TAI CHI FOR DRIVING HEALTH: COGNITIVE AND PHYSICAL FUNCTION RELATED TO SAFE DRIVING PERFORMANCE AMONG OLDER TAI CHI PRACTITIONERS

by

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DEDICATION

This work is dedicated to older adults everywhere who strive to maintain their independence.
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ABSTRACT

By the year 2030 it is estimated that one in five licensed drivers in the United States will be over the age of 65. Driving allows engagement in the community for shopping, banking, maintaining social connections, and accessing health care. However, age-related decline can impact many of the cognitive processes and physical abilities necessary for safe driving performance.

Exercise has beneficial effects on specific cognitive processes and physical function, many of which are related to safe driving performance. Tai Chi exercise is known to benefit cognitive and physical function and may influence safe driving performance.

The aims of this observational study were to: 1) examine relationships between Tai Chi exercise habits, cognitive processes and physical function related to safe driving performance, 2) compare cognitive processes and physical function related to safe driving performance to normative reference values, and 3) explore potential predictors of safe driving performance.

Fifty-eight current Tai Chi practitioners (mean age = 72.9), with a median of greater than three years of Tai Chi practice were recruited from community Tai Chi classes and Tai Chi events. Participants completed a study packet describing self-reported Tai Chi and non-Tai Chi exercise habits, driving habits, self-report measures of dispositional mindfulness (Mindful Attention Awareness Scale, MAAS) and overall well-being (Vitality Plus Scale, VPS), personal history, and health history. Investigator-administered study measures included the DrivingHealth InventoryTM, digit span tests, the Driving Scenes Test, and the Right Foot Tapping test.

Statistically significant correlations were found between several study measures. Compared to normative reference values participants performed better on several cognitive and
physical measures, and on the MAAS and the VPS measures. Small to large effect sizes were calculated. The strongest predictor of safe driving performance was the digit span backward. Tai Chi exercise has the potential to positively impact cognitive processes and physical function related to safe driving performance through aerobic exercise mechanisms, development of mindfulness, and beneficial influence on overall vitality. The results of this study support the need for further investigation of Tai Chi exercise as a strategy to maintain safe driving performance in older adults.
Introduction

Background

The population of the United States is aging, and by the year 2030 the number of Americans 65 and older will almost double, from approximately 40 million to an estimated 72 million (Administration on Aging, 2010). With this growing population, strategies to maintain safety, independence, and quality of life are important for individuals as well as society.

Independence in Instrumental Activities of Daily Living (IADL) is important to quality of life. Instrumental Activities of Daily Living include managing finances, shopping, food preparation, medication management, and transportation (Graf, 2008), and can be viewed as interactions between the individual and the environment. For community-dwelling older adults, automobile driving is viewed as an IADL and promotes ‘community mobility’ (Bonder & Bello-Haas, 2008; Wieland, 2013) which is the ability of an individual to move around the community using public or private transportation. Community mobility facilitates participation and connection to the larger community and society by promoting individuals’ engagement in IADLs such as accessing healthcare or participating in social activities (Stav, 2011; Wieland, 2013). Many older adults achieve community mobility by driving private automobiles. However, age-related cognitive and physical declines often compromise safe driving performance, leading to driving cessation, loss of independence, social isolation, or increased risk of automobile crashes with associated injuries or death (Centers for Disease Control and Prevention, 2011a; Marottoli et al., 2000).

In 2009 there were 33 million licensed drivers aged 65 and older and this number is expected to nearly double - to approximately 60 million licensed drivers - by 2030, representing
one in five drivers (Centers for Disease Control and Prevention, 2011a; National Highway Traffic Safety Administration, 2013). In the United States, many older adults prefer private vehicles for transportation (American Association of Retired Persons, 2010). Lifelong driving habits, the growth of suburbs lacking public transportation options, and the desire to maintain independence make driving individual automobiles a desirable, necessary, and often critical mode of transportation (Burkhardt, 2000).

The purpose of this study is to examine specific cognitive processes and physical function related to safe driving performance in adults aged 65 and older who participate in Tai Chi exercise, and to explore the potential of Tai Chi exercise as an innovative approach to maintain and improve automobile driving performance in older adults. This study is significant because it will add to the growing body of knowledge regarding the benefits of Tai Chi exercise in healthy community-dwelling older adults, specifically the relationship of Tai Chi exercise to cognitive processes and physical function necessary for automobile driving. The findings from this study may lead to future Tai Chi interventional research to study the effect of Tai Chi exercise on driving performance in older adults.

**Significance**

**Motor vehicle crash rates.** Drivers aged 65 and older make up approximately 16% of total licensed drivers in the United States and this age group accounts for more motor vehicle crashes per miles driven. On average, older adults drive fewer miles than other age groups, and the miles driven are typically in city driving conditions. When compared to highway driving, city driving has higher crash rates than highway miles due to more potential hazards such as traffic congestion and numerous intersections, potentially inflating the annual crash rate of older drivers.
(National Highway Traffic Safety Administration, 2014a). Because many older adults are frailer, have comorbidities, and have decreased resilience, they are at increased risk of injury or death from motor vehicle crashes (Centers for Disease Control and Prevention, 2011a).

Although older adults make up 12% of the population of the United States, of the traffic fatalities in 2011, adults aged 65 and over comprised 17% of all fatalities and 8% of nonfatal injuries as a driver or passenger (National Highway Traffic Safety Administration, 2014a). The total lifetime costs of fatal and nonfatal injuries for adults 65 and older accounted for over $2 billion of the $70 billion cost among drivers or passengers of all ages (Naumann, Dellinger, Zaloshnja, Lawrence, & Miller, 2010). Therefore, there are significant individual, economic, and societal implications of motor vehicle crashes in adults aged 65 and older.

**Types of crashes involving older adults.** Motor vehicle crashes involving older adults often involve failure to yield the right-of-way and are more likely to involve negotiating intersections, when overtaking other vehicles, and when merging with traffic (Insurance Institute for Highway Safety, 2013; National Highway Traffic Safety Administration, 2014b). These driving situations involve several cognitive processes including selective attention, divided attention, attention-switching, hazard detection, and estimation. Ongoing *situation awareness* is critical for safe driving performance, and is defined as “the updated, meaningful knowledge of an unpredictably changing, multifaceted situation that operators use to guide choice and action when performing a real-time, multitasking task” (Gugerty, 2011, pp. 19-17). During driving, situation awareness is needed to sort relevant from irrelevant information, selectively attend to and act on stimuli, and complete several driving decisions and maneuvers in relatively quick succession. These driving demands increase the cognitive workload, and due to age-related
slower processing speeds, contribute to risk of motor vehicle crashes in older adults (Insurance Institute for Highway Safety, 2013; National Highway Traffic Safety Administration, 2014b).

**Concepts**

**Safe Driving Performance**

The ability to drive an automobile relies on a combination of cognitive, physical, and perceptual capabilities, and can be impacted by common age-related changes, as well as acquired diseases and conditions (Anstey, Wood, Lord, & Walker, 2005; Emerson et al., 2012; National Highway Traffic Safety Administration, 2014a; Tuokko, Rhodes, & Dean, 2007). Controlling speed of travel through use of the gas and brake pedals, steering to adjust to the road, tracking objects in the periphery and rear vision, paying attention to brake lights ahead, considering environmental conditions, anticipating approaching hazards, and monitoring and reacting to the actions of other drivers are some of the cognitive and physical functions involved in driving (Castro, 2009; Federal Motor Carrier Safety Administration, 2013). Safe driving performance can be conceptualized as a complex process of attention, working memory, decision-making, planning, and the physical ability to respond and adjust to changing driving conditions. Safe Driving Performance is therefore dependent upon integrated cognitive and physical function.

**Cognitive Processes Necessary for Safe Driving Performance**

Several cognitive processes are necessary for Safe Driving Performance. These include executive function, working memory, attention, speed of processing, and reaction time.

**Executive function.** Executive function is composed of several factors critical for Safe Driving Performance and include attention and working memory. Attention is a complex, multifaceted concept overlapping with other cognitive processes such as working memory (Strauss,
Sherman, & Spreen, 2006). Attention is composed of several processes including sensory selection or the filtering and focusing on received stimuli; response selection, including initiation of response, inhibition of response, and the ability to switch tasks; attentional capacity, which is dependent on alertness and the effort required; and sustaining attention, known as vigilance. Attentional components needed for Safe Driving Performance include selectively responding to stimuli, dividing attention between several simultaneous stimuli, filtering distractors, vigilance in monitoring the actions of other drivers or road conditions, inhibiting habitual responses, choosing the safest options, and completing planned actions.

Working memory includes information gathered from sensory input that can be retained, stored, and manipulated for brief periods of time, for example, for a few seconds to one to two minutes (Strauss et al., 2006). Working memory is important for information processing and subsequent action, and includes word and task recall. An example of the importance of working memory associated with Safe Driving Performance includes the ability to remember that a car was approaching from the rear and might be in the process of passing, and is currently in the “blind spot”, as well as remembering directions, landmarks, and upcoming hazards.

**Speed of information processing and reaction time.** Speed of information processing is the amount of time it takes to analyze received information, such as visual or auditory stimuli. Reaction time depends on speed of information processing and also contains a motor component (Ekelman, 2009). For example, when brake lights suddenly appear on a car, the ability to recognize the need for reducing speed or applying the brakes is dependent on integration of cognitive interpretation and coordination of motor function. Processing the stimulus, recognizing that an action is required, and the resulting motor component comprised of musculoskeletal
strength and flexibility allows adequate reaction time to respond to routine and unanticipated driving situations.

Physical Function Related to Safe Driving Performance

Physical fitness promotes and maintains physical function related to Safe Driving Performance including range of motion and flexibility of the neck and torso, range of motion and strength of upper and lower extremities, hand strength, endurance, such as the ability to walk a block or climb stairs, and proprioception (National Highway Traffic Safety Administration, 2009). Physical fitness is defined as

The ability to carry out daily tasks with vigor and alertness, without undue fatigue, and with ample energy to enjoy leisure-time pursuits and respond to emergencies. Physical fitness includes a number of components consisting of cardiorespiratory endurance (aerobic power), skeletal muscle endurance, skeletal muscle strength, skeletal muscle power, flexibility, balance, speed of movement, reaction time, and body composition. (Centers for Disease Control and Prevention, 2011b)

Physical function of the upper and lower body is required for drivers to be able to manage automobile controls such as steering and braking, gripping and turning the steering wheel, and manipulating in-vehicle controls and levers. Strength, flexibility and range of motion of the shoulder and arm are needed to reach and secure seatbelts (Rikli & Jones, 2013). Flexibility of the neck and torso are needed when backing up, checking intersections, changing lanes, making turns, or tracking objects such as pedestrians or other vehicles in the periphery. Lower extremity flexibility is important for entering and exiting the vehicle, and lower extremity strength is necessary to press the brake and gas pedal with adequate force and speed.

Proprioception is the awareness of the body, such as the limbs, in relationship to each other and within the environment (Bonder & Bello-Haas, 2008). Proprioception is important for
adequate speed and/or accuracy when moving the foot between the gas pedal and the brake pedal, and for using dashboard dials, knobs, and levers without distraction.

**Perceptual problems**

Perceptual problems impacting Safe Driving Performance include visual deficits such as cataracts, macular degeneration, and glaucoma. Hearing impairment can affect driving safety when in-vehicle alerts, such as seatbelt alarms or turn indicators, or external sounds such as sirens are not readily heard. While these visual-perceptual abilities are very important for Safe Driving Performance, they are not the focus of this study. However, visual acuity and contrast sensitivity are a component of a test battery to be used, and will be assessed.

**Methods to Facilitate Safe Driving Performance**

Many older adult drivers self-regulate their driving habits, including not driving during inclement weather, limiting driving to daytime and non-rush hour, and not driving long distances (Centers for Disease Control and Prevention, 2011a; Pickard, Tan, Morrow-Howell, & Jung, 2009). Although these self-regulatory behaviors are helpful in reducing higher risk driving situations, additional methods are needed to maintain or improve Safe Driving Performance.

Current methods to address Safe Driving Performance in older adults include online driving assessments, refresher instruction, road tests, informational brochures, discussing driving with healthcare providers, and programs to evaluate and recommend appropriate physical adjustments and modifications of vehicles (Automobile Association of America, 2013; CarFit, 2013; National Highway Traffic Safety Administration, 2014a; Tuokko, McGee, Gabriel, & Rhodes, 2007). However, these strategies do not affect both the age-related changes in cognitive function and decreased physical function known to compromise Safe Driving Performance.
Exercise is one method that may impact driving performance through combined influence on cognitive function and physical function.

**Exercise**

Exercise has many health benefits for older adults, including decreased morbidity and mortality associated with chronic diseases and conditions such as cardiovascular disease, arthritis, and obesity. Exercise reduces the risk of falls, improves mental health and health-related quality of life. Exercise is important for physical and cognitive function, and is a strategy to maintain function and preserve independence in the growing older adult population (Agency for Healthcare Research and Quality, 2012; Centers for Disease Control and Prevention, 2008; Kramer, Colcombe, McAuley, Scalf, & Erickson, 2005).

Exercise is defined as a planned and structured form of physical activity that requires a person to expend more energy than they would in a resting state (National Heart Lung and Blood Institute, 2013). Exercise is classified by the individual’s energy expenditure using metabolic equivalents of task (METs) (Ainsworth et al., 2011). Some examples of activities with low MET values are home activities such as cleaning and sweeping (< 4 METs), moderate MET values include walking with a brisk or moderate pace, and water aerobics (3-6 METs), and high MET values include activities such as jogging or vigorous biking (>6 METs) (Centers for Disease Control and Prevention, 2012).

The effect of exercise on cognitive function is based on several proposed mechanisms including increased cerebral blood flow, neurogenesis, synaptogenesis, and exercise-induced increases in brain structure and volume (Colcombe et al., 2006; Kramer et al., 1999; Lista & Sorrentino, 2010). The ability of the brain to respond to the effects of exercise is termed
“neuroplasticity” and these changes are considered to be achievable in all stages of life (Willis, Schaie, & Martin, 2009).

The benefits of exercise on physical function in all age groups are well-documented and includes improvement in muscle tone and strength, joint range of motion, endurance, balance, and decreased risk of falls (Agency for Healthcare Research and Quality, 2012; Centers for Disease Control and Prevention, 2011c).

The combined effect of exercise on cognitive function and physical function may provide a method to maintain or improve Safe Driving Performance in older adults. One form of exercise that is accessible and appropriate for older adults is Tai Chi, a mindful exercise with both cognitive and physical benefits.

**Tai Chi Exercise**

Tai Chi is considered a moderate-intensity physical activity with cardiovascular conditioning benefits (Lan, Chen, & Lai, 2008; Li, Hong, & Chan, 2001). Several components distinguish Tai Chi from other forms of exercise such as walking, stretching and toning, and other fitness activities. These include the meditative aspects, proprioceptive awareness, breath-centering, attention to anatomic alignment, imagery, intention, awareness of intrinsic energy, and memorization of postures and sequences (La Forge, 2005; Wayne & Kaptchuk, 2008). The slow, coordinated movements and the low impact on joints makes Tai Chi an appropriate form of exercise for older adults (National Institutes of Health, 2010). Tai Chi has positive effects on cognitive function, mood, sleep, and physical function (Chang, Nien, Tsai, & Etnier, 2010; Li et al., 2004; Taylor-Piliae, Haskell, Waters, & Froelicher, 2006). Tai Chi’s therapeutic effect may
be associated with “structural integration” (Wayne, 2013, p. 30) as physiological and structural systems interact to “dissolve the hyphen in the phrase ‘mind-body’” (Wayne, 2013, p. 194).

Tai Chi is a form of exercise appropriate for older adults and can be beneficial for people of any age, for people with chronic conditions, for those who have inadequate levels of exercise, or for those who have been previously sedentary. The potential cognitive and physical effects of Tai Chi can benefit people of any age and is consistent with lifespan development theory.

**Theoretical and Conceptual Framework**

Lifespan development theory proposes that growth, adaptation, and change are a continuous possibility, regardless of a person’s age and that a person’s potential, in the form of latent reserves, can be activated through learning, exercise, training, and social connection (Baltes & Baltes, 1993; Overton, 2010). Through the lens of lifespan development theory, humans are viewed as complex, self-organizing systems, composed of interrelated and non-reducible parts. Humans are in dynamic, interactive relationships with the environment, making the influence of context all-important. Humans constantly respond to inner and outer influences in nonlinear, unpredictable ways, and change is toward ever-increasing complexity (Overton, 2010). This organismic-contextual worldview perceives the mind and body not as separate entities, but integrated and inseparable.

