.12$) using a 2-sample t-test. RPW was, therefore, not included in the final model.

Driving exposure

Like Woolnough et al. (2013), Langford et al. (2013) used data from the Candrive II/Oz Candrive prospective cohort study. Their cross-sectional analysis included data from the baseline assessments for 1,222 participants and focused on driving exposure as the driving outcome, with the participants self-reporting annual driving distances for the previous year. They dichotomized performance on the RPW into high performance (completion in less than six seconds) and low performance (completion in greater than six seconds) although it is unclear where the 6-second participants would go. They reported

unadjusted comparisons of low mileage drivers (<5001 km) and high mileage drivers (15,000 km), which revealed support for both the low mileage driver hypothesis (RR=1.30, 95% CI 1.08-1.55) and the high mileage driver hypothesis (RR=1.43, 95% CI 1.09-1.88), meaning that the low mileage drivers (lower driving exposure) had a 30% increased risk of being low performers on the RPW (relative to high mileage drivers) and that the high mileage drivers (higher driving exposure) had a 43% increased risk of being high performers on the RPW (relative to low mileage drivers).

Driving cessation

Like Ball et al. (2006), Edwards et al. (2010) used data from the Maryland Older Drivers Project, which was a prospective cohort study. Their sample consisted of a subset of 1,248 participants who were successfully followed for a 10-year period. The RPW was assessed at both baseline and at a 5-year assessment, both of which were included in the Cox hazard regression models as time-varying covariates. Driving cessation was self-reported every year over the 10-year period. The mean RPW completion time at baseline for drivers (n=1,099) was 6.34 seconds and the mean RPW completion time at baseline for those who ceased driving (n=149) was 7.34 seconds, which was a significant difference (p<.001). The researchers built three initial models that each independently examined demographic, physical performance, and cognitive performance indicators. In the physical performance model, poorer RPW performance was the only significant indicator of an increased rate of driving cessation (HR=1.91, 95% CI 1.37-2.65, p<.001), with adjustment for head-neck rotation, arm reach, and self-reported difficulty walking a block or climbing several flights of stairs. However, when included in the final Cox hazards model, with adjustment for all of the significant predictors from the first three models (age at baseline, days driven per week, Motor Free Visual Perception Test, Trail Making Test Part B, and Useful Field of View), poorer RPW performance was no longer associated with increased rate of driving cessation (HR=1.33, 95% CI 0.95-1.87, p=0.094).

Discussion

This systematic review finds that lower scores on the SPPB are associated with increased driving cessation and reduced driving exposure, poorer performance on the RPW is associated with poorer driving ability in some studies and with reduced driving exposure in one study but is not convincingly associated with increased driving crashes, citations, or cessation, and poorer TUG scores are not associated with any driving outcomes (increased driving cessation, crashes, or citations, or decreased driving ability). These limitations of the RPW and TUG should guide the use of these measures with specifically appropriate driving outcomes. The ability for the SPPB to be utilized successfully across multiple driving outcomes indicates that the SPPB is a promising measure, particularly for identifying older adults at risk of limiting or ceasing driving. It would be interesting for future driving studies to examine the SPPB with driving outcomes beyond driving cessation and exposure, as at this point we cannot speak to any potential associations of the SPPB with driving ability or certain negative driving events, such as citations or crashes.

Lower SPPB scores were consistently associated with reduced driving exposure and increased driving cessation (Davis et al., 2011; Gill et al., 2012; Sims et al., 2007). The SPPB is a modifiable risk factor and gains in scores can certainly be accomplished through various fitness interventions. In fact, studies investigating meaningful change have determined that a gain of only one point on this 12-point scale can be considered a substantial change (Perera, Mody, Woodman, & Studenski, 2006; Kwon et al., 2009; Perera et al., 2014). A gain of one point could be accomplished by making progress on just one of the three included tasks (standing balance, walking speed, or ability to rise from a chair). We posit that the SPPB could possibly be used successfully as a risk factor assessment for identifying older adults who may be at risk of reducing driving exposure or of driving cessation. Once an individual is identified as “at risk,” various exercise interventions could be suggested for the individual and improvement could be measured at the next visit via the same SPPB. As previously mentioned, exercise interventions have been shown to be beneficial for improving fitness and longevity in older adults (Pahor et al., 2014). Additionally, some recent, yet limited, research has also suggested that such exercise interventions could also be specifically beneficial for maintaining or improving driving performance (Marmeleira, Godinho, & Fernandes, 2009; Marottoli et al., 2007).

In a study asking older adults who had ceased driving why they had made this decision (Dellinger et al., 2001), medical reasons was the top response (41%) and the next most popular reason was age-related reasons (19.4%). As older adults self-assess their own physical functioning and reaction times, they may use this information to self-regulate their driving behavior. If improvements can be made regarding physical functioning, older adults may be able to reevaluate and revise the driving decisions they have made, while still taking into consideration their own safety and the safety of others.

Regarding safety, one TUG study (Emerson et al., 2012) and three RPW studies (Ball et al., 2006; Marottoli et al., 1994; Woolnough et al., 2013) included crashes as an outcome (although the Marottoli et al. study actually included a composite measure of crashes and citations). Poorer performance on the physical performance measures (TUG and RPW) was not associated with increased crashes in any of these studies. It is worth noting that studies with small sample sizes may have trouble assessing crashes, which are not a frequent

outcome. However, only the TUG study (Emerson et al., 2012) had a relatively small sample size of 98 participants with crash data. The other crash studies included here reported higher sample sizes: 1,910 (Ball et al., 2006), 278 (Marottoli et al., 1994), and 1,230 (Woolnough et al., 2013). Another important crash factor that should be considered is the difference between at-fault and not at-fault crashes. The only study that included strictly at-fault crashes was Ball et al. (2006). The other studies looked at overall crashes that may have been at-fault or not at-fault, which may account, in part, for the lack of association observed.

Two of the RPW driving ability studies (Classen et al., 2013; Stav et al., 2008) found that poorer RPW performance was associated with poorer driving ability, and one study did not (Carr et al., 2011). The one TUG driving ability study did not find poorer TUG performance to be associated with poorer driving ability (Dawson et al., 2010). One RPW study included driving cessation as an outcome and did not find a link between poorer RPW scores and increased driving cessation in their final analyses (Edwards et al., 2010). One RPW study included a driving exposure outcome and determined that low mileage drivers are likely to have worse completion times on the RPW, whereas high mileage drivers are likely to have better completion times on the RPW (Langford et al., 2013). Like the SPPB, improvement on the RPW can be accomplished through exercise interventions.