Based on lifespan development theory, Baltes’ Selection with Optimization and Compensation (SOC) model (Baltes et al., 2005; Freund, 2008) recognizes the ability of older adults to evolve, grow, and adapt to losses in specific functions and reduced capacity, such as those due to normal aging.
Changes in function and reductions in capacity are termed antecedent conditions. For example, reductions in cognitive processes such as age-related declines in working memory, attention, or speed of processing, or declines in physical function such as diminished strength, decreased flexibility, or reduced endurance are antecedent conditions that set into motion the process of selection, optimization and compensation to maximize gains, minimize losses, and maintain function. Selection of specific activities focuses energy and resources on goals most important to the individual, and may include a restructuring of priorities, based on available internal and external resources (Baltes & Carstensen, 2003; Lang, Rieckmann, & Baltes, 2002). Optimization of function through effort, energy, or acquiring new skills maximizes capacity. Compensation through external assistance or substitution of means or methods supplements the optimization process, and promotes goal attainment through modified approaches. Through the process of selection, optimization, and compensation, the outcome is adaptation to reduced resources, including regulation of loss, and attainment of goals. These transformative changes provide feedback to the individual and modify the antecedent conditions in a feedback loop.

Application of the SOC Model to Safe Driving Performance

The SOC model provides a framework to study Tai Chi as a potential strategy to optimize driving performance through enhanced cognitive function and physical function (Figure 1).
Although age-related cognitive decline may not interfere with everyday function or the ability to live independently (Salthouse, 2012), automobile driving is a skill which relies on several cognitive processes. Driving is often cited as an at-risk IADL due to declines in cognitive function (Drag & Bieliauskas, 2010; Harada, Natelson Love, & Triebel, 2013). Declines in physical function further compromise Safe Driving Performance, which could ultimately lead to impaired IADL. Therefore, the individual’s decision to continue driving requires effort to maintain or improve Safe Driving Performance through optimization of internal and external resources, and when needed, the use of compensatory processes.
Age-related declines in specific cognitive processes and physical function necessary for Safe Driving Performance are the antecedent conditions contributing to the process of selection (to continue driving), optimization (maximizing function through Tai Chi practice), and compensation (adaptive equipment or techniques) with the outcome goal of Safe Driving Performance (Figure 2).

![Cognitive function diagram]

**Figure 2.** Conceptual Framework of the Relationships between Age-related Changes in Cognitive Function, Physical Function, Safe Driving Performance, and Tai Chi in Older Adults.

**Purpose and Significance of the Study**

Specific cognitive processes and physical function related to Safe Driving Performance among older adult Tai Chi practitioners has not been explored. This research will help fill an important knowledge gap regarding the potential of Tai Chi exercise for maintenance and optimization of this vital IADL. As the older adult population increases, safety, independence and quality of life for individuals, families, and society will be significantly impacted with
promotion of independence. This study is guided by an overarching belief in the potential for growth, adaptation, and change throughout the lifespan.

**Research Question**

Determine what cognitive and physical factors contribute to Safe Driving Performance among older adult Tai Chi practitioners compared to normative reference values.

**Aims**

The aims of this study among older adult Tai Chi practitioners were to:

**Aim #1** Examine relationships between Tai Chi exercise habits, cognitive processes and physical function related to safe driving performance, mindfulness, and overall perceptions of wellness.

**Aim #2** Compare cognitive processes and physical function related to safe driving performance to normative reference values for adults aged 65 and older.

**Aim #3** Explore potential predictors of safe driving performance.
LITERATURE REVIEW

Four distinct areas of evidence among the older adult population underpin the present research. These include 1) predictors of Safe Driving Performance, 2) the association of Tai Chi exercise and physical function, 3) the association of Tai Chi exercise and cognitive function, and 4) the association of physical activity, exercise, cognitive processes, and driving performance.

This section reviews predictors of Safe Driving Performance and the association of Tai Chi exercise and physical function. The remaining two bodies of literature, the association of Tai Chi exercise and cognitive function, and the association of physical activity, exercise, cognitive processes and driving performance in older adults are included as published or publishable manuscripts and are more fully described in the Present Study section.

Predictors of Safe Driving Performance

A literature search on predictors of Safe Driving Performance in healthy community-dwelling older adults yielded 13 observational studies including cross-sectional \( n = 8 \), longitudinal \( n = 1 \), and prospective cohort studies \( n = 4 \). Study populations were healthy community-dwelling older adults without known dementia diagnoses, 42.45% of whom were female (one study did not report gender), with a mean age of approximately 71 years (Appendix A).

Nine cross-sectional studies investigated predictors of driving performance in older adults (Anstey, Horswill, Wood, & Hatherly, 2012; Brown et al., 2005; De Raedt & Ponjaert-Kristoffersen, 2000; Goode et al., 1998; Hoffman, McDowd, Atchley, & Dubinsky, 2005; Zook, Bennett, & Lane, 2009), compared healthy controls to people with mild dementia (Brown et al., 2005), compared young adults to older adults (Lambert, Watson, Cooper, & Strayer, 2010),
middle-aged adults to older adults (Dawson, Uc, Anderson, Johnson, & Rizzo, 2010), and low fall risk compared to high fall risk drivers (Gaspar, Neider, & Kramer, 2013). One longitudinal study (Emerson et al., 2012) followed participants a mean of 6.6 years after initial cognitive, physical, and driving assessments to predict driving cessation, moving violations, and crash rates. Four prospective cohort studies (Ball et al., 2006; Margolis et al., 2002; Marottoli, Cooney, Wagner, Doucette, & Tinetti, 1994; Wood, Anstey, Kerr, Lacherez, & Lord, 2008) evaluated cognitive function, physical measures, and risk factors related to several driving outcomes.

Driving Outcomes

Outcome measures of driving performance include self-report of driving habits and incidents (Emerson et al., 2012; Hoffman et al., 2005; Marottoli et al., 1994), state-recorded crashes (Ball et al., 2006; Dawson et al., 2010; De Raedt & Ponjaert-Kristoffersen, 2000; Emerson et al., 2012; Goode et al., 1998; Hoffman et al., 2005; Margolis et al., 2002; Marottoli et al., 1994), simulated driving assessments (Hoffman et al., 2005; Lambert et al., 2010), the Useful Field of View (UFOV) subset 2 (Anstey et al., 2012), hazard perception tests (Anstey et al., 2012), on-road assessments (Brown et al., 2005; Dawson et al., 2010; De Raedt & Ponjaert-Kristoffersen, 2000; Emerson et al., 2012; Wood et al., 2008; Zook et al., 2009), and driving cessation (Emerson et al., 2012).

Predictors of Safe Driving Performance

Cognitive function. Executive functions including working memory, recall, and attention, reaction time, and task-switching measures were predictive of driving safety errors including following distance, maintenance of speed, brake reaction time, and crash risk (Anstey et al., 2012; Ball et al., 2006; Dawson et al., 2010; De Raedt & Ponjaert-Kristoffersen, 2000;
Goode et al., 1998; Lambert et al., 2010). The ability to detect and identify changes in pictures depicting common driving scenes similar to a ‘dashboard’ view was correlated with on-road assessments in healthy adults and adults with mild dementia (Brown et al., 2005). Also, performance on measures of global cognition was predictive of driving performance, including time to driving cessation, moving violations, and crash risk (Dawson et al., 2010; Emerson et al., 2012).

**Visual-perceptual function.** Performance on measures of visual-perceptual function were predictive of time to driving cessation, moving violations, and crashes (Anstey et al., 2012; Ball et al., 2006; Dawson et al., 2010; De Raedt & Ponjaert-Kristoffersen, 2000; Emerson et al., 2012; Goode et al., 1998; Margolis et al., 2002; Wood et al., 2008).

**Speed of visual processing.** The useful field of view (UFOV), a measure of speed of information processing and visual attention predicted time to driving cessation, moving violations, and crash risk (Ball et al., 2006; De Raedt & Ponjaert-Kristoffersen, 2000; Emerson et al., 2012; Goode et al., 1998; Zook et al., 2009).

**Physical function.** Lower extremity strength and coordination, fall risk, balance, and general mobility predicted driving performance including on-road and simulated driving, moving violations, and crash rates (Gaspar et al., 2013; Lambert et al., 2010; Margolis et al., 2002; Marottoli et al., 1994; Wood et al., 2008).

The results of these studies provide evidence that predictors of Safe Driving Performance include measures of executive function, visual-perceptual function, speed of visual processing and physical function. The cognitive and physical benefits of exercise may provide one method to maintain or improve Safe Driving Performance in older adults.
Tai Chi Exercise and Physical Function

Physical function outcomes associated with Tai Chi exercise have been studied including strength and flexibility of the upper and lower extremities, endurance, balance, reaction times, and somesthesia. As stated earlier, these physical functions are important for Safe Driving Performance (National Highway Traffic Safety Administration, 2009).

A review of the literature of physical benefits of Tai Chi exercise specifically related to these physical functions in healthy community-dwelling adults yielded nine studies including a RCT \((n=1)\), quasi-experimental \((n = 3)\), and cross-sectional \((n = 5)\). Study participants were healthy community-dwelling older adults, 59% of whom were female, with a mean age of approximately 60 years (Appendix B).

The cross-sectional studies compared younger and older non-Tai Chi practitioner comparison groups to older Tai Chi practitioners (Kwok, Hui-Chan, & Tsang, 2010), older Tai Chi practitioners to non-Tai Chi practitioners (Lu, Siu, Fu, Hui-Chan, & Tsang, 2013; Pei et al., 2008), and Tai Chi practitioners, runners/swimmers, and non-Tai Chi comparison groups (Xu, Hong, Li, & Chan, 2004). The quasi-experimental studies compared a Tai Chi intervention group to a comparison group (Jacobson, Ho-Cheng, Cashel, & Guerrero, 1997), short- and long-term Tai Chi practitioners (Fong & Ng, 2006), and within-group repeated measures (Taylor-Piliae, Haskell, Stotts, & Froelicher, 2006). The RCT compared Tai Chi exercise, proprioception exercise, and a non-intervention comparison group (Liu et al., 2012).

Tai Chi exercise dose varied with cross-sectional studies reporting existing Tai Chi practitioners practicing from at least one year to greater than four years, more than one time per week, and one to two hours per session. In the quasi-experimental studies and RCT, Tai Chi
interventions ranged from 12-16 weeks duration, two-to-three times per week, and 45 – 120 minutes per session. Although the exercise dose varied among the studies, improved physical function measures were reported in Tai Chi practitioners across all research designs.

**Strength, endurance, and flexibility.** Upper and lower body strength, endurance, and flexibility are important physical functions for Safe Driving Performance including entering and exiting a vehicle, steering, rotating the head, neck, and torso for backing up or lane changes, and adequate control of brake and gas pedals.

Tai Chi exercise had statistically significant effects on upper extremity strength, endurance, and flexibility (Taylor-Piliae, Haskell, Stotts, et al., 2006) and lower extremity strength and endurance including knee joint strength (Jacobson et al., 1997), and lower extremity strength, endurance, and flexibility (Taylor-Piliae, Haskell, Stotts, et al., 2006). However, foot/ankle strength was not significantly improved when comparing Tai Chi, proprioception exercises, and non-intervention comparison groups (Liu et al., 2012).

**Balance.** Balance, or postural stability, is dependent upon integration of several physiologic systems including sensory-perceptual processes, the musculoskeletal system, and neuromuscular control (Bonder & Bello-Haas, 2008). Trunk stability and motor control are components of postural stability and are important for Safe Driving Performance (Bonder & Bello-Haas, 2008). Poor balance, manifested as postural sway, is associated with increased fall risk (Bonder & Bello-Haas, 2008) in older adults, and increased fall risk is associated with poor driving outcomes (Ball et al., 2006; Gaspar et al., 2013).

Balance, measured by tilt board and stability platform was significantly better in short- and long-term Tai Chi practitioners compared to non-Tai Chi practitioners (Fong & Ng, 2006).
Improved balance measured by tilt board stability was also found in a Tai Chi intervention group compared to a control group (Jacobson et al., 1997). Statistically significant improvement was also found in functional reach and single-leg stance in a repeated-measures study (Taylor-Piliae, Haskell, Stotts, et al., 2006).

**Reaction time.** Reaction time is dependent on coordinated cognitive and motor function, and can be slowed by age-related cognitive changes, pain with movement, or mobility restriction due to musculoskeletal conditions. Reaction time can be either simple (responding to a single stimulus) or choice (responding to multiple stimuli) and is important for Safe Driving Performance such as when steering, braking, and responding to driving-related stimuli.

Lower extremity reaction time measured by electromyography (EMG) was significantly faster in long-term Tai Chi practitioners when compared to short term Tai Chi practitioners and controls (Fong & Ng, 2006). Upper extremity reaction times measured by EMG were found to be significantly faster in younger Tai Chi practitioners (mean age 24.2) than both older Tai Chi practitioners (mean age 70.3) and older non-Tai Chi (mean age 72.3) when performing a finger-pointing task with stationary and moving visual targets (Kwok et al., 2010). In the same study, accuracy was also measured, and Tai Chi practitioners were more accurate than the non-Tai Chi control group with both stationary and moving visual stimuli (Kwok et al., 2010).

**Somesthesis.** Somesthesis includes kinesthetic sense, defined as sensation and awareness of active or passive movement, and proprioception, defined as the awareness of the limbs or other body parts in relation to each other and their orientation in the environment (Bonder & Bello-Haas, 2008). Kinesthetic sense and proprioception are necessary for manipulating dashboard controls and operation of brake and gas pedals.
The effects of Tai Chi on somesthesis was measured by upper limb kinesthesiometry (Jacobson et al., 1997), fingertip tactile spatial acuity (Kerr et al., 2008), accuracy of finger-pointing (Kwok et al., 2010), hand-eye coordination (Pei et al., 2008), knee joint angle repositioning (Fong & Ng, 2006; Xu et al., 2004), and ankle joint kinesthetic sense (Liu et al., 2012; Xu et al., 2004). Statistically significant differences or improvement were reported in all measures across study designs, in both long- and short-term Tai Chi practitioners, and when compared to controls.

The physical benefits of Tai Chi exercise include increased upper and lower extremity strength and flexibility, increased endurance, improved balance, better reaction times, and enhanced somesthesis. Although study designs, Tai Chi exercise dose, and specific measures varied, Tai Chi exercise had significant benefits on physical functions necessary for Safe Driving Performance.

Summary

Safe Driving Performance relies on a combination of specific cognitive processes and physical function and can be compromised in adults aged 65 and older due to age-related decline. Cognitive processes necessary for Safe Driving Performance include working memory, attention, and mental flexibility. Physical functions necessary for Safe Driving Performance include upper and lower limb strength and flexibility, postural stability, and control of limbs to safely operate a vehicle and respond to changes in driving-related stimuli. Traditional forms of exercise are known to benefit these specific cognitive processes and physical functions - many of which are directly related to Safe Driving Performance. Finding and promoting an age-appropriate form of exercise with both cognitive and physical benefits could potentially influence Safe Driving
Performance. Tai Chi exercise provides many of the same beneficial effects as traditional forms of exercise through shared aerobic mechanisms of action and also through Tai Chi exercise’s unique active ingredients that distinguish it from traditional exercise. Tai Chi exercise is unexamined in the driving literature. Therefore, the focus of the present study was to explore the association of Tai Chi exercise, cognitive processes and physical function related to Safe Driving Performance in older adult Tai Chi practitioners.
Present Study

Manuscript Option

The manuscript option was approved by the dissertation committee, and the following manuscripts have been published, submitted for publication, or will be ready for submission by the dissertation defense date: 1) Miller, S. M., & Taylor-Piliae, R. E. (2014). “Effects of Tai Chi on Cognitive Function in Community-dwelling Older Adults: A Review”. Geriatric nursing, 35(1), 9-19 (published) (Appendix C), 2) Miller, S. M., Taylor-Piliae, R. E., & Insel, K. C. (2015). “The Association of Physical Activity, Exercise, Cognitive Processes and Automobile Driving Ability in Older Adults: A Review of the Literature” (submitted to the Journal of Applied Gerontology) (Appendix D), 3) data manuscript, Miller, S.M., & Taylor-Piliae, R.E., Tentative title: “Tai Chi Exercise and Safe Driving Performance in Older Adults: An Observational Study” (to be submitted to the Journal of Aging and Health) (Appendix E). In addition to the above three manuscripts, the opportunity arose to submit a theory-based manuscript, and a fourth manuscript is included in this dissertation: Miller, S. M. “Connecting East and West by a Developmental Theory for Older Adults: Application of Baltes’ Selection, Optimization, and Compensation Model”. Applied Nursing Research. (In press, June 6, 2015) (Appendix F).