Our review did not find any association between the TUG and driving outcomes (increased driving cessation, crashes, or citations, or decreased driving ability), but this could be due to the limited number of studies (two) and their small sample sizes (100 and 111 participants). It is also worth considering if there are specific differences in the administration of the TUG compared to the RPW and the SPPB that could account for these differences in our findings. Compared to the other two, the TUG does appear to have less standardization across protocols. Differences between published guidelines of the TUG, include: using a cone on the floor versus a line, walking as quickly as possible versus walking at a normal pace, recording the fastest of two trials versus recording only one trial, and starting from an arm chair versus a folding chair (Rikli & Jones, 2001; ACR 2015; CDC 2015). Perhaps most critically, the distance travelled varies in protocols from “8 feet” (2.44 meters) to “3 meters” (9.84 feet) to “3 meters or 10 feet” (9.84 feet or 3.05 meters) (Rikli & Jones, 2001; ACR 2015; CDC 2015).

This review is limited by the number of studies that were obtained and by some components of the individual studies. Although the search strategy was systematic, it is possible that critical studies were overlooked for not being available in full-text or for being in a state of pre-publication. Study types included cross-sectional and cohort designs. The majority of the included studies (12/13) included at least 100 participants, and the one study that did not included 99 (Carr et al., 2011). This Carr et al. (2011) study also included only older adults who had been diagnosed with dementia, which does not represent the average older adult population. However, additional prospective studies focusing on targeted medical populations may be useful for determining if these physical performance measures could be used successfully in a clinical setting to identify medically-impaired older adults at risk of negative driving outcomes. Many of the driving outcomes examined in this review are rare (e.g. crashes) in the general older adult population and, due to this low prevalence, it may be difficult for these physical performance tests to identify risks. If used among older adult populations who may have strength and balance problems (such as among individuals with arthritis, Parkinson’s disease, etc.), researchers may be more likely

to observe a direct association between some of the physical performance measures and certain negative driving outcomes.

There are collinearity concerns that arise with some of the studies and could possibly explain the absence of some statistical associations. Many of the studies that built models included age in their modeling, and yet this variable was likely correlated with the physical performance measure that was included (Tables 2a-c). Other variables that may be cause for collinearity concern in some of the TUG and RPW studies that did not report significant associations included days driven per week, miles driven per week, road safety errors, and especially the functional reach balance (Emerson et al., 2012; Dawson et al., 2010; Edwards et al., 2010; Marottoli et al., 1994). Researchers should assess for collinearity in the premodeling stages and also assess whether covariates are time-dependent or time-independent (Robins, Hernan, & Brumback, 2000).

In addition, future driving studies should pay careful attention to the standardization of measures. Studies that use the SPPB should attempt to maintain the fidelity of this battery as described in a training CD on the NIA website (<http://www.grc.nia.nih.gov/branches/leps/sppb/index.htm>). All three of the studies reviewed here included all of the main SPPB components (standing balance, walking speed, and the chair stand test). Two of the three studies used a completely unmodified battery. Modifications in the other study included changing the number of chair stands and using a timed rapid gait measure instead of a timed usual gait measure (Gill et al., 2012). While the reviewers recognize that modifying existing measures can sometimes be advantageous for specific studies, we advocate here that when there is no risk of compromising the study's aims, researchers should consider using the SPPB unmodified so that there can be more standardization across the field, allowing for better comparability between studies.

Both TUG studies (Emerson et al., 2012; Dawson et al., 2010) called the TUG by the original name: "Get-up and Go," and the true nature of the test was only identified via a reference to Podsiadlo & Richardson (1991) or to a mention of the timed nature of the measure. Researchers should be mindful of carefully tracking the transformation of measures over time so that confusions are avoided regarding literature search terms and the interpretation of study results. Additionally, in one study (Emerson et al., 2012) the average score of two trials was recorded. The reviewers recommend further standardizing the TUG in practice by conducting only one trial when possible.

It is further worth noting that although the SPPB, TUG, and RPW are traditionally thought of only as physical functioning measures, performance on these measures may be impacted by other aspects of health and functioning, including visual and cognitive impairments. Recent studies, for example, have found that performance on the TUG is associated with cognitive impairment (Ayan, Cancela, Gutierrez, & Prieto, 2013; Eggermont et al., 2010). It has been postulated that this association could be due in part to older adults with cognitive impairment slowing their speed as a compensatory strategy in order to maintain accuracy on a task (McGough et al., 2011). When it comes to vision, one study found that poor performance on the SPPB is not associated with poor vision, although poorer vision has been associated with poorer performance on chair stands, gait speed, and the TUG (Rezapour et al., 2012; Aartolahti et al., 2013). To proceed from that point, this review was concerned only with the association between driving outcomes and complete physical performance tests. Future inquiry into this topic may wish to examine associations

between driving outcomes and the individual components of these tests (standing balance, usual and rapid walking speed, and chair stands) separately.

Conclusion

The SPPB has been associated with two of the driving outcomes in the research articles that are reviewed here, but the literature in this field is still sparse and the driving outcomes included here are limited, as no studies examining a potential association between SPPB and driving crashes, citations, or ability were found. More longitudinal studies and clinical trials are needed to confirm the potential association of SPPB scores and other mobility measures with driving outcomes. Despite its respected position in older adult falls research, the TUG did not prove to be a useful measure in the driving research here, which included a wide range of driving outcomes, although studies were limited. Perhaps more standardized protocols to train assessors and implement the TUG across studies would improve the precision to measure change in driving outcomes. We advocate using other physical performance measures besides the TUG in driving studies based on the evidence reviewed here.

It seems likely that the RPW is a useful measure for studies that include driving ability or exposure as an outcome, but it may not be useful in its ability for predicting crashes or citations. The research literature frequently cites the original Marottoli et al. (1994) study as partial evidence for the continued use of this measure, but it is important to keep in mind that although the RPW was significant in bivariate analyses, the relative risk model did not find it to be a useful variable. The reviewers do not advocate discontinuing the use of the RPW in driving studies, but rather recommend that researchers consider carefully whether the measure would likely be useful in the context of their specific research goals. The LongROAD (Longitudinal Research on Aging Drivers) Study selected the SPPB and RPW as the lower extremity physical performance measures in this new, multi-site prospective cohort (From: <http://www.longroadstudy.org/>; Accessed December 2015). The conclusions of this systematic review suggest that these measures, used in combination, will be appropriate for this study, which will include a focus on driving cessation and exposure, among other driving outcomes.

The importance of continued motor vehicle driving for the mental, physical, and social well-being of older adults, as well as the importance of preventing crashes, has been established in the literature. As previously stated, longstanding research in aging populations supports the notion that physical functioning can improve with exercise interventions. This review supports future interventions that target physical performance improvements in order to maintain safe and continued driving for older adults.

References

- Aartolahti, E., Hakkinen, A., Lonroos, E., Kautiainen, H., Sulkava, R., & Hartikainen, S. (2013). Relationship between functional vision and balance and mobility performance in community-dwelling older adults. *Aging Clinical and Experimental Research*, 25(5), 545-52.
- AAA Foundation for Traffic Safety. (2015). The LongROAD Study: Longitudinal Research on Aging Drivers. Available: <http://www.longroadstudy.org>. Accessed: 29 Dec 2015.
- Abdel-Aty, M., Chen, C., & Radwan, A. (1999). Using conditional probability to find driver age effect in crashes. *Journal of Transportation Engineering*, 125(6), 502-507.
- Abellan van Kan, G., Rolland, Y., Andrieu, S., Bauer, J., Beauchet, O., Bonnefoy, M., Cesari, M., Donini, L.M., Gillette-Guyonnet, S., Inzitari, M., Nourhashemi, F., Onder, G., Ritz, P., Salva, A., Visser, M., & Vellas, B. Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people. An International Academy of Nutrition and Aging (IANA) task force. *Journal of Nutrition, Health and Aging*, 13(10), 881-889.
- Ackerman, M.L., Edwards, J.D., Ross, L.A., Ball, K.K., & Lunsman, M. (2008). Examination of cognitive and instrumental functional performance as indicators for driving cessation risk across 3 years. *The Gerontologist*, 48(6), 802-810.
- American College of Rheumatology (ACR). (2015). Timed Up and Go (TUG). Available: <http://www.rheumatology.org/I-Am-A/Rheumatologist/Research/Clinician-Researchers/Timed-Up-Go-TUG>. Accessed: 7 Mar 2016.
- Anstey, K.J., Windsor, T.D., Luszcz, M.A., & Andrews, G.R. (2006). Predicting driving cessation over 5 years in older adults: psychological well-being and cognitive competence are stronger predictors than physical health. *Journal of the American Geriatrics Society*, 54, 121-126.
- Artaud, F., Singh-Manoux, A., Dugravot, A., Tzourio, C., & Elbaz, A. (2015). Decline in fast gait speed as a predictor of disability in older adults. *Journal of the American Geriatrics Society*, 63(6), 1129-1136.
- Ayan, C., Cancela, J.M., Gutierrez, A., & Prieto, I. Influence of the cognitive impairment level on the performance of the Timed "Up & Go" Test (TUG) in elderly institutionalized people. *Archives of Gerontology and Geriatrics*, 56(1), 44-49.
- Ball, K.K., Roenker, D.L., Wadley, V.G., Edwards, J.D., Roth, D.L., McGwin, G., Raleigh, R., Joyce, J.J., Cissell, G.M., & Dube, T. (2006). Can high-risk older drivers be identified through performance-based measures in a Department of Motor Vehicles setting? *Journal of the American Geriatrics Society*, 54, 77-84.
- Barr, R.A. (2002). More road to travel by: implications for mobility and safety in late life. *Gerontechnology*, 2(1), 50-54.

- Beauchet, O., Annweiler, C., Assal, F., Brindenbaugh, S., Herrmann, F.R., Kressig, R.W, & Allali, G. (2010). Imagined Timed Up & Go test: a new tool
- Beauchet, O., Fantino, B. Allali, G., Muir, S.W., Montero-Odasso, M., & Annweiler, C. (2011). Timed up and go test and risk of falls in older adults: a systematic review. *The Journal of Nutrition, Health & Aging*, 15(10), 933-938.
- Beller, E.M., Glasziou, P.P., Altman, D.G., Hopewell, S., Bastian, H., Chalmers, I., Gotsche, P.C., Lasserson, T., Tovey, D., & the PRISMA for Abstracts Group. (2013) PRISMA for abstracts: reporting systematic reviews in journal and conference abstracts. *PLoS Medicine*, 10(4), e1001419.
- Bennie, S., Bruner, K., Dizon, A., Fritz, H., Goodman, B., & Peterson, S. (2003). Measurements of balance: comparison of the Timed “Up and Go” Test and Functional Reach Test with the Berg Balance Scale. *Journal of Physical Therapy Science*, 15, 93-97.
- Bieri, R., Jager, M., Gruber, N., Nef, T., Muri, R.M., & Mosimann, U.P. (2014). A novel computer test to assess driving-relevant cognitive functions—a pilot study. *International Psychogeriatrics*, 26(2), 229-238.
- Bischoff et al. (2003). Identifying a cut-off point for normal mobility: a comparison of the timed ‘up and go’ test in community-dwelling and institutionalised elderly women. *Age and Ageing*, 32(3), 315-320.
- Caird, J.K. & Hancock, P.A. (2002). Contributing factors to left turn and gap acceptance crashes. In Dewar, R.E. & Olson, P. (Eds.), *Human Factors in Traffic Safety*. (613-652). Tucson, AZ: Lawyers & Judges Publishing.
- Campbell, M.K., Bush, T.L., & Hale, W.E. (1993). Medical conditions associated with driving cessation in community-dwelling, ambulatory elders. *Journal of Gerontology*, 48(4), S230-S234.
- Carr, D.B., Barco, P.P., Wallendorf, M.J., Snellgrove, C.A., & Ott, B.R. (2011). Predicting road test performance in drivers with dementia. *Journal of the American Geriatrics Society*, 59, 2112-2117.
- Carr, D.B., Flood, K.L., Steger-May, K., Schechtman, K.B., & Binder, E.F. (2006). Characteristics of frail older adult drivers. *Journal of the American Geriatrics Society*, 54, 1125-1129.
- Carr, D.B., Schwartzberg, J.G., Manning, L., & Sempek, J. (2010). *Physician’s guide to Assessing and counseling older drivers*, 2nd ed. Washington, D.C.: National Highway Traffic Safety Administration.
- Centers for Disease Control and Prevention (CDC). (2015). The Timed Up and Go (TUG) Test. Available: http://www.cdc.gov/steady/pdf/tug_test-a.pdf. Accessed 7 Mar 2016.