For all manuscripts the primary author (Miller) was responsible for conceptualization of the topic, creating first drafts, assembling expertise, assigning responsibilities, organizing revisions, communicating with editors and publishers, and creating and negotiating deadlines. Co-authors guided the manuscript development process, provided expert content advice, gave feedback, imparted insight, and approved final manuscript versions.
The methods, results, and conclusions of this study are presented in the papers appended to this dissertation. The following is a summary of the most important findings in this document and are presented in Appendices C, D and E. The study was approved by the Institutional Review Boards of the University of Arizona and Vanderbilt University (Appendix G).

**Background**

Automobile driving is an essential instrumental activity of daily living for many older adults to access healthcare, shop, bank, and maintain social connections (Wieland, 2013). However, age-related changes in specific cognitive processes and physical function can impair the ability to drive safely, severely impacting independence and well-being, or putting the driver or others at risk of injury or death (Centers for Disease Control and Prevention, 2013; Dawson et al., 2010).

Exercise has positive benefits on specific cognitive processes and physical function (Carvalho, Rea, Parimon, & Cusack, 2014), many of which are necessary not only for independent daily living activities but also for Safe Driving Performance. Because guidelines for recommended amounts of exercise and physical activity in older adults have been published (Centers for Disease Control and Prevention, 2015), it is important for older adults to find appropriate forms of exercise to sustain recommended levels. One form of exercise gaining popularity with older adults is Tai Chi, and there is growing evidence regarding its cognitive and physical benefits (Chodzko-Zajko et al., 2009; NCCIH, 2015). However, Tai Chi exercise has not been explored in the driving literature. The purpose of the present study was to explore the association between Tai Chi exercise habits, cognitive processes, and physical function related to Safe Driving Performance among older adult Tai Chi practitioners.
While there is much variability in age-related cognitive decline several cognitive processes are commonly affected by the aging process including planning, working memory, attention, and speed of information processing. These cognitive processes are particularly important for Safe Driving Performance. In fact, automobile driving is often used as an exemplar for the problems associated with multifaceted age-related cognitive changes (Drag & Bieliauskas, 2010; Harada, Natelson Love, & Triebel, 2013). Driving relies on several abilities such as remembering and recalling traffic rules and regulations, focusing and dividing attention, processing incoming information, and making decisions in the ever-changing and dynamic driving environment.

In addition to the cognitive processes necessary for Safe Driving Performance, several physical functions are also important and are impacted by the aging process (Tuokko, Rhodes, & Dean, 2007). These include the ability to enter and exit the vehicle, operate controls, steer the vehicle, move the lower extremity and foot between gas and brake pedals, and turn the upper torso and neck when negotiating intersections, merging with traffic, or changing lanes. The integration of cognitive processes and physical function is therefore required for Safe Driving Performance.

There is much evidence regarding the beneficial effects of traditional forms of exercise and physical activity on cognitive and physical function in older adults. However, Tai Chi exercise is a more recent area of investigation in the exercise literature. The past two decades have seen a growth in the examination of many of the physical benefits of Tai Chi, including benefits to psychological health, sleep, and the impact of Tai Chi on diseases and conditions such as cardiovascular disease, arthritis, and fall reduction (Chang, Nien et al., 2010; Li et al., 2004;
Taylor-Piliae, Haskell, Waters, & Froelicher, 2006; Taylor-Piliae, 2008). But only more recently have the cognitive benefits of Tai Chi exercise been more closely studied. Because Tai Chi exercise is becoming increasingly popular with older adults it is important to expand the scientific knowledge of its potential benefits. Randomized controlled trials (RCTs), quasi-experimental, and observational studies have been conducted to examine cognitive processes including working memory, attention, and learning in Tai Chi practitioners (Miller & Taylor-Piliae, 2014; Wayne et al., 2014).

To this end, Manuscript One (Appendix C), a review of the literature on Tai Chi and cognition in older community-dwelling older adults was conducted (Miller & Taylor-Piliae, 2014) and is partially presented in Chapter 2, Review of the Literature. Manuscript One synthesized results from 12 studies of various designs including RCTs (n=6), quasi-experimental (n=3), and observational (n=3). Although results were not conclusive across study designs, several cognitive processes including executive function, language, learning, working memory, and global cognition showed improvement associated with Tai Chi exercise. The results of the literature review support, make explicit, and help link specific cognitive processes that have also been studied in driving research and are known to be associated with Safe Driving Performance. Consequently, the result of this literature review assisted in further exploring specific cognitive processes related to existing driving-related research, and instruments to test relevant cognitive processes were then examined for potential inclusion in the present study.

The second manuscript written and submitted to a peer reviewed journal (Appendix D) (Miller, Taylor-Piliae, & Insel, 2015) explored a gap in the literature and a crucial link between the concepts of the present study: the association of exercise, physical activity, and cognitive
processes specifically associated with driving-related outcomes. Manuscript Two reviewed and synthesized the literature from six studies, including RCTs (n=3) and observational studies (n=3). Outcome measures included simulated driving, on-road driving, computerized and investigator-administered tests, and self-reported driving difficulties. Results from these studies yielded a positive association between exercise and physical activity and several cognitive measures including reaction time, speed of information processing, and attention. However, several measures using verbal or paper-and-pencil did not show improvement, a finding inconsistent with other exercise and physical activity literature. This literature review and manuscript informed the selection of measures which were common to both the exercise/cognitive function research and the exercise/driving research.

The two bodies of literature reviewed - Manuscript One, the effect of Tai Chi exercise and cognition, and Manuscript Two, the association of exercise, physical activity and cognitive processes related to driving – link two of the vital concepts and support the need for further exploration in Tai Chi research: specifically, the association between Tai Chi exercise, cognitive processes, and physical function related to Safe Driving Performance in older adults. As stated, Safe Driving Performance relies on many interrelated cognitive processes and physical functions – many of which a positive association with Tai Chi exercise exists. The results of this research are summarized below and presented in full in Appendix E.

**Methods**

**Aims**

The aims reported in the present study were to 1) examine relationships between Tai Chi exercise, cognitive processes and physical function related to Safe Driving Performance,
mindfulness, and overall perceptions of wellness, 2) compare cognitive processes and physical function related to Safe Driving Performance to normative reference values for adults aged 65 and older, and 3) explore potential predictors of Safe Driving Performance.

**Study Design**

An observational design examined relationships between Tai Chi practice, cognitive processes, and physical function related to Safe Driving Performance.

**Setting and Sample**

A purposive sample of Tai Chi practitioners aged 65 or older were recruited from community Tai Chi classes, events, and through snowball recruiting. Inclusion criteria were: 1) age 65 years or older, 2) having practiced Tai Chi for three months or greater, 3) having had formal instruction in Tai Chi exercise, 4) currently practice Tai Chi at least 30 minutes per week, 5) able to read, speak and write English. Exclusion criteria were 1) acute unstable medical conditions, 2) impaired cognition, or 3) depression.

**Sample size calculation.** Based on a one-sample, two-tailed *t*-test, alpha = .05, power = 0.80, effect size *d* = 0.40 the calculated sample size was 52. Due to possible attrition an additional 10-15% participants were recruited for a final sample size of 58.

**Procedure**

Potential participants were approached at community Tai Chi classes and events and provided study information. If interested, a brief eligibility screening was conducted, and if eligible, a study packet provided, and a study appointment made. Study appointment sites were arranged in as close proximity to the recruitment sites as possible, and in rooms that would allow privacy, a quiet environment, and adequate space for the physical measures to be performed.
**Measures**

The take-home study packet collected information on driving habits, Tai Chi exercise habits, non-Tai Chi exercise and physical activity habits, and personal and medical history. Additionally, self-report measures collected included dispositional mindfulness, overall well-being, and engagement with essential elements of Tai Chi exercise. Face-to-face individual study appointments (lasting approximately 90 minutes per participant) included data collected via the DrivingHealth Inventory™, a computer-generated and interactive driver assessment instrument composed of a variety of cognitive and physical measures including recall, planning, speed of information processing, visual search, visual scanning and attention, head and neck flexibility, and a measure of general mobility. In addition to the DrivingHealth Inventory™ investigator-administered measures of immediate recall, working memory, attention, visual scanning, right lower extremity control and proprioception were also gathered.

**Statistical Analysis**

Data were analyzed according to the level of measurement of the variable. Descriptive statistics including frequencies, means, standard deviations, medians and interquartile ranges were used to examine the distribution of variables. Additionally, histograms, tests of normality using the Shapiro-Wilk test statistic, kurtosis and skewness were reviewed. Parametric tests were used for normally distributed variables and non-parametric tests were used for variables with non-normal distribution. Data transformations were not conducted. Effect sizes were calculated based on the statistical test used. Significance levels were set at $p < .05$. Version 23 of International Business Machines-SPSS (IBM-SPSS) software was used for data analysis. Descriptive statistics are presented in Appendix H.
Results

Fifty-eight participants (age range 65-87) completed the study. One participant was screened out due to cognitive impairment and was referred to their primary care provider. Seventy-two percent of participants were female, 90% were Caucasian, and 91% had completed 13 or more years of education. Participants drove an average of 6 days per week, and made on average, two trips per day. Fifty-three percent of participants had been practicing Tai Chi greater than three years, and 74% of participants practiced in a group one or two times per week for 45 to 60 minutes duration. Two styles of Tai Chi were most prevalent; Yang and Sun/Sun for Arthritis, 41% and 40%, respectively, and most participants (86%) characterized their Tai Chi practice as light-to-moderate exertion. Participants’ self-reported engagement with essential elements of Tai Chi exercise were collected through an exploratory eight-item scale, with the majority of participants selecting Strongly Agree or Agree with statements regarding the benefits and components of Tai Chi exercise practice. In addition to Tai Chi exercise, nearly half the participants engaged in moderate-to-vigorous weekly physical activity or exercise, and 43% performed weekly strengthening and flexibility activities.

Relationships between study measures. Several study measures were statistically significantly correlated, with weak to moderate correlations ($r = .26$ to $.50$) between several cognitive processes, physical measures, mindfulness, and vitality. In addition to correlations between study measures, participants Tai Chi practice dose (Low versus High) was calculated and a biserial correlation coefficient conducted to determine the strength of the relationship between Tai Chi dose and study measures. Only one measure, Visualizing Missing Information,
showed a statistically significant correlation between High Tai Chi dose category and performance on the measure.

**Comparison of measures to normative reference values.** Participants performed statistically significantly better in several cognitive and physical measures, with small to large effect sizes. Likewise, study participants scored statistically significantly higher on scales measuring dispositional mindfulness and overall well-being/vitality, with medium to large effect sizes. Sources of normative reference values are presented in Appendix I.

**Predicting Safe Driving Performance.** A four stage hierarchical multiple regression was conducted with the Driving Scenes Test (DST), a measure of visual scanning, attention, and working memory as the dependent variable. Predictor variables were selected based on theoretical considerations and included the Useful Field of View (visual speed of processing, divided attention), the digit span backward test (working memory), and two categories of exercise: Tai Chi exercise dose (Low and High) and non-Tai Chi exercise dose (Underactive and Active). Digit span backward was the variable most strongly predictive of the outcome variable, accounting for 11% of variability in DST scores.

**Discussion**

As evidenced by the driving habits reported, driving is an important activity of daily living for these study participants. Also, the self-reported exercise habits of both Tai Chi and non-Tai Chi exercise demonstrate the contribution of these activities to the recommended exercise and physical activity levels for older adults.

Relationships among several study measures reached statistical significance, possibly due to shared cognitive processes or physical abilities measured. Two noteworthy correlations were
found; first, the Rapid Walk test (a measure of general mobility) and the digit span backward (a measure of working memory) were statistically significantly correlated demonstrating a link between overall physical mobility and working memory. Second, Mindful Attention Awareness Scale scores and Vitality Plus Scores were significantly correlated, indicating a relationship between dispositional mindfulness and overall well-being.

Comparison of study sample results to normative reference values revealed statistically significant better performance in several cognitive process and physical function measures. These results are consistent with other Tai Chi exercise evidence reporting improvement in varied cognitive processes and physical function measures. However, some measures, including visual search with divided attention and working memory were not statistically significantly different from normative reference values. Interestingly, study participants performed worse than the normative reference value when measured for head/neck flexibility, possibly due the prevalence of arthritis in this study sample, or due to the focus on core movement in Tai Chi exercise.

The Driving Scenes Test, a measure of several cognitive processes including visual scanning, attention, and working memory was used as the outcome variable for predicting Safe Driving Performance. The Useful Field of View, a measure of visual speed of information processing was not a significant predictor of Safe Driving. When controlling for the Useful Field of View, the digit span backward test significantly added to the predictive ability of the model, possibly due to the moderate correlation ($r_s = .31$) between digit span backward and the Driving Scenes Test. And while neither self-reported Tai Chi exercise dose nor other exercise dose
significantly added to the predictive ability of the model this finding could be due to the method used to estimate self-reported activity dose.

**Conclusion**

The present study integrated several areas of literature. First, drawing from research examining the association between Tai Chi exercise and cognitive processes in older adults specific cognitive measures were selected. Second, the association between exercise and physical activity and driving-related cognitive processes provided a context for the study of Tai Chi exercise and Safe Driving Performance. Third, the association between Tai Chi exercise and physical function demonstrated the importance of physical function to Safe Driving Performance. And fourth, Tai Chi exercise was examined using conventional research methods and instruments to more firmly situate it in traditional research. The present study adds new knowledge to the driving literature, to exercise science in general, and to Tai Chi exercise science specifically. The results of this observational study establish the need for further research in this area.
REFERENCES


APPENDIX A

PREDICTORS OF SAFE DRIVING PERFORMANCE
Predictors of Driving Performance in Healthy Community-dwelling Older Adults without Dementia.