- Cesari, M., Onder, G., Zamboni, V., Manini, T., Shorr, D.I., Russo, A., Bernabei, R., Pahor, M., & Landi, F. (2008). Physical function and self-rated health status as predictors of mortality: results from longitudinal analysis in the ilSIRENTE study. *BMC Geriatrics*, 8, 34-42.
- Chihuri, S., Mielenz, T.J., DiMaggio, C.J., Betz, M.E., DiGuseppi, C., Jones, V.C., & Li, G. (2015). *Driving cessation and health outcomes in older adults: a LongROAD study*. Washington, DC: AAA Foundation for Traffic Safety.
- Choi, M., Mezuk, B., Lohman, M.C., Edwards, J.D., & Rebok, G.W. (2012). Gender and racial disparities in driving cessation among older adults. *Journal of Aging and Health*, 24(8), 1364-1379.
- Choi, M., Mezuk, B., & Rebok, G.W. (2012). Voluntary and involuntary driving cessation in later life. *Journal of Gerontological Social Work*, 55(4), 367-376.
- Cicchino, J.B. (2015). Why have fatality rates among older drivers declined? The relative contributions of changes in survivability and crash involvement. *Accident Analysis and Prevention*, 83, 67-73.
- Cicchino, J.B. & McCartt, A.T. (2014). Trends in older driver crash involvement rates and fragility in the United States: an update. *Accident Analysis and Prevention*, 72, 44-54.
- Classen, S., Crizzle, A.M., Winter, S.M., & Lanford, D.N. (2013). Gender differences among older drivers in a comprehensive driving evaluation. *Accident Analysis and Prevention*, 61, 146-152.
- Davis, M.G., Fox, K.R., Hillsdon, M., Coulson, J.C., Sharp, D.J., Stathi, A., & Thompson, J.L. (2011). Getting out and about in older adults: the nature of daily trips and their association with objectively assessed physical activity. *International Journal of Behavioral Nutrition and Physical Activity*, 8, 116.
- Dawson, J.D., Uc, E.Y., Anderson, S.W., Johnson, A.M. & Rizzo, M. (2010). Neuropsychological predictors of driving errors in older adults. *Journal of the American Geriatrics Society*, 58, 1090-1096.
- Dellinger, A.M., Sehgal, M., Sleet, D.A., & Barrett-Connor, E. (2001). Driving cessation: what older former drivers tell us. *Journal of the American Geriatrics Society*, 49, 431-435.
- Dingus, T.A. et al. (2006) 100 Car naturalistic driving study—Phase II results of the 100 Car field experiment. National Highway Traffic Safety Administration. DOT HS 810 593.
- Dugan, E. & Lee, C.M. (2013). Biopsychosocial risk factors for driving cessation: findings from the Health and Retirement Study. *Journal of Aging and Health*, 25(8), 1313-1328.

- Edwards, J.D., Bart, E., O'Connor, M.L., & Cissell, G. (2010). Ten years down the road: predictors of driving cessation. *The Gerontologist*, 50(3), 393-399.
- Edwards, J.D., Ross, L.A., Ackerman, M.L., Small, B.J., Ball, K.K., Bradley, S., & Dodson, J.E. (2008). Longitudinal predictors of driving cessation among older adults from the ACTIVE clinical trial. *Journal of Gerontology*, 63B(1), P6-P12.
- Eggermont, L.H., Gavett B.E., Volkers K.M., Blankevoort, C.G., Scherder, E.J., Jefferson, A.L., Steinberg, E., Nair, A., Green, R.C., & Stern, R.A. Lower-extremity function in cognitively healthy aging, mild cognitive impairment, and Alzheimer's disease. *Archives of Physical Medicine and Rehabilitation*, 91, 584-588.
- Emerson, J.L., Johnson, A.M., Dawson, J.D., Uc, E.Y., Anderson, S.W., & Rizzo, M. (2012). Predictors of driving outcomes in advancing age. *Psychology and Aging*, 27(3), 550-559.
- Federal Highway Administration. (1997). 1995 nationwide personal transportation survey. Washington, DC: US Department of Transportation. Available: <http://www.icpsr.umich.edu/icpsrweb/ICPSR/studies/3595>. Accessed: 28 Dec 2015.
- Fiatarone, M.A., O'Neill, E.F., Ryan, N.D., Clements, K.M., Solares, G.R., Nelson, M.E., Roberts, S.B., Kehayias, J.J., Lipsitz, L.A., & Evans, W.J. (1994). Exercise training and nutritional supplementation for physical frailty in very elderly people. *The New England Journal of Medicine*, 330(25), 1769-1775.
- Fonda, S.J., Wallace, R.B., & Herzog, A. R. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *Journal of Gerontology*, 56B(6), S343- S351.
- Freeman, E.E., Gange, S.J., Munoz, B., & West, S.K. (2006). Driving status and risk of entry into long-term care in older adults. *American Journal of Public Health*, 96(7), 1254- 1259.
- Freeman, E.E., Munoz, B., Turano, K.A., & West, S.K. (2005). Measures of visual function and driving cessation in older adults. *Optometry and Vision Science*, 82(8), 765-773.
- Freter, S. & Fruchter, N. (2000). Relationship between timed 'up and go' and gait time in an elderly orthopaedic rehabilitation population. *Clinical Rehabilitation*, 14, 96-101.
- Gill, T.M., Gahbauer, E.A., Murphy, T.E., Han, L., & Allore, H.G. (2012). Risk factors and precipitants of long-term disability in community mobility: a cohort study of older persons. *Annals of Internal Medicine*, 156, 131-140.
- Guralnik, J.M., Branch, L.G., Cummings, S.R., & Curb, J.D. (1989). Physical performance measures in aging research. *Journal of Gerontology: Medical Sciences*, 44(5), M141-146.
- Guralnik, J.M., Ferrucci, L., Simonsick, E.M., Salive, M.E., & Wallace, R.B. (1995). Lower-extremity function in persons over the age of 70 years as a predictor of subsequent

- disability. *The New England Journal of Medicine*, 332(9), 556-562.
- Guralnik, J.M. & Kritchevsky, S.B. (2010). Translating research to promote healthy aging: the complementary role of longitudinal studies and clinical trials. *Journal of the American Geriatrics Society*, 58, S337-S342.
- Guralnik, J.M., Simonsick, E.M., Ferrucci, L., Glynn, R.J., Berkman, L.F., Blazer, D.G., Scherr, P.A., Wallace, R.B. (1994). A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *Journal of Gerontology*, 49, M85-94.
- Kasper, J.D., Freedman, V.A., & Niefeld, M.R. (2012). Construction of performance-based summary measures of physical capacity in the National Health and Aging Trends Study. NHATS Technical Paper #4. Baltimore: Johns Hopkins University School of Public Health.
- Kwon, S., Perera, S., Pahor, M., Katula, J.A., King, A.C., Groessl, E.J., & Studenski, S.A. (2009). What is a meaningful change in physical performance? Findings from a clinical trial in older adults (the LIFE-P study). *The Journal of Nutrition, Health & Aging*, 6, 538-544.
- Langford, J., Charlton, J.L., Koppel, S., Myers, A., Tuokko, H., Marshall, S., Man-Son-Hing, M., Darzins, P., Di Stefano, M., & Macdonald, W. (2013). Findings from the Candrive/Ozcandrive study: low mileage older drivers, crash risk and reduced fitness to drive. *Accident Analysis and Prevention*, 61, 304-310.
- Lee, H.C., Lee, A.H., Cameron, D., & Li-Tsang, C. (2003). Using a driving simulator to identify older drivers at inflated risk of motor vehicle crashes. *Journal of Safety Research*, 34, 453-459.
- Li, G., Braver, E.R., & Chen, L. (2003). Fragility versus crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. *Accident Analysis and Prevention*, 35, 227-235.
- Lyman, S., Ferguson, S.A., Braver, E.R., & Williams, A.F. (2002). Older driver involvements in police reported crashes and fatal crashes: trends and projections. *Injury Prevention*, 8, 116-120.
- Marmeleira, J.F., Godinho, M.B., & Fernandes, O.M. (2009). The effects of an exercise program on several abilities associated with driving performance in older adults. *Accident Analysis and Prevention*, 41(1), 90-97.
- Marottoli, R.A., Allore, H., Araujo, K.L.B., Iannone, L.P., Acampora, D., Gottschalk, M., Charpentier, P., Kasl, S., & Peduzzi, P. (2007). A randomized trial of a physical conditioning program to enhance the driving performance of older persons. *Journal of General Internal Medicine*, 22(5), 590-597.
- Marottoli, R.A., Cooney, L.M, Wagner, R., Doucette, J., & Tinetti, M.E. (1994). Predictors of automobile crashes and moving violations among elderly drivers. *Annals of Internal*

- Medicine, 121, 842-846.
- Marottoli, R.A., Mendes de Leon, C.F., Glass, T.A., Williams, C.S., Cooney, L.M., & Berkman, L.F. (2000). Consequences of driving cessation: decreased out-of-home activity levels. *Journal of Gerontology*, 55B(6), S334-S340.
- Marottoli, R.A., Ostfeld, A.M., Merrill, S.S., Perlman, G.D., Foley, D.J., & Cooney, L.M. (1993). Driving cessation and changes in mileage driven among elderly individuals. *Journal of Gerontology*, 48(5), S255-S260.
- Marshall, S.C. (2008). The role of reduced fitness to drive due to medical impairments in explaining crashes involving older drivers. *Traffic Injury Prevention*, 9(4), 291-298.
- Mathias, S., Nayak, U.S., & Isaacs, B. (1986). Balance in elderly patients: the "get-up and go" test. *Archives of Physical Medicine and Rehabilitation*, 67(6), 387-389.
- McGough, E.L., Kelly, V.E., Logsdon, R.G., McCurry, S.M., Cochrane, B.B., Engel, J.M., & Teri, L. (2011). Associations between physical performance and executive function in older adults with mild cognitive impairment: gait speed and the Timed "Up & Go" Test. *Physical Therapy*, 91(8), 1198-1207.
- Medley, A. & Thompson, M. (1997). The effect of assistive devices on the performance of community dwelling elderly on the Timed Up and Go Test. *Issues on Ageing*, 20, 3-6.
- Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., & the PRISMA Group (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of Internal Medicine*, 151, 264-269.
- Nelson, M.E., Fiatarone, M.A., Morganti, C.M., Trice, I. Greenberg, R.A., & Evans, W.J. (1994). Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures: a randomized controlled trial. *Journal of the American Medical Association*, 272(24), 1909-1914.
- Noren, A.M., Bogren, U., Bolin, J., & Stenstrom, C. (2001). Balance assessment in patients with peripheral arthritis: applicability and reliability of some clinical assessments. *Physiotherapy Research International*, 6(4), 193-204.
- Ostir, G.V., Kuo, Y., Berges, I.M., Markides, K.S., & Ottenbacher, K.J. (2007). Measures of lower body function and risk of mortality over 7 years of follow-up. *American Journal of Epidemiology*, 166, 599-605.
- Ostir, G.V., Volpato, S., Fried, L.P., Chaves, P., & Guralnik, J.M. (2002). Reliability and sensitivity to change assessed for a summary measure of lower body function: results from the Women's Health and Aging Study. *Journal of Clinical Epidemiology*, 55, 916-921.
- Oxley, J. & Whelan, M. (2007). It cannot be all about safety: the benefits of prolonged mobility. *Traffic Injury Prevention*, 9(4), 367-378.

- Pahor et al. (2014). Effect of structured physical activity on prevention of major mobility disability in older adults: the LIFE Randomized Clinical Trial. *Journal of the American Medical Association*, 311(23), 2387-2396.
- Penninx, B.W.J.H., Ferrucci, L., Leveille, S.G., Rantanen, T., Pahor, M., & Guralnik, J.M. (2000). Lower extremity performance in nondisabled older persons as a predictor of subsequent hospitalizations. *Journal of Gerontology*, 55A(11), M691-M697.
- Perera, S., Mody, S.H., Woodman, R.C., & Studenski, S.A. (2006). Meaningful change and responsiveness in common physical performance measures in older adults. *Journal of the American Geriatrics Society*, 54, 743-749.
- Perera, S., Studenski, S., Newman, A., Simonsick, E., Harris, T., Schwartz, A., & Visser, M.; for the Health ABC Study. (2014). Are estimates of meaningful decline in mobility performance consistent among clinically important subgroups? (Health ABC Study). *Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 69, 1260-1268.
- Phelan, E.A., Mahoney, J.E., Voit, J.C., & Stevens, J.A. (2015). Assessment and management of fall risk in primary care settings. *Medical Clinics of North America*, 99(2), 281-293.
- Podsiadlo, D. & Richardson, S. (1991). The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society*, 39, 142-148.
- Ragland, D.R., Satariano, W.A., & MacLeod, K.E. (2004). Reasons given by older people for limitation or avoidance of driving. *Gerontologist*, 44(2), 237-244.
- Rezapour, M., Chan, E.S., Hochberg, C., Ferrucci, L., Friedman, D.S., & Ramulu, P. (2012). Physical performance measures in glaucoma and macular degeneration. *Investigative Ophthalmology & Visual Science*, 53(14), 4415.
- Rikli, R.E. & Jones, C.J. (2001). *Senior fitness test manual*. Champaign, IL: Human Kinetics.
- Robins, J.M., Hernan, M.A., & Brumback, B. (2000). Marginal structural models and causal inference in epidemiology. *Epidemiology*, 11(5), 550-560.
- Rolland, Y., Lauwers-Cances, V., Cesari, M., Vellas, B., Pahor, M., & Grandjean, H. (2006). Physical performance measures as predictors of mortality in a cohort of community-dwelling older French women. *European Journal of Epidemiology*, 21(2), 113-122.
- Shumway-Cook, A., Brauer, S., & Woollacott, M. (2000). Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Physical Therapy*, 80(9), 896-903.
- Sims, R.V., Ahmed, A., Sawyer, P., & Allman, R.M. (2007). Self-reported health and driving