<table>
<thead>
<tr>
<th>First author, year, country</th>
<th>Sample size, gender, age</th>
<th>Study Purpose</th>
<th>Measures</th>
<th>Driving Outcome</th>
<th>Findings/Conclusions</th>
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<tbody>
<tr>
<td><strong>Cross-sectional studies</strong></td>
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<tr>
<td>Anstey, 2012, Australia</td>
<td>n = 297, 33.8% female, Age range 65-96 (M=75.10, SD=7.00)</td>
<td>Determine cognitive and visual predictors of “Capacity to Drive Safely”</td>
<td>Cognitive function: Choice reaction time, Perceptual speed, Spatial ability, Task switching, Visual closure, Visual search, Working memory</td>
<td>“Capacity to Drive Safely” composed of UFOV (Subset 2), Hazard Perception Test (HPT), and Hazard Change Direction Test (HCDT)</td>
<td>Cognitive function: Executive function, working memory, and speeded tests associated with poorer driving. Visual-Perceptual: Vision was associated with HPT. Age explained 26% of the variance in the UFOV. Approximately 85% of age-related variance in the UFOV was explained by cognitive factors and vision. Processing speed and timed executive function tests are the strongest correlates of driving skills.</td>
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<td>Brown, 2006, United States</td>
<td>n = 55, 47 healthy controls (CDR=0), 58% female, Age: M=72.04, SD=10.28; 31 people with mild dementia (CDR=0.5), 35% female, Age: M=76.87, SD=5.41</td>
<td>Assess ecological validity of the Driving Scenes test using an on-road driving assessment</td>
<td>Cognitive function: Driving Scenes test</td>
<td>On-road assessment</td>
<td>Cognitive function: Healthy control group performed better on both the Driving Scenes and on-road assessment. Driving Scenes test and on-road assessment score correlated (r=.55, p &lt; .01). Significant group differences (F(2,52) = 7.75, p &lt; .01).</td>
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<td>First author, year, country</td>
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<td>Dawson, 2010 United States</td>
<td>$n = 191$ 111 older adults: 47.7% female Age range 65-89 (M=72.3) 80 middle-aged adults: 52.5% female Age range 40-64 (M=57.2)</td>
<td>Identify neuro-psychological factors associated with driving errors in older adults compared to middle-aged adults</td>
<td>Cognitive function Block design (WAIS-III); BVRT; Complex Figure Test (CFT); TMT A and B; RAVLT JLO; COWA; COGSTAT (composite) Visual-Perceptual Acuity Contrast Perception of motion Speed of visual processing, attention Useful field of view Physical function Functional reach Get-Up-and-Go Grooved pegboard</td>
<td>On-road assessment</td>
<td>Better overall cognitive function (COGSTAT composite) was predictive of fewer safety errors. In the older adults predictors of total safety errors were CFT (Copy and Recall) and block design Visual-Perceptual More safety errors associated with decreased near visual acuity Speed of visual processing, attention NSS correlations in driving safety errors Physical function More safety errors associated with slower grooved pegboard task completion Conclusions Older drivers committed 29% more driving safety errors than middle-aged drivers, 67% more serious errors, and 27% more less-serious errors. In the older adults each five-year age increment was predictive of more safety errors</td>
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<td>First author, year, country</td>
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<td>De Raedt, 2000 Belgium</td>
<td>n=84 28.5% female Age range 65-96 (M=78.6,SD 6.8)</td>
<td>Identify age-sensitive neuro-psychological skills related to driving problems</td>
<td>Cognitive function Paper folding Single-choice RT Visual- and aural-choice RT (cognitive flexibility) Dot counting task (selective and divided attention) Incompatibility task (mental flexibility) Visual-perceptual function Movement perception Speed of visual processing, attention Useful field of view</td>
<td>On-road assessment; at-fault crashes (12 months prior to study)</td>
<td>Cognitive function Cognitive flexibility explained 30% and selective attention 19% of the variance of the on-road assessment scores Visual-perceptual function Movement perception ability was highly correlated with on-road assessment scores Speed of visual processing, attention UFOV explained 44% of the variance of the on-road assessment scores Significant correlation found between distance driven and on-road assessment scores Significant negative correlation between on-road assessment scores and crashes. Conclusions Movement perception, UFOV, double-choice reaction time, and selective attention explained 64% of the variance of the on-road assessment scores. 19% of the variance in at-fault crashes could be explained by the neuropsychological tests</td>
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<td>First author, year, country</td>
<td>Sample size, gender, age</td>
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<td>Gaspar, 2013 United States</td>
<td>n=38</td>
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<td>Simulated driving</td>
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<td></td>
<td>Gender not reported</td>
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<td>Cognitive function</td>
<td>High fall risk had significantly higher dual-task cost than low fall risk, but NSS in single-task</td>
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<td>Age:</td>
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<td>Visual-Perceptual</td>
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<td>High fall risk (n=14):</td>
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<td>Speed of visual processing, attention</td>
<td>NSS difference in high- and low fall risk groups</td>
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<td></td>
<td>M=75.8, SD 3.3</td>
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<td>Physical function</td>
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<td>Low fall risk (n=14)</td>
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<td>Conclusions</td>
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<td></td>
<td>M=74.4, SD 5.5</td>
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<td>Speed of visual processing, attention</td>
<td>Low fall risk had faster brake response times and hazard response</td>
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<td>Explore the relationship between fall risk and simulated driving performance under single- and dual-task conditions</td>
<td>Cognitive function RT for single- and dual-task computer test</td>
<td>Simulated driving</td>
<td>High fall risk responded more slowly to critical driving events (braking and peripheral hazards) than low fall risk</td>
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<td>Visual-Perceptual Change detection</td>
<td>Visual-Perceptual</td>
<td>Speed of visual processing, attention</td>
<td>NSS difference in high- and low fall risk groups</td>
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<td>Functional field of view</td>
<td>Functional field of view</td>
<td>Physical function</td>
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<td>Speed of visual processing</td>
<td>Speed of visual processing, attention</td>
<td>Conclusions</td>
<td>Conclusions</td>
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<td>change detection</td>
<td>Physical function</td>
<td>Low fall risk had faster brake response times and hazard response</td>
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<td>Functional field of view</td>
<td>Physical function</td>
<td>Conclusions</td>
<td>High fall risk responded more slowly to critical driving events (braking and peripheral hazards) than low fall risk</td>
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<td>Physical function</td>
<td>Physical function</td>
<td>Conclusions</td>
<td>High fall risk responded more slowly to critical driving events (braking and peripheral hazards) than low fall risk</td>
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<td>Self-reported falls</td>
<td>Conclusions</td>
<td>High fall risk responded more slowly to critical driving events (braking and peripheral hazards) than low fall risk</td>
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<tr>
<td>Goode, 1998</td>
<td>n=239, 46.8% female, Age range 56-90 (M=70.36, SD 8.95)</td>
<td>Compare the <em>Useful Field of View</em> to common neuro-psychological and cognitive tests in predicting at-fault crash risk</td>
<td>Cognitive function: MOMSSE, TMT-A and B, Visual-Perceptual: WMS-VR, Rey-O copy score and immediate recall, Speed of visual processing, attention</td>
<td>At-fault crashes (crashers) v. non-crashers</td>
<td>Cognitive function and Visual-Perceptual: MOMSSE, Rey-O, TMT-A and B, WMS-VR: Overall correct classification 58.6%; correctly identified crashers 57.3% (sensitivity) and non-crashers 60% (specificity). MOnSSSSE, Rey-O, TMT-A and B, WMS-VR plus UFOV: Overall correct classification 77.4%; correctly identified crashers 76.6% (sensitivity) and non-crashers 78.3% (specificity). Speed of visual processing, attention: UFOV alone: Overall correct classification 85.4%; correctly identified crashers 86.3% (sensitivity) and non-crashers 84.3% (specificity). Conclusion: The UFOV can be used to distinguish safe and unsafe drivers</td>
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Notes:
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</table>
| Hoffman, 2005 | United States | n=155  
56% female  
Age range 63-87  
(M=75.2,SD 4.7) | Examine the contribution of the UFOV, a change detection task, age, and visual impairment on simulated driving performance | Visual-Perceptual  
Visual acuity and contrast sensitivity  
Speed of visual processing, attention UFOV  
Change detection DriverScan | Simulated driving; self-reported and state-recorded crashes (no-fault, at-fault) including crashes involving other cars or property | Visual-Perceptual  
Visual impairment did not directly affect performance  
Speed of visual processing, attention  
UFOV divided attention and selective attention (subtests 2 and 3) correlated highly with change detection task UFOV speed of visual processing (subtest 1) was not predictive of simulated driving performance  
Change detection DriverScan could predict simulated driving performance  
Conclusions Change detection task (DriverScan), UFOV subtests 2 and 3 were most predictive of simulated driving performance |
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<tr>
<td>Lambert, 2010</td>
<td>n=35</td>
<td>Examine relationships between cognitive function, UFOV, age, and simulated driving performance</td>
<td>Cognitive function</td>
<td>Simulated driving performance: speed, following distance, brake reaction time</td>
<td>Cognitive function</td>
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<td>United States</td>
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<td>Working memory: OSPAN</td>
<td>Speed of visual processing, attention UFOV</td>
<td>Physical function</td>
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<tr>
<td>Zook, 2009</td>
<td>n=39</td>
<td>To examine several instruments and measures as predictors of driving competence</td>
<td>Cognitive function CBDI CDT HVLT-R HVOT IVA MFPT-III Ruff 2&amp;7 ST TMT A and B WAIS-III subtests: Block design, picture completion, digit symbol WCST</td>
<td>On-road assessment</td>
<td>Cognitive function The IVA, HVLT-R, and TMT-B significantly predicted 58% of the variance of on-road assessment scores The CBDI explained 31% of the variance Speed of visual processing, attention UFOV explained 23% of the variance Conclusions Significant predictors of driving performance included executive function (working memory and attention) and visual perception</td>
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<tr>
<td>United States</td>
<td>51.2% female</td>
<td>Age range 62-92 (M=74.03, SD 6.45)</td>
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<tr>
<td>Emerson, 2012 United States</td>
<td>n=100 49% female Age range 65-89 (M=72.68, SD=5.03)</td>
<td>Develop predictive models of real-life driving outcomes based on cognitive, visual-perceptual, and physical function measures</td>
<td>Cognitive function Executive function Global cognition Visual-Perceptual Basic vision Visual perception Visual recognition Speed of visual processing, attention Useful field of view Physical function Functional reach Get-up-and-Go Grooved pegboard</td>
<td>On-road driving performance; self-reported driving habits Follow-up survey (mean 6.6 years after baseline): driving cessation, moving violations, crashes</td>
<td>Time to driving cessation predictors Cognitive function Visual recognition, global cognition Visual-Perceptual Acuity, contrast sensitivity and visual spatial ability Speed of visual processing, attention Useful field of view loss Physical function Increased grooved pegboard</td>
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<td>Visual-Perceptual</td>
<td>Decreased visual-perceptual performance</td>
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<td><strong>Conclusions</strong></td>
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<td>The best multivariate predictive model for <em>driving cessation</em> consisted of age and visual contrast sensitivity</td>
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<td>The best multivariate predictive model for <em>moving violations</em> consisted of education, driving exposure, and auditory recall</td>
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<td>The best multivariate predictive model for <em>crashes</em> consisted of education, number of crashes in past year, auditory recall, and TMT (B-A)</td>
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<td>Prospective cohort studies</td>
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| **Ball, 2006** United States | n=1,910  
46% female  
Age range 55-96  
(M=68.55,  
SD=7.95) | Evaluate cognitive and physical measures related to at-fault crashes | **Cognitive function**  
Recall/memory  
Symbol scan  
TMT A and B | At-fault crashes | Cognitive function  
NSS difference between crashers and non-crashers in recall or TMT A |
|  |  |  | **Visual-Perceptual**  
Visual closure/spatial perception (MVPT)  
Speed of visual processing, attention  
Useful field of view (subset 2) |  | Visual-Perceptual  
Poorer visual closure/spatial perception associated with crash incidence |
|  |  |  | **Physical function**  
Arm reach  
Foot tap  
Head/neck rotation  
Rapid walk  
Self-reported mobility |  | Speed of visual processing, attention  
Poorer UFOV performance associated with crash incidence |
|  |  |  | **Other**  
Age  
Driving exposure  
Gender |  | Physical function  
NSS difference between crashers and non-crashers in foot tap or rapid walk |
|  |  |  |  |  | Other  
Greater age and history of falls associated with crashes |
|  |  |  |  |  | **Conclusions**  
Significant predictors of crashes include driving exposure, age, male gender, history of falls, increased time to complete TMT B, poorer MVPT, and poorer UFOV subset 2 |
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</thead>
<tbody>
<tr>
<td>Margolis, 2002</td>
<td>United States</td>
<td>n=1416 100% female Age range 65-84 (M=71.3 SD 4.2)</td>
<td>Describe crash rates and identify risk factors for crashes in older women</td>
<td>Cognitive function State-reported crash rates</td>
<td>Cognitive function NSS association</td>
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<td>MMSE</td>
<td>Physical function</td>
<td>Visual-Perceptual Decreased visual acuity associated with crash risk</td>
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<td>TMT B</td>
<td>Physical function</td>
<td>Physical function Foot reaction time associated with crash risk History of falls increased risk of crash by approximately 50%</td>
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<td>DSS</td>
<td>Physical function</td>
<td>Other Increased age associated with crash risk Driving exposure (miles driven) associated with crash risk Orthostatic blood pressure drop associated with crash risk</td>
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<td></td>
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<td>Visual-Perceptual</td>
<td>Other</td>
<td>Conclusions Predictors of crashes included increased age, increased driving exposure, history of falls in non-walkers, very light alcohol use, orthostatic blood pressure drop, and foot reaction time</td>
</tr>
<tr>
<td>First author, year, country</td>
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<tr>
<td>Marottoli, 1994&lt;br&gt;United States</td>
<td>n=283&lt;br&gt;43% female&lt;br&gt;Age range 72-92&lt;br&gt;(M=77.8,SD not provided)</td>
<td>Identify factors associated with moving violations and crashes</td>
<td>Cognitive function&lt;br&gt;Global cognition (MMSE)&lt;br&gt;Depression&lt;br&gt;Physical function&lt;br&gt;Balance&lt;br&gt;Streng&lt;br&gt;ROM (shoulder, grip, hip, knee&lt;br&gt;Heel/toe stand&lt;br&gt;Timed signature&lt;br&gt;Chair stands&lt;br&gt;Usual and rapid pace walk&lt;br&gt;Foot taps&lt;br&gt;Foot abnormalities</td>
<td>Self- and state-reported 'adverse driving events': Stopped by police, moving violations, crashes</td>
<td>Cognitive function&lt;br&gt;Lower MMSE associated with adverse driving events with impaired design copy most predictive&lt;br&gt;Physical function&lt;br&gt;Walking less than one block/day, three or more foot abnormalities, impaired left knee flexion, and &gt;7 second rapid pace walk associated with adverse driving events&lt;br&gt;Conclusions&lt;br&gt;If three factors were present (poor design copy, walking less than one block/day, foot abnormalities) 47% of drivers had adverse driving events</td>
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<tr>
<td>Wood, 2008 Australia</td>
<td>n=270 29% female Age range 70-88 (M=75.8, SD4.0)</td>
<td>Identify battery of tests to predict safe and unsafe driving performance</td>
<td>Cognitive function Digit symbol matching TMT A and B Self-ordered pointing Reaction time Complex reaction time for driving Visual-Perceptual Acuity Contrast sensitivity Visual fields Dot motion Speed of visual processing, attention UFOV Physical function Neck range of motion Proprioception Quadriceps strength Postural sway Other Driving exposure (years of experience, weekly distance driven)</td>
<td>On-road assessment: 10-point scale (higher numbers indicate better performance) Reaction time Choice reaction time was predictive of driving performance Visual-Perceptual Visual field (dot motion) was predictive of driving performance Physical function Postural sway (sensorimotor integration) was predictive of driving performance Conclusions Choice reaction time, visual field motion sensitivity, and postural sway lead to 91% sensitivity and 70% specificity when classifying safe and unsafe drivers</td>
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Note: AVLT=Auditory Verbal Learning Test; BVRT=Benton Visual Retention Test; CBDI=Cognitive Behavioral Driver’s Inventory; CDR=Clinical Dementia Rating Scale; CDT=Clock Drawing Test; CFT=Complex Figure Task-Copy; COWA=Controlled Oral Word Association; CSS=Cross-Sectional Study; FR=Functional Reach; GP=Grooved Pegboard; GUG=Get-Up-and-Go; HVOT=Hooper Visual Organization Test; HVLTR=Hopkins Verbal-Learning Test-Revised; IVA=Integrated Visual and Auditory Continuous Performance Test; JLO=Judgment of Line Orientation; LS=Longitudinal Study; MVPT=Motor-Free Visual Perception Test-Third Edition; MMSE=Mini-Mental State Exam; MOMSEE=Mattis Organic Mental Syndrome Screening Examination; OSPAN=Operation Span; PCS=Prospective Cohort Study; RAVLT=Rey Auditory Verbal Learning Test; RT=Reaction Time; Rey-O=Rey-Osterrieth Complex Figure Test; ROM=Range of Motion; RT=Reaction Time; Ruff 2&7=Ruff 2&7 Selective Attention Test; ST=Stroop Test; TMT=Trail Making Test; UFOV=Useful Field of View; WAIS-III=Wechsler Adult Intelligence Scale-III; WCST=Wisconsin Card-Sorting Test; WMS-VR=Wechsler Memory Scale-Visual Reproduction Subtest.
APPENDIX B

TAI CHI EXERCISE AND PHYSICAL FUNCTION
The Effect of Tai Chi Exercise on Measures of Physical Function Associated with Driving Performance.