- cessation in community-dwelling older drivers. *Journal of Gerontology*, 62A(7), 789-793.
- Sink, K.M., Espeland, M.A., Castro, C.M., Church, T., Cohen, R., Dodson, J.A., Guralnik, J., Hendrie, H.C., Jennings, J., Katula, J., Lopez, O.L., McDermott, M.M., Pahor, M., Reid, K.F., Rushing, J., Verghese, J., Rapp, S., Williamson, J.D., & the LIFE Study Investigators. (2015) Effect of a 24-month physical activity intervention vs health education on cognitive outcomes in sedentary older adults: the LIFE randomized trial. *Journal of the American Medical Association*, 314(8), 781-790.
- Smith, A., Marshall, S., Porter, M., Ha, L., Bedard, M., Gelinias, I., Man-Son-Hing, M., Mazer, B., Rapoport, M., Tuokko, H., & Vrkljan, B. (2013). Stability of physical assessment of older drivers over 1 year. *Accident Analysis and Prevention*, 61, 261-266.
- Stav, W.B., Justiss, M.D., McCarthy, D.P., Mann W.C., & Lanford, D.N. (2008). Predictability of clinical assessments for driving performance. *Journal of Safety Research*, 39, 1-7.
- Studenski, S., Perera, S., Patel, K., Rosano, C., Faulkner, K., Inzitari, M., Brach, J., Chandler, J., Cawthon, P., Connor, E.B., Nevitt, M., Visser, M., Kritchevsky, S., Badinelli, S., Harris, T., Newman, A.B., Cauley, J., Ferrucci, L., Guralnik, J. (2011). Gait speed and survival in older adults. *Journal of the American Medical Association*, 305(1), 50-58.
- Studenski, S., Perera, S., Wallace, D., Chandler, J.M., Duncan, P.W., Rooney, E., Fox, M., & Guralnik, J.M. (2003). Physical performance measures in the clinical setting. *Journal of the American Geriatrics Society*, 51, 314-322.
- Volpato, S., Cavalieri, M., Guerra, G., Sioulis, F., Ranzini, M., Fellin, R., & Guralnik, J.M. (2008). Performance-based functional assessment in older hospitalized patients: feasibility and clinical correlates. *Journal of Gerontology*, 63A(12), 1393-1398.
- Volpato, S., Cavalieri, M., Sioulis, F., Guerra, G., Maraldi, C., Zuliani, G., Fellin, R., & Guralnik, J.M. (2011). Predictive value of the Short Physical Performance Battery following hospitalization in older patients. *Journal of Gerontology*, 66A(1), 89-96.
- Wells, G.A., Shea, B., O'Connell, D., Peterson, J., Welch, V., Losos, M., & Tugwell, P. (1999). The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Ottawa (ON): Ottawa Health Research Institute.
- Windsor, T.D., Anstey, K.J., Butterworth, P., & Luszcz, M.A. (2007). The role of perceived control in explaining depressive symptoms associated with driving cessation in a longitudinal study. *The Gerontologist*, 47(2), 215-223.
- Woolnough, A., Salim, D., Marshall, S.C., Weegar, K., Porter, M.M., Rapoport, M.J., Man-Son-Hing, M., Bedard, M., Gelinias, I., Korner-Bitensky, N., Mazer, B., Naglie, G., Tuokko, H., & Vrkljan, B. (2013). Determining the validity of the AMA guide: a

historical cohort analysis of the Assessment of Driving Related Skills and crash rate among older drivers. *Accident Analysis and Prevention*, 61, 311-316.

Yim-Chiplis, P.K. & Talbot, L.A. (2000). Defining and measuring balance in adults. *Biological Research for Nursing*, 1(4), 321-331.

Appendix

Tables – see below

Table 1a. Characteristics of driving studies using the SPPB as a measure of physical functioning

<i>First author, Year</i>	<i>Study participants</i>	<i>Data source</i>	<i>Study design</i>	<i>Location</i>	<i>Study time period</i>	<i>Type of driving outcome</i>	<i>Source of driving outcome information</i>
Davis, 2011	214 participants aged 70 years and older	Project OPAL (Older People and Active Living)	Cohort study	Bristol, UK	2007-2008	Driving exposure (number of car trips as a driver per week)	Combination of accelerometry (Actigraph GT1Ms) and daily trips logs
Gill, 2012	507 community-dwelling adults aged 70 years and older who were active drivers or nondisabled in walking a quarter mile	Precipitating Events Project	Cohort study	Greater New Haven, Connecticut	1998-2009	Driving cessation (long-term disability in driving a car, indicated by not driving in the past 6 months)	Participant responses during monthly interviews
Sims, 2007	649 community-dwelling adults aged 65 years and older who reported driving at baseline	University of Alabama at Birmingham (UAB) Study on Aging (SOA)	Cohort study	Five central Alabama counties	1999-2003	Driving cessation	Participant responses during 2-year telephone follow-up interview

Table 1b. Characteristics of driving studies using the TUG as a measure of physical functioning

<i>First author, Year</i>	<i>Study participants</i>	<i>Data source</i>	<i>Study design</i>	<i>Location</i>	<i>Study time period</i>	<i>Type of driving outcome</i>	<i>Source of driving outcome information</i>
Dawson, 2010	111 participants aged 65 and older who were current drivers	Participants recruited through announcements throughout the community	Cross-sectional study	Iowa City, Iowa	Not specified	Driving ability (safety errors per drive)	Video review of performance on a 35-mile road test in an instrumented vehicle
Emerson, 2012	100 participants aged 65 and older who were current drivers	Participants recruited through announcements throughout the community	Cohort study	Iowa City, Iowa	Not specified	Driving cessation, citations, and crashes (time to driving event over a length of follow-up ranging from 3 to 8 years)	Cessation was determined by participant or family report at end of follow-up period (or, if needed, by driving records, ARGOS drive status, death date, or the Driving Habits Questionnaire (DHQ)); citations were tracked with yearly requests to Iowa DOT driving records; crashes were determined from DHQs at annual visits and from Iowa DOT driving records

Table 1c. Characteristics of driving studies using the RPW as a measure of physical functioning