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<tr>
<th>First author, year, country</th>
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<th>Findings/ Conclusions</th>
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<tbody>
<tr>
<td>Liu, 2012 China</td>
<td>n=42</td>
<td>To compare the effects of TC and PE on ankle strength and endurance, and ankle joint position</td>
<td>TC: 16 wk 2x/wk x 45 min/session</td>
<td>Strength/endurance Plantar and dorsiflexion peak torque measured by dynamometer</td>
<td>Strength/endurance NSS between groups</td>
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<td></td>
<td>15 TC</td>
<td></td>
<td>PE: 16 wk 2x/wk x 45 min/session</td>
<td>Somesthesis Ankle joint inversion and eversion angle matching at 10° and 20°</td>
<td>Somesthesis TC and PE groups showed statistically significant accuracy compared to controls (p=.014 and p =.039, respectively) in the left ankle TC and PE were not statistically significantly different</td>
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<td></td>
<td>53% female</td>
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<td>Control: No regular exercise habits</td>
<td>NSS difference in right ankle or when matching both ankles</td>
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<td>First author, year, country</td>
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<td>Jacobson, 1997 United States</td>
<td>n=24 50%female Age range 20-45 yrs (M=30.4, SD=4.3)</td>
<td>Evaluate knee extension strength, balance, kinesthetic sense</td>
<td>12 wk 3x wk x 60-90 mins.</td>
<td>Strength Knee extension tensiometer Balance Tilt board/stability platform (degrees of instability) Somesthesis Upper limb kinesthesiometry at 30, 45 and 60°</td>
<td>Strength Significant difference between TC and control (p&lt;.05) Balance Significant difference between TC and control group (p&lt;.01) Somesthesis Significant difference between TC and control at 60° (p&lt;.05)</td>
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<td>First author, year, country</td>
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<td>Taylor-Piliae, 2006 United States</td>
<td>( n=39 ) 69.2% female Age (( M=65.7, \ SD=8.3 ))</td>
<td>Determine the effect of Tai Chi on upper- and lower-body strength, flexibility, and balance</td>
<td>12 wk 3x wk x60 mins</td>
<td>Strength/Endurance Arm curls Chair stand</td>
<td>Strength/Endurance Statistically significant improvement: 49% of the variance in upper-body and 42% of the variance in the lower-body improvement could be explained (( p &lt; .05 ))</td>
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<td>Flexibility Back scratch Chair sit-and-reach</td>
<td>Flexibility Statistically significant improvement: 22% of the variance in upper-body and 19% of the variance in lower body improvement could be explained (( p &lt; .05 ))</td>
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<td>Balance Functional reach Single-leg stance</td>
<td>Balance Statistically significant improvement: Approximately 8% of the variance in right leg and 23% of the variance in left leg stance could be explained (( p &lt; .05 ))</td>
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<td>Conclusions Tai Chi had significant effect on upper- and lower-body strength, endurance, flexibility, and balance</td>
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<td>Cross-sectional</td>
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<td>Fong, 2006</td>
<td>n=48</td>
<td>Compare reaction time, proprioception, and balance among short- and long-term TC practitioners and non-TC practitioners</td>
<td>NA Short-term TC practitioners: 12 wk 3x/wk 1-2 hrs/ session Long-term TC practitioners: 1-3 yrs 3x/wk 1-2 hrs/ session Control: Sedentary, no TC experience</td>
<td>Reaction time Onset of hamstrings and gastrocnemius muscle EMG response to disturbance</td>
<td>Reaction time Long-term TC practitioners had statistically significantly faster hamstring and gastrocnemius Reaction times than short-term TC practitioners or controls (p&lt;.05)</td>
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<td>Hong Kong</td>
<td>16 long-term TC 50% female Age range 41-78 (M=53.8, SD=12.2) 16 short-term TC 31% female Age range 40-75 (M=52.9,SD=11.7) 16 control Age range 44-77 (M=59.5, SD=10.6) 68% female</td>
<td>Balance Tilt board/stability platform (degrees of instability)</td>
<td>Somesthesis Knee joint angle repositioning between 20-75°</td>
<td>Balance Long-term TC practitioners had statistically significantly stability than short-term TC practitioners or controls (p&lt;.001)</td>
<td>Somesthesis Long- and short-term TC practitioners had statistically significant better accuracy at knee joint repositioning than the controls (p=.001 and p=.027, respectively)</td>
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<td>Kerr, 2008</td>
<td>n=28</td>
<td>Evaluate tactile spatial acuity in TC practitioners compared to controls; compare tactile spatial acuity in younger and older TC practitioners</td>
<td>NA Existing TC practitioners compared to control. Weekly TC practice M=7.25 hrs/wk (range 2.5-15.8 hrs/wk); hours of lifetime practice M=2957 (range 718-7,576 hrs)</td>
<td>Somesthesia Tactile spatial acuity: Measured by Grating Orientation Test (GOT)</td>
<td>Somesthesia Tactile spatial acuity: Significant main effect for group: greater tactile acuity in TC [F(1.24) = 4.67, p = 0.04] than control; (1.38 vs. 1.83 mm, respectively). (d=0.68). Significant main effect for age: greater tactile acuity in younger [F(1.24) = 9.3, p = 0.006] (1.29 vs. 1.93 mm, respectively). (d=1.03) Trend toward interactive effect (TC x Age) in improved tactile acuity</td>
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<tr>
<td>First author, year, country</td>
<td>Sample size, gender, age</td>
<td>Study Purpose</td>
<td>Intervention Type and Dose</td>
<td>Measures</td>
<td>Findings/ Conclusions</td>
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<tr>
<td>Kwok, 2010 Hong Kong</td>
<td>n=91</td>
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<tr>
<td></td>
<td>30 younger non-TC</td>
<td>Compare the effect of age and TC practice on speed and accuracy of a finger-pointing task toward stationary and moving visual signals</td>
<td>NA</td>
<td>Reaction time Onset of anterior deltoid EMG response</td>
<td>Reaction time (Stationary visual signal) Younger participants had statistically significantly faster Reaction ((p&lt;.05))</td>
</tr>
<tr>
<td></td>
<td>Age (M=24.2, SD=3.1)</td>
<td></td>
<td></td>
<td></td>
<td>Movement time Onset of EMG response to touching dot ‘endpoint’ on screen</td>
</tr>
<tr>
<td></td>
<td>50% female</td>
<td></td>
<td></td>
<td></td>
<td><strong>Somesthesis</strong> Accuracy: Absolute deviation of finger-pointing location from center of ‘endpoint’ dot</td>
</tr>
<tr>
<td></td>
<td>30 older non-TC</td>
<td></td>
<td></td>
<td></td>
<td>Moving visual signal: Reaction time Younger participants had statistically significantly faster Reaction times ((p=.011)) than older participants</td>
</tr>
<tr>
<td></td>
<td>Age (M=72.3, SD=7.2)</td>
<td></td>
<td></td>
<td></td>
<td><strong>Accuracy</strong> TC practitioners had statistically significantly better Accuracy than older non-TC practitioners ((p=.045)), similar to younger participants</td>
</tr>
<tr>
<td>First author, year, country</td>
<td>Sample size, gender, age</td>
<td>Study Purpose</td>
<td>Intervention Type and Dose</td>
<td>Measures</td>
<td>Findings/ Conclusions</td>
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<tr>
<td><strong>Lu, 2013</strong></td>
<td><strong>Hong Kong</strong></td>
<td>Compare postural control (sway) among TC and control group while under single and dual-task conditions</td>
<td>TC: At least 1.5 hrs/wk X 3 yrs (M=6.7, SD 4.6)</td>
<td>Reaction time Auditory Stroop test (ST)</td>
<td>Reaction time Both TC and controls had increased RT and error rates during dual- compared to single-task, but TC had faster RT than non-TC (p=.046)</td>
</tr>
<tr>
<td></td>
<td>n=58</td>
<td></td>
<td>Control: No TC experience</td>
<td>Stepping-down task to single-leg stance (simple) and stepping-down task with concurrent cognitive task</td>
<td>Total sway of TC group was less than controls under dual-task condition (p=.033)</td>
</tr>
<tr>
<td></td>
<td>28 TC</td>
<td></td>
<td></td>
<td></td>
<td>Hand-eye task</td>
</tr>
<tr>
<td></td>
<td>Age (M=73.6, SD=4.2)</td>
<td></td>
<td></td>
<td></td>
<td>Statistically significant better accuracy (p=.003), less pauses (p&lt;.001), and better movement (p=.002) in TC group compared to controls</td>
</tr>
<tr>
<td></td>
<td>68% female</td>
<td></td>
<td></td>
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<td></td>
<td>30 control</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Age (M=72.4, SD=6.1)</td>
<td></td>
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<tr>
<td></td>
<td>77% female</td>
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<td></td>
<td>20 control</td>
<td></td>
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<tr>
<td></td>
<td>75% female</td>
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<tr>
<td></td>
<td>Age (M=68.2, SD=5.2)</td>
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<tr>
<td><strong>Pei, 2008</strong></td>
<td><strong>Taiwan</strong></td>
<td>Compare hand-eye coordination among TC practitioners and controls</td>
<td>NA</td>
<td>Hand-eye task Pencil-like stick used to sequentially touch small, medium, and large target sensors to measure pauses, total time, and accuracy of movement</td>
<td>Differences between peak velocity were NSS</td>
</tr>
<tr>
<td></td>
<td>n=42</td>
<td></td>
<td>TC practitioners: &gt;3 yrs 5-7 x/wk 1-2 hrs/day</td>
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<tr>
<td></td>
<td>22 TC</td>
<td></td>
<td>Control: ‘Active’ (not defined) but no TC practice</td>
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<tr>
<td></td>
<td>Age (M=67.8, SD=5.1)</td>
<td></td>
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<tr>
<td></td>
<td>63% female</td>
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<tr>
<td></td>
<td>20 control</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>75% female</td>
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<tr>
<td></td>
<td>Age (M=68.2, SD=5.2)</td>
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<tr>
<td>First author, year, country</td>
<td>Sample size, gender, age</td>
<td>Study Purpose</td>
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<td>Findings/ Conclusions</td>
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<tr>
<td>Xu, 2004</td>
<td>n=68</td>
<td>Compare ankle and knee proprioception and kinesthetic sense among TC practitioners, swimmers/runners, and control groups</td>
<td>NA</td>
<td>Somesthesis Ankle: motion and direction (plantar and dorsiflexion)</td>
<td>Somesthesis Ankle: TC practitioners detected smaller flexion passive motion than the control group ($p=0.026$).</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>21 TC 43% female</td>
<td></td>
<td>TC practitioners: ≥4 yrs x 1.5 hrs/day</td>
<td>Somesthesis Knee: measured by goniometer to detect direction of movement of knee</td>
<td>NSS differences between TC practitioners and swimmer/runners, or swimmer/runners and control groups</td>
</tr>
<tr>
<td></td>
<td>Age (M=66.1, SD=5.2)</td>
<td>20 swimmer/runner 40% female</td>
<td>Swimmers/Runners: ≥4 yrs x 1.5 hrs/day</td>
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<td></td>
<td></td>
<td>Age (M=65.4, SD=3.0)</td>
<td>Control: No regular physical activity in past 5 yrs</td>
<td></td>
<td>NSS difference found in knee extension between groups</td>
</tr>
<tr>
<td></td>
<td>27 control 44% female</td>
<td></td>
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<td></td>
<td>Knee: TC practitioners detected statistically significant smaller amount of motion than the swimmer/runner ($p=0.022$) and control groups ($p=0.001$).</td>
</tr>
<tr>
<td></td>
<td>Age (M=65.6, SD=3.9)</td>
<td></td>
<td></td>
<td></td>
<td>NSS difference between swimmer/runner and control groups</td>
</tr>
</tbody>
</table>

Note: EMG=electromyography; hrs=hours; M=Mean; NSS=Not Statistically Significant; RT=reaction time; SD=Standard Deviation; TC=Tai Chi; wk=week; yrs=years
APPENDIX C

EFFECTS OF TAI CHI ON COGNITIVE FUNCTION IN COMMUNITY-DWELLING OLDER ADULTS: A REVIEW
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Effects of Tai Chi on cognitive function in community-dwelling older adults: A review

Sally M. Miller, MS, RN*, Ruth E. Taylor-Piliae, PhD, RN, FAHA
College of Nursing, The University of Arizona, 1305 N. Martin, P.O. Box 213023, Tucson, AZ 85721-2003, USA

ABSTRACT
As the population of the United States ages, activities to maintain or improve cognitive function will become increasingly important to preserve functional ability, independence and health-related quality of life. This article is a review of recent research on Tai Chi and cognitive function in community-dwelling older adults. Of the 12 studies reviewed, 10 reported improvement in measures of executive function, language, learning, and/or memory. Several design features make comparisons across studies challenging. As a moderate-intensity, low-impact form of exercise, Tai Chi is appropriate for older adults and seems to offer positive cognitive benefits. Recommendations for future research are provided.

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Introduction
The population of the United States is aging, and by the year 2030 the number of Americans older than 65 will almost double.1 Although older adults exhibit wide variability in the aging process, age-related changes in cognitive function are common, including declines in executive function, information processing speed, and attention.2 Changes in cognitive function can be viewed on a continuum, with age-related cognitive changes on one end of the continuum, mild cognitive impairment as a mid-stage, and dementia as the most severe end-point on the continuum of cognitive decline. Age-related cognitive changes cause minimal to no interference in instrumental activities of daily living (ADL) and independence,1 while mild cognitive impairment causes minor but noticeable changes and abnormal findings in one or more cognitive domains.4 The final stage of the cognitive decline continuum is dementia, characterized by a broad range of severe cognitive deficits, behavioral changes and functional decline, leading to dependence.5 Cognitive impairment places older adults at risk for progression to dementia,6 and strategies are needed to maintain or enhance cognitive function, and prevent cognitive decline. One promising intervention to enhance cognitive function in older adults is through exercise.

Exercise and cognitive function
The health benefits of exercise in older adults are well-documented.7,8 Exercise is important for physical and cognitive function, and is a strategy to maintain or increase independence in the growing population of older adults in the United States. Despite this, adults aged 65 and older are the least active group of Americans2,9 and can benefit from regular physical exercise. Exercise is classified by the energy cost to the individual using metabolic equivalents of task (METs).10 For example, low-intensity activities such as cooking or dusting have a MET value <3, moderate-intensity activities such as brisk walking or water aerobics are 3–6 METs, and high-intensity activities such as jogging are greater than 6 METs.11,12

Aerobic exercise in older adults has been shown to improve task-related cognitive function, brain connectivity (measured by functional magnetic resonance imaging), and regional brain volume.13 The biological mechanisms of action of exercise impacting cognitive function are thought to include changes at the molecular, vascular, synaptic and neural levels.14 Mechanisms include neurogenesis and synaptogenesis and involve substances such as lactate, enzymes, proteins, cytokines and glucose uptake. For example, at the vascular level, exercise promotes angiogenesis, while learning motor skills promotes synaptic connectivity. Neuronal growth and maintenance is impacted by substances such as hormones, growth actors, and neurotransmitters. Neural functions such as neuroplasticity, neurotransmitter release, and cell growth and differentiation are influenced by several factors.
including brain-derived neurotrophic factor, insulin-like growth factor-1, neurotransmitters and intracellular pathways. Although precise causal mechanisms for each of the neurocognitive changes have not been determined, growing evidence supports a positive association between aerobic exercise and cognitive function and suggests that physical exercise maintains or improves cognitive function. However, the type of exercise, the exercise dose, and methods to target specific cognitive functions are still under investigation. 

An additional area of cognitive aging research is the concept of cognitive enrichment as an intervention to maintain or improve cognitive function in older adults. Cognitive enrichment activities include deliberate practice of mentally stimulating, novel, and challenging cognitive skills focusing on areas such as attention, memory, and other executive-control functions. One potential strategy to combat cognitive decline is through exercise of both the mind and the body. One type of mind-body exercise is Tai Chi, a centuries-old form of martial arts combining memorized, sequenced physical postures and movement with imagery, visualization, relaxation, and meditation. Tai Chi is practiced using slow, balanced movements, and has low impact on joints, making it an appropriate activity for older adults.

Tai Chi as exercise

As a form of physical exercise, Tai Chi has a MET value of 3–6 and is a moderate-intensity activity, comparable to brisk walking. Tai Chi can also be considered a conditioning activity with cardiovascular benefits. In addition to being a form of physical exercise, Tai Chi also exercises the mind through memorization of sequences of postures, concentration, and meditation. Through the combined physical and mind exercise components, possible pathways affecting cognitive function include the benefits of aerobic exercise, cognitive enrichment, and secondary effects of improved mood, sleep promotion, and stress reduction.

As the population of the United States and the world ages, promotion of a form of exercise that benefits both the body and the mind may help maintain or improve cognitive function, reduce the rate of cognitive decline, preserve IADL, and ultimately improve quality of life. This paper reviews current research on the effect of Tai Chi on cognitive function in community-dwelling older adults, makes recommendations for future research, and provides suggestions for promoting Tai Chi as a beneficial exercise supporting cognitive function.

Methods

An electronic search was conducted in OVID, PubMed, and Web of Science using controlled vocabulary terms and keywords (Tai Chi) and “cognition.” The search was restricted to adults aged 55 years or older, articles written in the English language, and articles published between June 2003–June 2013, yielding a total of 46 articles. One additional article was found via a hand search of references from published articles. Abstracts and full-text articles were reviewed for measures of executive function, attention, memory, learning, and verbal fluency. Studies reporting psychological measures such as sleep, energy, depression, stress, or quality of life, but not cognitive measures listed above were excluded. The purpose of this review was to explore the effect of Tai Chi on cognitive function in community-dwelling older adults; therefore, studies which included adults with significant dementia diagnoses (Mini-Mental State Exam [MMSE] score < 24) or Clinical Dementia Rating [CDR] scale score > 1 were excluded. Data from studies meeting the inclusion criteria were extracted including: country of study, study design, Tai Chi style and exercise dose, comparison group, cognitive domains measured, and findings.

Results

Study designs and populations

A total of 12 articles were included in this review examining the effects of Tai Chi on cognitive function in community-dwelling older adults (Fig. 1). Study designs included randomized controlled trials (RCT) (n = 6), quasi-experimental (n = 3), and cross-sectional (n = 3) studies (Table 1). The cross-sectional studies compared Tai Chi to other forms of exercise such as walking, stretching/toning, and/or no exercise. The studies reviewed were conducted in Asia, North America, and South America and included community-dwelling adults ranging in age from 55 to 80, with a majority of female participants (average = 71%). None of the 12 studies listed exclusion criteria of participants with unstable conditions, substance abuse, diagnoses for which physical activity would be contraindicated, or active

![Fig. 1. Study selection flow diagram showing reasons for exclusion.](Image)
<table>
<thead>
<tr>
<th>Randomized clinical trial</th>
<th>Tai Chi style/duration</th>
<th>Cognitive domain/measures</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hall, 2005, United States</td>
<td>Yang style (24 form)</td>
<td>Executive function</td>
<td>No significant effect of time, group or interaction for either equilibrium or verbal reaction scores (dual task) increased dual task cost for TC group; improvement in control group under single and dual tasks decreased obstacle avoidance under dual tasks; no improvement in TC group NS improvement in control group</td>
</tr>
<tr>
<td>Lam, 2012, Hong Kong</td>
<td>Simplified TC (24 form)</td>
<td>Executive function</td>
<td>Exec. function NS improvement in DSB, VSB Complete only; improved DSB (group difference at 1 year 0.37, p = 0.05) VSB greater after 8th month in TC group, NS after 1 year Language NS difference NS difference Global cognition Global cognition NS improvement in ADAS-Cog 2% lower CDR sum of boxes in TC group than control (beta = 0.79, 95% CI 0.63–0.95, p = 0.04) MMSE no change MMSE no change</td>
</tr>
<tr>
<td>Leverette, 2011, United States</td>
<td>Chih style (with Qi Gong)</td>
<td>Executive function</td>
<td>ST NS difference Learning/memory CVLT long delay recall, cued word recall improvement in carry-over with TC than control with health education (group × time interaction: F[1,65] = 5.29, p &lt; 0.05)</td>
</tr>
<tr>
<td>Nguyen, 2012, Vietnam</td>
<td>TC style not specified (24 form)</td>
<td>Executive function</td>
<td>significant difference between TC and control in TMT-A (F[1,71] = 19.33, p &lt; 0.001) and TMT-B (F[1,71] = 17.59, p &lt; 0.001) significant interactions in TMT-A for time (eta squared = 0.446, p = 0.000) and time × group (eta squared = 0.219, p = 0.001) and TMT-B between time (eta squared = 0.186, p = 0.000) and time × group (eta squared = 0.125, p = 0.000)</td>
</tr>
<tr>
<td>Taylor-Piliae, 2010, United States</td>
<td>Yang style-24 posture</td>
<td>Executive function</td>
<td>Adop. phase: TC had greater improvement in DSB than WE or control (F[1,32] = 7.75, p &lt; 0.001) Maintenance phase: TC maintained improvement in DSB compared with WE (F[2,74] = 2.52, p = 0.014) Statistically significant within group improvement in DSB in TC (F[2,74] = 3.26, p = 0.038) Language Maintenance phase: within group improvement in TC (F[2,74] = 2.47, p = 0.037) and WE (F[2,74] = 2.81, p = 0.008); NS between groups</td>
</tr>
<tr>
<td>First author, year, country</td>
<td>Sample</td>
<td>Tai Chi style/duration</td>
<td>Cognitive domain/measures</td>
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</tr>
<tr>
<td>Yang style (24 form)</td>
<td>Other</td>
<td>ST</td>
<td>No significant effect of time, group or interaction for either equilibrium or verbal reaction scores (dual task) increased dual task cost for TC group; improvement in control group under single and dual tasks decreased obstacle avoidance under dual tasks; no improvement in TC group NS improvement in control group</td>
</tr>
<tr>
<td>1.5 h</td>
<td>OT</td>
<td>OT</td>
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<tr>
<td>2 × wk x 12 wks</td>
<td>Response to auditory or visual stimulus while stationary (single-task) and while walking (dual-task)</td>
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<tr>
<td>1x</td>
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<tr>
<td>2 × wk</td>
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<tr>
<th>First author, year, country</th>
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<th>Tai Chi style/duration</th>
<th>Cognitive domain/measures</th>
<th>Findings</th>
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</thead>
<tbody>
<tr>
<td><strong>Quasi-experimental studies</strong></td>
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<tr>
<td><strong>Koizumi, 2010, Japan</strong></td>
<td>n = 34</td>
<td>Adults with cerebrovascular disease</td>
<td>Yang style 50 min</td>
<td>Executive function</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female: 76%</td>
<td>1 wk = 12 wk</td>
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<td></td>
<td></td>
<td>TC, n = 17</td>
<td>Control</td>
<td>Executive function</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean age = 76.5 ± 9.7</td>
<td>Non-resistance</td>
<td>Learning/memory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control, n = 17</td>
<td>(20 min) plus</td>
<td>Learning/memory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean age = 77.6 ± 12.3</td>
<td>resistance</td>
<td>Improvement in RBMT (p = 0.007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exclusion: MMSE &lt; 20</td>
<td>Total: 80 min</td>
<td>Positive correlation (r = 0.008) between learning TC test and RBMT (r not supplied)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Other</td>
</tr>
<tr>
<td><strong>Koizumi, 2010, Brazil</strong></td>
<td>n = 26</td>
<td>Adults with subjective memory decline, no dementia diagnosis</td>
<td>Yang style 60 min</td>
<td>Executive function</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female: 100%</td>
<td>2 wk = 6 mos</td>
<td>Significant improvement in time to complete TMT A (p = 0.039) and TMT B (p = 0.039)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TC, n = 13</td>
<td>Brochure instructed to practice at home</td>
<td>Significant difference in CDT: On a seven-point scale (pre-intervention mean = 6.20 ± 0.77; post-intervention mean = 6.35 ± 0.69; p = 0.029)</td>
</tr>
<tr>
<td></td>
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<td>Cognitive function/dementia exclusion: MMSE corrected for educational level (cut-off score not specified)</td>
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<tr>
<td><strong>Matthews, 2008, United States</strong></td>
<td>n = 20</td>
<td>Community-dwelling adults</td>
<td>Sun style 50 min</td>
<td>Executive function</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Age range 66–84</td>
<td>3 wk = 10 wks</td>
<td>Significant improvement in TMT-A and B (p = 0.033)</td>
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<td></td>
<td></td>
<td>(Mean age = 76.5)</td>
<td></td>
<td>Learning/memory</td>
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<tr>
<td></td>
<td></td>
<td>Female: 55%</td>
<td></td>
<td>Learning/memory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Screened for dementia and mild cognitive impairment (method not specified)</td>
<td></td>
<td>Learning/memory</td>
</tr>
<tr>
<td><strong>Reid-Arndt, 2012, United States</strong></td>
<td>n = 23</td>
<td>Female cancer survivors</td>
<td>Modified Yang Style 1 h</td>
<td>Executive function</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean age = 62.3 ± 10.2</td>
<td>2 wk = 10 wks</td>
<td>Significant changes in TMT-A (1.22) = 6.46; p = 0.019; TMT-A (1.22) = 2.29; p = 0.003; and TMT-B (1.22) = 18.49; p &lt; 0.001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female: 100%</td>
<td></td>
<td>Language</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Screening for cognitive impairment or dementia not specified</td>
<td></td>
<td>Language</td>
</tr>
<tr>
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<td></td>
<td>Significant change [TMT-A (1.22) = 12.00; p = 0.002] in WMS-LM I</td>
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<td></td>
<td>Learning/memory</td>
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<td>Significant improvement in immediate memory: RAVLT 1 (TMT-A (1.22) = 5.74; p = 0.024); RAVLT 2 (TMT-A (1.22) = 5.03; p = 0.003); and WMS-LM II (TMT-A (1.22) = 26.32; p = 0.001)</td>
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<td>Other</td>
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<td>Significant improvement in delayed memory: WMS-LM II (TMT-A (1.22) = 15.97; p = 0.001)</td>
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<td>Other</td>
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<td>Significant improvement in time to complete TMT B (p = 0.039) and visual memory subscales [TMT-A (1.22) = 4.98; p = 0.037]</td>
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<td><strong>Cross-sectional studies</strong></td>
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<tr>
<td><strong>Carr, 2009, Hong Kong</strong></td>
<td>n = 250 Community-dwelling adults</td>
<td>TC style not specified</td>
<td>Language</td>
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<td>Age range: 54–94</td>
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<td>Female: 81%</td>
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<td>No exercise control, n = 35</td>
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<td>No exercise control, n = 35</td>
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<td>Mean age = 62.37 ± 4.03</td>
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<td>Mean age = 66.11 ± 4.57</td>
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<td>Mean age = 66.11 ± 4.57</td>
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<td>Mind–Body exercise, n = 35</td>
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<td>Learning/memory</td>
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<td></td>
<td>Cardiovascular + Mind–Body activity: less words than No exercise group (F[3,136] = 3.30; p = 0.02)</td>
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<td></td>
<td>Other</td>
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<td></td>
<td></td>
<td>Cardiovascular and Mind–Body groups were not significantly different</td>
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</table>
Mean age = 68.34 ± 5.27
Cardiovascular + Mind-Body, n = 35
Mean age = 69.94 ± 4.80
Cardiovascular plus Mind-Body group had a significantly higher mean age than the Exercise group (t(33) = 2.16, p = 0.037). Cognitive function/dementia exclusion criteria: CDR < 1; CDR 0 mean MMSE-C = 24.48 ± 2.76

Lam, 2009, Hong Kong
n = 782
Community-dwelling adults
CDR 0: Mean age = 68.61 ± 6.39
CDR 0.5: Mean age = 74.37 ± 7.38
Female: 51%
Cognitive function/dementia exclusion: MMSE-C and MMSE-C (Chinese) scores
Exclusion: CDR > 1; CDR 0 mean MMSE-C = 27.26 ± 1.94;
CDR 0.5 mean MMSE-C = 24.48 ± 2.76

Man, 2010, Hong Kong
n = 135
Community-dwelling adults
Age range: 55-90
Female: 54%
N = 42
Exercise, n = 49
Control, n = 44
Cognitive function/dementia exclusion: MMSE-C = 24

Abbreviations: ADAS-Cog (Chinese) = Alzheimer’s Disease Assessment Scale-Cognitive Subscale (Chinese); AMIC = Abbreviated Memory Inventory for the Chinese; AV = Animal Naming; BNT-C = Chinese version Boston Naming Test; CDR = Clinical Dementia Rating; CFT = Clock Drawing Test; COWAT = Controlled Oral Word Association Test; CTT = Color Trails Test; CVFT = Category Verbal Fluency Test; CVLT = California Verbal Learning Test; DP = Delays Recall; DS = Digit Span; DSB = Digit Span Backward; DSF = Digit Span Forward; DS = Digit Symbol; ERP = Event Related Potential; HKT = Hong Kong Trail Making Test; HKT = Hopkins Verbal Fluency Test, delayed recall; MMSE = Mini-Mental State Examination; MMSE-C = Mini-Mental State Examination-Cantonese; NC = Not Significant; NCVLT = Rey Auditory Verbal Learning Test; RBMT = Rivermead Behavioral Memory Test; RBMT-CV = Rivermead Behavioral Memory Test-Cantonese Version; RCT = Randomized Controlled Trial; SD = Standard deviation; SMC = Subjective Memory Complaint; SOE = Sensory Organization Test; ST = Stroop Test; TC = Tai Chi; TMT = Trail Making Test; VSB = Visual Span Backward; WMS-LM = Wechsler Memory Scale-Logical Memory.
diseases such as cardiovascular or progressive neurological conditions. Other than these exclusion criteria, study participant comorbidities were not specified, although three of the studies targeted specific conditions including depression, cancer survivorship in women and cerebrovascular disease.

**Tai Chi exercise intervention**

The Tai Chi exercise interventions included diverse styles, number of postures, and duration of exercise sessions (Table 1). Styles included Yang (n = 5),32,33,35,36,38 Ng (n = 1),41 Sun (n = 1),37 or were not specified (n = 5).32,34,35,38,40 Additionally, two studies combined Tai Chi with either Qi Gong or yoga practitioners in their study population.40 The number of postures ranged between 12 and 108, but was not specified in five studies.40,42,43,45,46 The duration of Tai Chi exercise sessions varied between 30 and 120 min. Weekly practice also varied between one and three times per week, but was not specified in two cross-sectional studies.33,38,40 Length of practice ranged from 4 weeks to 12 months, but was not specified in two cross-sectional studies.32,40 Two studies42,43 asked participants to practice outside of study sessions, however self-report log information was not included.

The method of instruction was provided in varying degrees of detail in the RCT and quasi-experimental studies. For example, trained, certified or experienced Tai Chi instructors were utilized as interventionists in several studies,1,7,12,13,17,33,34,35,37,40,42 while in one study, instruction was provided by a physical therapist without further description of the therapist’s Tai Chi background knowledge. One study did not report Tai Chi instructor characteristics.25 Descriptions of instruction techniques such as verbal cues, visualization, and imagery was included in several studies,1,7,13,38 while other studies referenced specific Tai Chi programs or manuals utilized,1,7,13,37,38 but did not describe inclusion of additional Tai Chi components. One cross-sectional study included the Tai Chi style,17 and all three cross-sectional studies relied on self-report of exercise habits including reports of stretching, aerobic, Tai Chi and no exercise.

**Cognitive measures**

Measures of cognitive function included objective assessments using a variety of verbal and paper-and-pencil examinations of executive function, language, learning and memory, global cognition assessments, as well as other cognitive tests such as event related potentials, subjective measures and sensory organization tests (Table 2). Specifically, of the 12 studies reviewed, nine studies used seven different measures under the domain of executive function.1,12,13,17,32,34,38,40,42 Four of the 12 studies used different measures of language,1,7,13,38 six of the 12 studies used five different measures of learning and memory,1,12,17,32,35,38,40 Four of the 12 studies used three different measures of global cognition.1,7,32,35,36,38 The variety of measures used in these studies makes comparison of results difficult. Therefore, the measures have been categorized under several cognitive domains to facilitate comparison and are aligned with the current Diagnostic and Statistical Manual of Mental Disorders (DSM-5) of the American Psychiatric Association; with measures of attention included under executive function, as described below.

**Executive function**

Executive function is a complex concept which includes working memory, overlaps with attention, and requires sensory selection, response selection and vigilance. Components of executive function were measured by a variety of tests including the Clock Drawing Test (CDT), Color Trails Test (CTT), Digit Span Tests (DS), Digit Symbol Tests (DST), the Stroop Test (ST), and Trail Making Tests (TMT). The TMT is further divided into TMT-A which tests attention and processing speed, and TMT-B, which also tests mental flexibility.41 In addition to testing executive function, several of these measures also include motor, visual-spatial, and perceptual components.

Statistically significant improvements in attention were measured in Tai Chi practitioners compared to non-exercisers using the CTT-I (F = 2.69; p = 0.03) and CTT-II (F = 1.63; p = 0.02) in a cross-sectional study comparing Tai Chi, aerobic exercisers and non-exercisers.41 In a quasi-experimental study, a statistically significant improvement in the time to complete the TMT-B was reported (pre-intervention mean = 106.30; 73.48; post-intervention mean = 89.08 ± 32.78; p < 0.029) after a 10-week Tai Chi exercise intervention.42 Likewise, in an RCT comparing a six month Tai Chi intervention with a non-exercising comparison group, significant improvements in TMT-A (F = 17.71; 78.77, p < 0.001) and TMT-B (F = 17.71; 75.80, p < 0.001) were observed.43 In the same study, significant interactions in TMT-A for time (eta squared = 0.746, p = 0.000) and time × group (eta squared = 0.768, p = 0.000) and in TMT-B between time (eta squared = 0.860, p = 0.000) and time × group (eta squared = 0.854, p = 0.000) were also reported. Improvement in attention and mental flexibility were also observed in female cancer survivors who practiced Tai Chi for 10 weeks, with statistically significant improvement in TMT-A (F = 12.28; p = 0.002) and TMT-B (F = 12.28; p < 0.001).44 Conversely, in a population with clinical depression pairing an antidepressant with a 12 week Tai Chi intervention, no statistically significant increase in attention as measured by TMT-A was reported.45

Digit span tests were used as a measure of working memory in an RCT comparing an attention control group, Western Exercise and Tai Chi.46 Improvement in digit span backward (F = 7.75, p < 0.001) was reported during the six-month adoption phase, and was sustained at the conclusion of the 12-month maintenance phase when comparing the Tai Chi and Western Exercise groups (F = 2.94; p = 0.014). However, in a quasi-experimental study of older women with mild cognitive impairment, improvement in digit span forward but not digit span backward was found (p = 0.031).47 Working memory was also assessed using digit span backward in a study comparing Tai Chi to stretching and toning48 with no statistically significant differences found.