<i>First author, Year</i>	<i>Study participants</i>	<i>Data source</i>	<i>Study design</i>	<i>Location</i>	<i>Study time period</i>	<i>Type of driving outcome</i>	<i>Source of driving outcome information</i>
Ball, 2006	1,910 participants aged 55 years and older who were current drivers	Maryland Older Drivers Project	Cohort study	Maryland	1998-2003	Driving crashes (at-fault motor vehicle collision involvement during follow-up period of between 4.18 and 5.13 years)	Maryland MVA Administration of Driver Safety Research Office crash records
Classen, 2013	195 community dwelling current older drivers aged 65 years and older	National Older Driver Research and Training Center (NODRTC) study and	Cross-sectional study	North-central Florida	2004-2006 and 2010-2012	Driving ability (passing or failing an on-road driving test)	Road test administered by a certified driving rehabilitation specialist (CDRS)
Carr, 2011	99 participants aged 52 years and older with dementia who were current drivers	Participants recruited through physician referral	Cross-sectional study	St. Louis, Missouri	2007-2009	Driving ability (passing or failing the Washington University Road Test)	Washington University Road Test administered by driving instructors from Independent Drivers, LLC
Edwards, 2010	1,248 participants aged 55 years	Maryland Older Drivers Project	Cohort study	Maryland	1998-2008	Driving cessation (time to cessation in	Self-reported driving cessation

	and older (1,099 active drivers)					months over 10-year period)	on the Mobility Questionnaire
Langford, 2013	1222 participants aged 70 years and older who were active drivers	Candrive II/Ozcandrive cohort	Cohort study (baseline data analyzed cross- sectionally)	British Columbia, Manitoba, Ontario and Quebec, Canada; Queensland, Australia; Wellington, New Zealand	2009- 2014	Driving exposure (low mileage vs. high mileage drivers)	Self-reported annual driving distance
Marottoli, 1994	278 participants aged 72 years and older who were current drivers	Project Safety cohort	Cohort study	New Haven, Connecticut	1990- 1991	Driving crashes and citations (crashes, moving violations, and being stopped by police in a 1-year period)	Participant responses at the 1-year follow-up interview
Stav, 2008	120 participants aged 65 and older who were current drivers	Participants recruited through physician referral and research at University of Florida's National Older Driver Research and Training Center	Cross- sectional study	North Central Florida	Not specified	Driving ability (Global Rating Score assigned based on driving performance during a road test)	Global Rating Score assigned by a driving rehabilitation specialist

Woolnough, 2013	1230 participants aged 70 and older who were active drivers	Candrive II/ Ozcandrive cohort	Cohort study	British Columbia, Manitoba, Ontario and Quebec, Canada; Queensland, Australia; Wellington, New Zealand	2009- 2014	Driving crashes (at- fault or not-at- fault crashes in the past 2 years)	Data on crashes obtained from provincial/state jurisdictions using participant driver license numbers
--------------------	---	--------------------------------------	--------------	--	---------------	---	---

Table 2a. Exposures, covariates and outcomes for driving studies using SPPB as a measure of physical functioning

<i>First author, Year</i>	<i>Exposures, precipitants, and covariates assessed</i>	<i>Outcomes measured</i>
Davis, 2011 ⁱ	SPPB scores ^{***} , age ^{***} , sex ^{***} , education ^{**} , home circumstances (living alone or with others), BMI category, walking and mobility aid use ^{**} , IMD [*] , amenities within 5-min walking category, number of cars in household ^{***}	Driving exposure (number of car trips as a driver per week)
Gill, 2012 ⁱⁱ	low SPPB score [*] , intermediate SPPB score, age (75-79y [*] , 80-84y [*] , ≥ 85 [*]), female sex [*] , living with others, chronic conditions, moderate visual impairment, severe visual impairment [*] , weight loss [*] , cognitive impairment [*] , low physical activity [*] , lower-extremity weakness, gross motor coordination (8.8-10.3s [*] , 10.4-12.4s [*] , ≥ 12.5s [*]), peak expiratory flow; precipitants: hospitalization [*] and restricted activity [*]	Driving cessation (long-term disability in driving a car, indicated by not driving in the past 6 months)
Sims, 2007 ⁱⁱⁱ	SPPB scores ^{**} , age [*] , sex, race, education, rural residence, SRH [*] , visual acuity, MMSE scores, GDS scores, CCI scores	Driving cessation

*p<.05, **p<.01, ***p<.001

ⁱT-test and ANOVA analyses

ⁱⁱCox proportional hazards regression reporting hazard ratios; reference values: SPPB score (high), age (70-74y), visual impairment (none or mild), gross motor coordination (≤8.7s)

ⁱⁱⁱMultivariable logistic regression analysis reporting adjusted odds ratios

SPPB= Short Physical Performance Battery; IMD= Index of Multiple Deprivation; SRH=Self-rated health; MMSE=Mini-Mental State Examination; GDS= Geriatric Depression Scale; CCI=Charlson Comorbidity Index

Table 2b. Exposures, covariates and outcomes for driving studies using the TUG as a measure of physical functioning

<i>First author, Year</i>	<i>Exposures and covariates assessed</i>	<i>Outcomes measured</i>
Dawson, 2010 ⁱ	TUG, age*, sex, education, days driven per week, miles driven per week, CFT-Copy*, CFT-Recall*, Blocks*, BVRT, TMT A, TMT B, AVLT, JLO, COWA, COGSTAT**, UFOV, CS, FVA, NVA*, SFM, FR balance, Pegs*	Driving ability (safety errors per drive)
Emerson, 2012 ⁱⁱ	TUG, age** ^a , male gender, education** ^b , miles per week*** ^b , number of crashes in past year, number of times pulled over in past year, exposure reduction score, intentional avoidance score, GDS, FR balance, Pegs* ^a , NVA* ^a , FVA, CS* ^a , JLO* ^a , SFM, UFOV* ^a , Blocks, CFT-Copy, CFT-Recall, BVRT* ^a , AVLT-Recall, TMT A* ^a , TMT B* ^c , TMT (B-A)* ^c , COWA, COGSTAT** ^a , overall road safety errors year 1, serious road safety errors year 1* ^{bc}	Driving cessation, citations, and crashes (time to driving event over a length of follow-up ranging from 3 to 8 years)

*p<.05, **p<.01, ***p<.001

ⁱMultiple linear regression analysis of estimated changes in total driving safety errors for a 1-standard deviation increase in cognitive, visual, and motor predictors, controlling for age, education, and sex

ⁱⁱCox proportional hazards regression reporting hazard ratios for a 1 standard deviation increase in visual, motor, and cognitive predictors, controlling for age, gender, education, and baseline mileage driven per week; 3 regression models for the 3 driving outcomes with significance indicated by ^adriving cessation ^bcitations ^ccrashes

TUG=Timed Up-and-Go Test; CFT-Copy=Complex Figure Test-Copy; CFT-Recall=Complex Figure Test-Recall; Blocks= WAIS-III Block Design; BVRT=Benton Visual Retention Test; TMT=Trail Making Test; AVLT=Rey Auditory Verbal Learning Test; JLO=Judgment of Line Orientation; COWA=Controlled Oral Word Association; COGSTAT=composite measure of cognitive function; UFOV=Useful Field of View; CS=contrast sensitivity; FVA=far visual acuity; NVA=near visual acuity; SFM=Structure from Motion; FR=Functional Reach; Pegs=Grooved Pegboard Test; GDS=Geriatric Depression Scale

Table 2c. Exposures, covariates and outcomes for driving studies using the RPW as a measure of physical functioning

<i>First author, Year</i>	<i>Exposures and covariates assessed</i>	<i>Outcomes measured</i>
Ball, 2006 ⁱ	RPW, age*, female sex*, history of at-fault crash involvement, history of falling*, delayed recall, tap time, MVPT**, TMT A, TMT B*, UFOV substest 2**	Driving crashes (at-fault motor vehicle collision involvement during follow-up period of between 4.18 and 5.13 years)
Carr, 2011 ⁱⁱ	RPW, age, male sex, African American race, driving experience in years, days driven per week, miles driven per day, ≥ 1 crashes in previous year, FVA, CS*, presence of any abnormal score on visual field test, cervical range of motion left, cervical range of motion right, 9-Hole Peg Test right, 9-Hole Peg Test left*, grip strength right, grip strength left, brake reaction*, Short Blessed Test**, SMT**, CDT***, TMT A***, TMT B***, eight-item informant interview to differentiate aging and dementia total***, Digit Span Forwards, Digit Span Backwards**, MVPT, UFOV*	Driving ability (passing or failing the Washington University Road Test)
Classen, 2013 ⁱⁱⁱ	RPW*, age, sex*, education, medication, MMSE, UFOV**, days of driving/week**, avoiding rush hour, avoiding the interstate*, avoiding rain, avoiding night driving, avoiding left turns, avoiding other	Driving ability (passing or failing the on-road driving test)
Edwards, 2010 ^{iv}	RPW, age*, days driven per week, MVPT, TMT B, UFOV*	Driving cessation (time to cessation in months over 10-year period)
Langford, 2013 ^v	RPW*, gender*, age*, crash involvement in the last year, one leg stance (left leg), one leg stance (right leg), Ruler Drop*, Snellen visual acuity*, MMSE, Montreal cognitive assessment, MVPT*, TMT A*, TMT B*, Digit Span Forwards, Digit Span Backwards, months in reverse order*, self-rated abilities (see road signs at distance*, see road signs at distance at night*, see road lines at night*, see objects on road at night with glare or on wet roads*, quickly find street or exit in unfamiliar area and heavy traffic*, get in and out of car*), comfort in daytime driving situations (in light rain*, in heavy rain*, parking in tight spots*, in unexpected storm*, seeing street or exit signs with little warnings*, surrounded by multiple transport trucks*, tailgated by other	Driving exposure (low mileage drivers [$< 5,001$ km/yr] vs. high mileage drivers [$\geq 15,000$ km/yr])

	drivers, passed by other drivers in non-passing lane, other drivers do not signal or seem distracted*)	
Marottoli, 1994 ^{vi}	RPW, impaired design copying*, number of blocks walked*, number of foot abnormalities*, driving frequency, housing type	Driving crashes and citations (crashes, moving violations, and being stopped by police in a 1-year period)
Stav, 2008 ^{vii}	RPW***, MMSE***, UFOV***, TMT B***, Letter cancellation, Digit Span Forwards*, digit symbol substitution task, delayed recall, visual fields, acuity, MVPT spatial orientation subtask*, MVPT visual closure task, depth perception**, CS A***, CS B***, CS C***, CS D***, CS E***, Rules of the Road Test*, Road Sign Test***, right grip strength**, left grip strength*, trunk/neck rotation to left*, trunk/neck rotation to right**,	Driving ability (Global Rating Score assigned based on driving performance during a road test)
Woolnough, 2013 ^{viii}	RPW, Snellen visual acuity, visual field by confrontation, TMT B, CDT, neck rotation, shoulder and elbow flexion, finger curl, ankle plantar flexion, ankle dorsiflexion, shoulder adduction and abduction, wrist flexion and extension, hand-grip strength, hip flexion and extension, ankle dorsiflexion and plantar flexion	Driving crashes (at-fault or not-at-fault crashes in the past 2 years)

*p<.05, **p<.01, ***p<.001

ⁱChi-squared test analyses for association between at-fault motor vehicle collisions and demographics and selected screening tests, all covariates adjusted for annual miles driven

ⁱⁱCorrelations of demographic, noncognitive, and selected psychometric tests with failure on the road test

ⁱⁱⁱLogistic regression reporting adjusted odds ratios

^{iv}Cox proportional hazards regression final model for time to driving cessation

^vBivariate comparisons between low mileage and high mileage drivers on demographics, physical/sensory performance, cognitive performance, and comfort with aspects of daytime driving

^{vi}Binomial relative risk modeling adjusted for driving frequency and housing type

^{vii}Correlations of independent variables with the Global Rating Score

^{viii}Fisher's exact test, Pearson's chi-squared test, and independent samples t-test analyses comparing those who were and were not involved in a collision on ADReS sub-tests

RPW=Rapid Pace Walk; MVPT=Motor Free Visual Perception Test; TMT=Trail Making Test; UFOV=Useful Field of View; FVA=far visual acuity; CS=contrast sensitivity; SMT=Snellgrove Maze Test; CDT=Clock Drawing Test; MMSE=Mini-Mental State Examination; ADReS=Assessment of Driving Related Skills

Table 3a. Quality ratings for 7 cohort studies included on the basis of Newcastle-Ottawa quality assessment scale

	Selection		Comparability			Outcome		Total Score	
	Representativeness of exposed cohort	Selections of non-exposed	Assessment of exposure	Absence of outcome at	Comparability	Assessment of outcome	Follow-up period (≥ 6 months)	Adequacy of follow-up	out of 9 points
Ball et al., 2006	1	1	1	1	1	1	1	1	9 (high)
Edwards et al., 2010	1	1	1	1	2	0	1	1	8 (high)
Emerson et al., 2012	1	1	1	1	2	1	1	1	9 (high)
Gill et al., 2012	1	1	1	1	2	0	1	1	8 (high)
Marottoli et al., 1994	1	1	1	1	2	0	1	1	8 (high)
Sims et al., 2007	1	1	1	1	2	0	1	1	8 (high)
Woolnough et al., 2013	1	1	1	1	0	1	1	1	7 (medium)

Table 3b. Quality ratings for 6 cross-sectional studies included on the basis of the modified Newcastle-Ottawa quality assessment scale

	Representativeness of sample	Sample size	Non-respondents	Ascertainment of primary measurement	Comparability	Ascertainment of the outcome	Statistical test	Total Score out of 10 points
Carr et al., 2011	1	0	0	2	0	2	1	6 (medium)
Classen et al., 2013	1	0	0	2	2	2	1	8 (high)
Davis et al., 2011	1	0	0	2	2	2	1	8 (high)
Dawson et al., 2010	1	0	0	2	2	2	1	8 (high)
Langford et al., 2013*	1	1	0	2	0	1	1	6 (medium)
Stav et al., 2008	1	0	0	2	2	2	1	8 (high)

*Langford et al., 2013 used baseline data from a prospective cohort study and analyzed the data obtained in a cross-sectional manner.