Delayed recall was measured by Lam and colleagues49 with a statistically significant improvement in participants who practiced mind-body or aerobic exercise for greater than five years when compared to those who practiced stretching exercises only (F = 17.71, p = 0.003). In a later study by Lam and colleagues,49 delayed recall was found to be significantly improved (p = 0.05) in participants at risk for cognitive decline who completed a one-year Tai Chi intervention.

In two small quasi-experimental studies,7,18 (n = 20 and n = 23, respectively), digit symbol substitution was measured with no statistically significant results reported. The authors in one study7 felt the non-significant results could be due to the speed component of the digit symbol substitution test, rather than lack of improvement in executive function. Specifically, in the same study7 executive function was also measured using the Clock Drawing Test, with a statistically significant improvement in scores after a 10 week Tai Chi intervention (pre-intervention mean = 6.26, SD ± 7.77; post-intervention mean = 6.50, SD ± 6.93; p = 0.029).

The Stroop Test measures cognitive control and the ability to suppress habitual responses. In a RCT7 of participants with a major depressive disorder receiving a Tai Chi exercise intervention plus antidepressants, a statistically significant change in the
Table 2
Cognitive domains, associated measures, test properties, and major findings.

<table>
<thead>
<tr>
<th>Cognition domain</th>
<th>Measure (abbreviation) and test properties showing improvement</th>
<th>Major findings</th>
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<tbody>
<tr>
<td></td>
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<td>RCT</td>
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<td>SS</td>
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<td>Executive function</td>
<td>Clock Drawing Test</td>
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<td></td>
<td>Higher scores indicate improvement</td>
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<tr>
<td></td>
<td>Color Trails Test (CTT)</td>
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<td></td>
<td>Shorter times and accuracy</td>
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<td></td>
<td>Delayed Recall (DR)</td>
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<td></td>
<td>Number of words recalled</td>
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<td></td>
<td>Digit Span Tests (DS)</td>
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<td></td>
<td>Number of digits correctly recalled or in reverse order</td>
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<tr>
<td></td>
<td>Digit Symbol Tests (DST)</td>
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<td></td>
<td>Correct amount of symbols within time allotted</td>
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<td></td>
<td>Strong Test (ST)</td>
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<td></td>
<td>Shorter times and accuracy</td>
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<td>Trail Making Test (TMT)</td>
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<td></td>
<td>Shorter times and accuracy</td>
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<td>Visual Span Tests (VS)</td>
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<td></td>
<td>Number of digits recalled in order presented</td>
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<tr>
<td>Language</td>
<td>Animal Naming (AN)</td>
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<td></td>
<td>Number of items named in time allotted</td>
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<td>Boston Naming Test (BNT)</td>
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<td>Number of correct responses (including spontaneous and cued)</td>
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<td>Category Verbal Fluid Test (CVFT)</td>
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<td>Number of responses in time allotted</td>
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<td>Controlled Oral Word Association Test (CONWAT)</td>
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<td>Number of responses in time allotted</td>
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<td>Learning and memory</td>
<td>California Verbal Learning Test (CVLT)</td>
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<td>Number of correct responses</td>
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<td>Hong Kong Easy Learning Test (HELT)</td>
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<td>Rey Auditory Verbal Learning Test (RAVLT)</td>
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<td>Number of correct responses</td>
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<td>Rivermead Behavioral Memory Test (RBMT)</td>
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<td>Number of correct responses in selected subsets</td>
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<td>Wechsler Memory Scale—Logical Memory (WMS-LM)</td>
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<td>Number of correct recalled responses</td>
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<td>Global cognition</td>
<td>Alzheimer’s Disease Assessment Scale—Cognitive (ADAS-Cog)</td>
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<td>Lower scores indicate improvement</td>
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<td>Clinical Dementia Rating Scale (CDR)</td>
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<td>Lower scores indicate improvement</td>
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<td>Mini-Mental State Examination (MMSE)</td>
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<td>Higher scores indicate improvement</td>
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<td>Other</td>
<td>Event Related Potentials (ERP)</td>
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<td></td>
<td>Shorter P300 latencies indicate improvement</td>
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<td></td>
<td>Multiple Abilities Self-Report Questionnaire (MASQ)</td>
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<td></td>
<td>Lower scores indicate lower perceived difficulties</td>
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<td>Sensory Organization Test (SOT)</td>
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<td>Higher scores indicate improvement</td>
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<td></td>
<td>Subjective Memory Complaint (SMC)</td>
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<td></td>
<td>Lower scores indicate lower perceived difficulties</td>
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</table>

RCT = randomized clinical trial; SS = statistically significant; NS = not significant.

1 Improved at month three, NS after one year.
2 Cardiovascular plus mind–body exercise.

Stroop Test was not reported. However, in a quasi-experimental study with female cancer survivors and a similar intervention dose, a statistically significant improvement in the Stroop Test was observed (F[1,22] = 6.46; p = 0.019).

Language

Verbal fluency is primarily a test of language, although verbal fluency also contains aspects of memory and executive function. Language was measured using four different tests including Animal Naming, the Boston Naming Test, the Category Verbal Fluid Test and the Controlled Oral Word Association Test.

Using Animal Naming as a measure of verbal fluency, Taylor-Piliae and colleagues reported within-group improvement for both Tai Chi (F[2,74] = 3.27, p = 0.003) and Western exercise groups (F[2,74] = 2.81, p = 0.008) during the maintenance phase of an RCT, although between-group differences were not statistically significant. In a cross-sectional study of community-dwelling Chinese older adults, the Category Verbal Fluid Test (CVFT) measured verbal fluency, with aerobic exercisers and mind–body practitioners showing statistically significant higher scores compared to groups who performed stretching exercise only (F[2, 12] = 12.00; p = 0.002). Statistically significant improvement in verbal fluency was also measured using the Controlled Oral Word Association Test in female cancer survivors after a Tai Chi exercise intervention (F[1,22] = 12.00; p = 0.002). In contrast, no statistically significant differences were measured in verbal fluency using the CVFT.
between Tai Chi and stretching and toning groups of Chinese older adults at risk for cognitive decline. Similarly, Chan and colleagues reported no effect of exercise on language as measured by the Boston Naming Test.

Learning and memory

Memory can be defined as long-term or working and involves recall of tasks, words, symbols and/or numbers. In this review, tests of immediate, delayed or long-term memory were categorized under the Learning and Memory heading. Several different measures were used including the California Verbal Learning Test, the Hong Kong List Learning Test, the Rey Auditory Verbal Learning Test, the Rivermead Behavioral Memory Test and subscales of the Wechsler Memory Scale.

Verbal memory was measured using the California Verbal Learning Test in participants with clinical depression and showed a statistically significant improvement (group × time interaction: F(1,145) = 5.29; p < 0.05) comparing participants receiving a Tai Chi exercise intervention plus antidepressants, with participants receiving health education plus antidepressants (controls).

In a pre-post Tai Chi intervention study among female cancer survivors, Reid-Arnold and colleagues found statistically significant improvements in immediate memory using the Rey Auditory Verbal Learning Test (RAVLT) trials 1 (F(1,22) = 5.74; p = 0.026), the RAVLT trials 1–5 (F(1,22) = 5.03; p = 0.035), and the Wechsler Memory Scale (WMS-IM) Factor 1 (F(1,22) = 22.32; p = 0.001). An improvement in delayed memory using the WMS-IM II (F (121) = 15.97; p = 0.001) was also reported.

Everyday memory was tested using the Rivermead Behavioral Memory Test (RBMT) by Kasa and colleagues who reported an improvement in a Tai Chi group compared to a control group (p = 0.007). Additionally, there was a positive correlation between performance of Tai Chi and the RBMT after three months (r not reported). Similarly, in a cross-sectional study, Tai Chi practitioners performed significantly better on the RBMT total standard score (F = 3.46; p = 0.03) and total screening score (F = 3.19; p = 0.04), and several subsets of verbal memory tests, than other exercise or control groups.

Learning and memory were measured by Chan and colleagues using the Hong Kong List Learning Test; by comparing cardiovascular exercise alone, mind–body exercise alone, cardiovascular plus mind–body and no exercise groups. No significant difference was found between the cardiovascular and mind-body groups; however, the cardiovascular plus mind-body group learned more words than the no exercise groups (F(3,136) = 3.30; p = 0.02), and the cardiovascular and mind–body groups recalled significantly more words than the no exercise group (F(3,136) = 6.39; p < 0.001). Finally, the cardiovascular exercise, cardiovascular plus mind-body, and mind-body groups were able to correctly retrieve more words than the no exercise group (F(3,135) = 6.09; p = 0.001).

Global cognition

Measures of global cognition included the Alzheimer's Disease Assessment Scale-Cognitive Subscale (ADAS-Cog), Clinical Dementia Rating Scale (CDR), and the MMSE. These measures test, screen, and/or track a variety of cognitive functions including speech comprehension, language, memory, and orientation. The CDR is used to stage dementia severity, with six domains that are summed for a global CDR score, labeled the ‘sum of boxes.’

In a cross-sectional study, Lam and colleagues reported improved MMSE scores when comparing mind–body and aerobic exercise participants with non-exercisers (x² = 6.77; p = 0.034). Additionally, lower CDR scores (x² = 11.89; p = 0.003) indicating improved global cognitive function, were reported among the mind–body practitioners. A more recent study by Lam and colleagues reported lower CDR sum of boxes scores (beta = 0.78, 95% CI = 0.63–0.93, p = 0.04)–indicates preserved cognitive function—for participants in the Tai Chi intervention group, though no changes in ADAS-Cog or MMSE scores were observed. However, two studies comparing Tai Chi and control groups found no significant changes in MMSE (39) or CDR scores.

Other cognitive tests

Several studies used measures categorized as ‘other’ including event-related potentials, sensory organization tests, and subjective measures of memory difficulties, specifically the Subjective Memory Complaint questionnaire (SMC) and the Multiple Abilities Self-Report Questionnaire (MARS).

Wang and colleagues studied event-related potentials as a measure of attention in participants with cerebrovascular disease. In this RCT, no significant difference was found when comparing participants in a 12 week Tai Chi intervention with a two-part non-resistance/resistance training control group.

Hall and colleagues examined the effect of Tai Chi on sensory organization under dual-task conditions (auditory and visual cognitive tasks and with postural stability) and observed no significant effect of time, group, or interaction between participants in a 12 week Tai Chi and those in an attention-control group. Although the studies by Wang and colleagues and Hall and colleagues used novel approaches to measure cognition, they both had small sample sizes. One of these studies had a sample size of 34 and an exercise intervention dose that consisted of one class per week for 50 min (a total of 6 h), making it one of the lowest exercise doses in this review. The study by Hall and colleagues had the smallest sample size (n = 15: Tai Chi, n = 15: Controls, n = 7) of all the studies reviewed, threatening statistical conclusion validity.

Two studies measured self-reported subjective memory complaints. A significant decrease in subjective memory complaint was reported by Kasa and colleagues (p = 0.023) as measured by the SMC questionnaire. Similarly, Reid-Arnold and colleagues measured subjective complaints of cognitive abilities using the MARS and found statistically significant improvements in two of five subscales, specifically verbal memory (F(1,21) = 7.83; p = 0.011) and visual memory subscales (F(1,21) = 4.98; p = 0.037). In this study, a simplified Tai Chi form was taught and emphasized the integration of movement, visualization and relaxation.

Discussion

This review examined the effect of Tai Chi exercise on cognitive function in community-dwelling older adults without documented dementia diagnoses. The universal appeal and utility of Tai Chi as a form of exercise is exemplified by the variety of countries where the studies were conducted, which were equally divided between the Americas (Brazil and the United States) and Asia (Hong Kong, Japan and Vietnam). Although the diverse Tai Chi forms, varying exercise doses and variety of cognitive outcomes measured makes comparisons across studies challenging, statistically significant improvements in executive function, language, learning and memory, and subjective memory were found in all but two studies. In the studies where non-significant results were reported, several factors such as small sample size and brief Tai Chi exercise intervention dose may partly explain the lack of significant findings. Additionally, one of these studies used event-related potentials, and one used sensory organization tests, both of which are novel approaches to measuring the effect of Tai Chi on cognitive function.

The majority of study participants were women, which reflects the older adult population in the countries where the studies were conducted. Older adults with chronic stable conditions were not
excluded from the studies, and several studies targeted specific populations including cancer survivors, cerebral vascular disease, and depression. Therefore, the inclusion of study participants with a wide variety of common health conditions increases the generalizability to older adults, regardless of gender or geographic location.

The multidimensional "active ingredients" of Tai Chi including the style, exercise dose, and teacher characteristics may impact delivery and receipt of the Tai Chi intervention. Although the exercise dose was described in most studies, many did not report the frequency that individuals were required to practice or include self-report of practice, in addition to the structured intervention sessions. The variety of forms, number of postures, and teaching styles varied, or were not specified. One study included yoga practitioners and one study included Qigong. These variations increase the difficulty in comparing the amount of practice and delivery of the Tai Chi exercise dose. As with other physical exercise interventions, the relationship between exercise dose, including intensity and duration, has not been determined and no clear association emerged regarding dose and results. Similarly, the cognitive exercise aspects of Tai Chi including visualization, imagery, mediation, and memorization of postures and sequences may be as important as the aerobic component in maintaining or improving cognitive function. In the studies reviewed, all but three described inclusion of these cognitive exercise components. Although the study by Hall and colleagues emphasized awareness of body alignment, breathing, and visualization, statistically significant changes in cognitive function were not reported.

Executive function

It is widely accepted that the aging process is associated with cognitive decline in executive functions including attention, immediate recall, response inhibition, working memory and information processing speed. Although there is no consensus regarding optimal exercise types or doses, exercise appears to provide protective effects on brain structure and function, including executive function. However, in the studies reviewed, the effect of Tai Chi exercise on executive function was unclear, with tests of attention such as the Trail Making Tests showing significant improvement in some studies, while not in others, with no explanatory pattern emerging. Likewise, audio digit span tests were improved in some studies and not in others, while visual span tests were significantly improved. In the two studies that measured delayed recall, significant improvement was found; but in one of the studies Tai Chi was paired with aerobic exercise, and in the other study the effects were not sustained, making the results difficult to interpret. Two studies with similar Tai Chi exercise doses measured the Stroop Test and showed conflicting results. One study used the Clock Drawing Test as a measure of executive function, and showed significant improvement, but conclusions cannot be drawn from one small (n = 20) quasi-experimental study.

Language

In normal cognitive aging, speech and language remain relatively intact and do not show large declines. Of the five studies that measured verbal fluency, three showed statistically significant improvements. The lack of improvement reported in the study by Lam and colleagues could be due to the inclusion of study participants at risk for cognitive decline (CDR scores of 0.5 or evidence of mild cognitive impairment), making these participants one of the most cognitively vulnerable of all studies in this review. Additionally, this RCT spanned one year, making it the longest of all the studies reviewed, increasing the possibility for progression of cognitive decline. The Boston Naming Test (BNT) used by Chan and colleagues measures visual naming ability and was not significantly impacted by Tai Chi, cardiovascular exercise or a combination of the two forms of exercise, when compared to a no exercise group.

Learning and memory

Factors influencing age-related declines in learning and memory include decreased speed of processing and ability to filter relevant from irrelevant information. Acquisition and retrieval of newly learned information are affected by these declines. Acquisition and retrieval from visual and auditory sources improved across all types of study designs. The addition of cardiovascular exercise with Tai Chi enhanced learning, possibly due to increased aerobic mechanisms. An interesting finding was the positive correlation measured by Kassai and colleagues between the ability to correctly perform Tai Chi postures and the Rivermead Behavioral Memory Test, which measures everyday memory. This finding underscores the importance of the delivery of a Tai Chi exercise intervention as well as participants' receiving the instructions, specifically memorization compared to mimicry of postures.

Global cognition

The results of global cognition testing are equivocal, with some studies showing statistically significant improvements in global cognition, while others did not. The conflicting results may be due to the use of screening versus clinical instruments, exercise self-report, or proxy reporting (e.g., CDR). Additionally, interventions with relatively short time frames may not provide enough of an exercise dose to be effective, as may be the case in the non-significant change in MMSE reported by Lavretsky and colleagues.

Other measures

The use of event-related potentials is gaining popularity for the study of acute and long-term exercise on cognition, and results of this type of research have shown improvements in cognitive function after exercise interventions. The results of the study by Wang and colleagues were not statistically significant, possibly due to a brief Tai Chi intervention dose of only 6 h during a 12 week study. Additionally, the population under study had known cerebral vascular disease including intracerebral hemorrhage, subarachnoid hemorrhage, or cerebral infarction, all of which may have impacted the results reported.

A surprising result reported was the lack of statistical significance during the sensory organization tasks, as the practice of Tai Chi requires coordination of breathing, focus, limb movement, weight shifting and attention to balance. These results may partly be explained by the sample size or lack of engagement in the integration of imagery and movement by the participants during the Tai Chi intervention and/or testing.

The effect of Tai Chi on self-reported memory complaints resulted in subjective improvement in two studies. It is interesting to note that in both of these studies the sample was comprised of women. Therefore, the influence of gender could impact self-appraisal.

Recommendations for future research

Tai Chi is an accessible form of exercise with physical, psychological and cognitive benefits, and research on Tai Chi as an
exercise intervention will likely continue to grow. To provide information for study replication and evidence for practice, it is important for researchers to document not only the dose of Tai Chi provided during the intervention, but also participant adherence to the intervention. Additionally, details of independent practice recommendations given to study participants will clarify the exercise dose. Although self-report logs may not yield precise practice amounts, they could aid in important information regarding exercise dose and adherence. By documenting exercise dose information, the effectiveness of the intervention can be more readily replicated and translated to practice. Although various styles of Tai Chi were used, all styles have many commonalities, such as properly shifting body weight and relaxation. Future studies should consider describing their Tai Chi instructional methods, such as mimicry of the instructor versus memorization of the movements.

The use of numerous and varied measures of cognitive function makes comparisons across studies a challenge. To address the overlap in measurement of the different cognitive domains, the wide selection of measures used in these studies may be due to personnel factors, time constraints, finances, feasibility, or accessibility; making synthesis of results difficult. Explained variances in which cognitive domain is being measured (e.g., executive function, language, learning, or memory) would help researchers standardize measurement, facilitate comparisons, draw conclusions, make recommendations for future research, and aid with translation to practice. In addition to providing information on the cognitive domains being tested, ensuring the measures are valid and reliable is important in older adult populations, and that they are sensitive to change are important factors to consider when selecting outcome measures.

Clinical implications

Health care professionals play an important role in recommending and facilitating activities to promote healthy lifestyles in older adults. One important component of a healthy lifestyle is regular exercise. Based on this review, Tai Chi displays the potential to maintain or improve function in several cognitive domains. Consequently, translation of these research findings to practice can include promoting Tai Chi classes that incorporate components found in these studies, including emphasis on the “active ingredients” that engage the mind such as memorization of the postures, concentration, imagery, meditation, and breathing. The exercise dose can be optimized through sessions that meet regularly (e.g., twice weekly for at least 1 h) in order to have a positive impact on attention and memory. By participating in regular exercise, particularly one that enriches both the body and the mind, older adults can maintain or improve cognitive function and ultimately sustain independence, decrease health care costs, and improve quality of life.

Conclusion

As the population of the United States ages, activities to maintain physical and cognitive function will be increasingly important to improve functional ability and positively impact health-related quality of life. Promotion of an age-appropriate, easily accessible, and socially engaging activity such as Tai Chi may help toward this goal. Well-designed quantitative and qualitative studies with clearly described methodology across broad populations of older adults are needed to contribute to the beneficial evidence of this centuries-old form of mind-body exercise.

References

APPENDIX D

THE ASSOCIATION OF PHYSICAL ACTIVITY, EXERCISE, COGNITIVE PROCESSES AND AUTOMOBILE DRIVING ABILITY IN OLDER ADULTS: A REVIEW OF THE LITERATURE
Permissions email from Sage Publications for Manuscript #2 under review, received October 2, 2015.

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The Association of Physical Activity, Exercise, Cognitive Processes and Automobile Driving Ability in Older Adults: A Review of the Literature

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Abstract
As the numbers of older adults in the United States grow, the number of automobile drivers over the age of 65 will also increase. Several cognitive processes necessary for automobile driving are vulnerable to age-related decline. These include declines in speed of information processing, reaction time, divided attention, and executive function. The benefits of physical activity or exercise on physical, psychological and particular cognitive processes are well-documented; however few studies have explored the relationship between physical activity or exercise and driving ability in older adults and if this relationship is mediated (or moderated) by specific cognitive processes. The purpose of this paper is to review the existing literature regarding physical activity or exercise, cognition and automobile driving. Recommendations for further research and utility of the findings to the healthcare team are provided.

Keywords: Automobile driving, Cognition, Exercise, Physical activity, Speed of processing, Older adults
The Association of Physical Activity, Exercise, Cognitive Processes and Automobile Driving Ability in Older Adults: A Review of the Literature

Aging population, aging drivers

The population of the world is aging and in the United States the number of adults aged 65 and over will almost double to nearly 60 million by 2030 (Administration on Aging, 2010). Accompanying this population surge will be an increase in older drivers representing approximately 33 million drivers aged 65 and over with a continued expected increase in the next several decades (Centers for Disease Control and Prevention, 2011). Due to lifelong driving habits, the growth of suburbs, and lack of public transportation options, many older adults will continue to rely on private automobiles to maintain social contacts, access healthcare, and remain independent. The ability to drive promotes ‘community mobility’ and is an instrumental activity of daily living (IADL) (Bonder & Bello-Haas, 2008; Wieland, 2013).

Age-related changes in cognitive processes can impact driving ability, lead to driving cessation, or increase the risk of automobile crashes. In addition to morbidity and mortality from crashes, loss of driving ability can lead to isolation, depression and functional decline (National Academy on an Aging Society, 2005). One avenue to maintain physical and cognitive health and promote IADL independence is through physical activity and exercise (Centers for Disease Control and Prevention, 2014a). However, adults aged 65 and older are the least physically active age group in the United States with only 12% meeting the requirement of at least 150 minutes of moderate-intensity aerobic activity and muscle-strengthening activities two or more days per week (Centers for Disease Control and Prevention, 2014b).
Cognitive Processes Associated with Driving Ability

Driving is a complex and dynamic activity requiring several cognitive processes to perform safely. These cognitive processes include selective and divided attention, recognition of pertinent cues, inhibition of habitual responses, storage, retrieval and processing of information, and working memory. Importantly, executive functions, or the ability to inhibit distractions, update information, and shift attention from one task to another are particularly associated with driving outcomes (Anstey, Wood, Lord, & Walker, 2005; Rizzo, 2011; Trick, L. M., Enns, J. T., Mills, J., & Vavrik, J., 2004). Working memory, that is, the ability to hold information while updating from both stored information and incoming information is sometimes considered separately from executive function (Strauss, Sherman, & Spreen, 2006) and is crucial for safe driving (Anstey, Horswill, Wood, & Hatherly, 2012). In summary, the ability to appropriately receive, store, interpret and respond to ever-changing driving stimuli requires several cognitive processes (Rizzo, 2011), all of which can be negatively affected by age-related decline, leading to driving cessation or increased crash risk.

Age-related Changes in Specific Cognitive Processes

Although there is variability in age-associated cognitive decline, there is general agreement regarding cognitive processes affected by aging, with some showing decline even in early adulthood (Baltes & Baltes, 1993; Deary et al., 2009; Glisky, 2007; Salthouse, 2009). While some cognitive processes such as procedural memory and language remain stable throughout the lifespan, executive function, attention, working memory, and speed of information processing often decline. This decline is especially seen in adults aged 65 and older.
Executive function is comprised of several complex and overlapping processes responsible for problem-solving, decision-making, monitoring actions, and evaluating the effectiveness of actions. Executive function can been viewed as three individual processes including 1) the ability to shift between tasks, 2) monitoring incoming stimuli while updating current information, and 3) deliberate inhibition of automatic responses (Strauss, Sherman, & Spreen, 2006). Working memory is the ability to retain and manipulate information over a short period of time (Strauss, Sherman, & Spreen, 2006). Working memory allocates attentional resources to maintain information for retrieval, avoid distraction, and suppress competing information or interference (Engle, 2002). Attention is the ability to focus and filter relevant from irrelevant stimuli, and can be selective (focused on relevant information), divided (processing information from multiple sources), or sustained (vigilance over time) (Strauss, Sherman, & Spreen, 2006). Speed of information processing includes a cognitive and physical component (reaction time) in response to stimuli (Drag & Bieliauskas, 2010).

**Impact of Age-related Cognitive Decline on Driving Ability**

The above-mentioned cognitive processes decline with age and are necessary during both routine and unanticipated driving situations. Executive function and working memory are needed to respond to novel driving circumstances, and to anticipate, plan and follow through on situations requiring judgment and decision-making. Examples include yielding the right-of-way, turning across traffic lanes, or merging with traffic (Insurance Institute for Highway Safety, 2014; National Highway Traffic Safety Administration, 2014). Driving also requires attentional processes including inhibition of distractions, constant surveillance of other road users, awareness of changing road conditions, and vigilance to detect and respond to real or potential
hazards. Selective attention enables drivers to preferentially attend to relevant stimuli, for example, negotiating intersections while ignoring visual clutter (Rizzo, 2011). Divided attention allows drivers to maintain awareness of in-vehicle alerts, for example initiating and terminating turn indicators, or noticing and responding to dashboard icons while simultaneously keeping track of other road users. Speed of information processing is important for integration and interpretation of perceptual stimuli including visual, auditory, and haptic input to plan and execute driving decisions. When these driving abilities decline due to age-related changes, older adults are at higher risk for crashes, and due to increased frailty and comorbidities are therefore at increased risk for serious injury and death (Centers for Disease Control and Prevention, 2011).

**Strategies to Increase Safe Driving**

Strategies to increase the safety of older adult drivers include providing driver safety information, adapting and compensating for physical and perceptual changes affecting driving, and self-regulation of driving habits (Marmeleira, Godinho, & Vogelaere, 2009). For example, safety information provided through senior driving classes, informational brochures, and websites can assist older drivers to assess their driving habits and increase their knowledge of safe driving techniques (Automobile Association of America, 2013; Foundation for Traffic Safety, 2014). Compensation for some physical and perceptual changes can be accomplished by fitting and adapting vehicles through use of equipment such as brake extenders and wide-angle mirrors (CarFit, 2013). Lastly, many older adults self-regulate their driving habits such as not driving during peak traffic times or driving only during daylight hours (Ackerman et al., 2011; Pickard, Tan, Morrow-Howell, & Jung, 2009). However, while education, compensation, and self-regulation may be helpful to increase safety, they do not directly impact the cognitive
processes necessary for driving ability. Physical activity and exercise, with the beneficial effects on cognitive and physical function, may be strategies to improve driving ability in older adults.

**Physical Activity and Exercise**

Although the terms physical activity and exercise are often used interchangeably, they are distinct from one another (Caspersen, Powell, & Christenson, 1985). Physical activity is defined as “any bodily movement produced by skeletal muscles that requires energy expenditure” (World Health Organization, 2015). Examples of physical activity include gardening, taking the stairs rather than the elevator, and raking leaves. Exercise is a subcategory of physical activity that is planned, structured, and repetitive with the goal of maintaining or improving physical fitness (World Health Organization, 2015). Both physical activity and exercise are classified using *metabolic equivalents of task* (METs) defined as the energy expended by the individual (Ainsworth et al., 2011; Caspersen, Powell, & Christenson, 1985). For example, home activities such as cleaning and sweeping have low MET values of 2.3-3.8, brisk walking is 3-6 METs, and high-impact activities such as aerobic dance are greater than 6 METs.

Both physical activity and exercise benefit physical well-being of older adults including improved aerobic endurance, lowered blood pressure, strengthened musculoskeletal system, improved ability to complete activities of daily living, and fall reduction. Physical activity and exercise also have psychological benefits including improved mental health and mood (Agency for Healthcare Research and Quality, 2012; Centers for Disease Control and Prevention, 2011). Additionally, there is a growing body of evidence on the benefits of physical activity and exercise on cognitive function.
The Effect of Physical Activity and Exercise on Cognitive Function

Physical activity and exercise benefit cognitive function in all age groups (Agency for Healthcare Research and Quality, 2012; Carvahlo, Rea, Parimon & Cusack, 2014) based on evidence that the brain creates new neural pathways and networks in all stages of life (Willis, Schaie, & Martin, 2009). Changes in structure and function related to physical activity and exercise include increased cerebral blood flow, new neuron growth, synaptogenesis, and increased brain volume, specifically in the prefrontal, temporal, and parietal regions (Colcombe et al., 2006; Kramer & Erickson, 2007; Lista & Sorrentino, 2010). Aerobic exercise promotes “selective improvement” of the frontal lobes, the area of the brain responsible for executive function (Kramer, et al., 1999). In a review of three meta-analyses on the effect of exercise on cognitive function, significant improvement in executive function, working memory, attention, speeded tasks, spatial processing, and tasks requiring inhibition of automatic responses were reported in exercise groups (Kramer & Erickson, 2007).

These cognitive processes are particularly important for driving ability as evidenced by a growing body of literature. Processing speed, attention, speeded executive tasks, and working memory were strongly associated with measures predictive of crash risk and unsafe on-road driving performance (Anstey et al., 2012). Similarly, a composite of cognitive measures which included speeded tasks and working memory were predictive of driving errors during on-road driving assessments (Dawson, et al., 2010) and speeded tasks and recall were also part of a multivariate model predictive of driving outcomes including driving cessation, moving violations, and crash risk (Emerson, et al., 2012). Lastly, declines in processing speed, attention, and executive function were associated with accidents and moving violations during simulated
driving performance (Park et al., 2011). In summary, several specific cognitive processes are critical for driving ability. These same cognitive processes are improved by physical activity and exercise. Therefore, a review of the existing scientific literature was conducted to examine the association between physical activity, exercise, specific cognitive processes, and automobile driving ability among community-dwelling older adults.

Methods

An electronic search was conducted in CINAHL, Embase, ProQuest Dissertation library, PsycINFO, PubMed, and Web of Science using the keywords physical activity or exercise, cognition, and automobile driving or driving. The search was restricted to English language, articles published between 1994-2014, and adults aged 55 and older. Full-text articles were retained for review if outcomes reflected established indicators of driving ability including simulated or on-road driving assessments, measures of speed of processing or attention, and/or investigator-administered verbal or paper-and-pencil tests of cognitive function associated with driving ability. For randomized controlled trials (RCTs), studies were included if an exercise intervention was conducted; or, in the observational studies, if either exercise or physical activity were measured by self-report, surveys or interviews. Exclusion criteria included studies that (1) focused on participants with specific diseases or conditions (such as stroke or dementia), (2) articles focused on other driving issues (such as driving cessation), (3) only subjective outcomes measurements were studied or (4) the intervention was non-physical (such as cognitive training). Data extracted from these studies included the study design, sample characteristics, exercise intervention or self-reported physical activity, outcome measures specifically associated with driving ability, and findings.
Study Quality

Study quality was assessed using the Quality Index checklist developed by Downs & Black (1998). The Quality Index checklist is widely used with established psychometric properties for determining the methodological quality of both RCTs and non-randomized studies (Downs & Black 1998; Viswanathan, M., et al., 2012). The Quality Index checklist contains 27 items, examining five content areas of reported research. These areas include: 1. reporting (10 items), 2. external validity (3 items), 3. bias (7 items), 4. confounding (6 items), and 5. power (1 item). All items are scored either a 1 (yes) or 0 (no or unable to determine), except for one item pertaining to distributions of potential confounders (yes=2, partial=1, no=0) and the single item on power which is scored from 0-5 (i.e. sample size required for clinically and statistically significant results). Possible scores range from 0-32. Two authors (S.M. and R.T-P.) independently assessed the studies using the Downs & Black (1998) Quality Index checklist. Discrepancies in scores were rechecked and consensus achieved by discussion.

Results

The search of six databases yielded 54 articles for screening for potential inclusion (Figure). One additional article was identified from the reference list of one article meeting the inclusion criteria. Five articles and one dissertation were retained for this review. Although several measures of physical function were also reported in two of the studies (Chattha, 2010; Marmeleira, Godinho, & Fernandes, 2009), only information about physical activity or exercise, cognitive function, and driving measures were reviewed.
Studies identified through database searching (n = 54)

Additional studies identified through reference lists (n = 1)

Studies after duplicates removed (n = 44)

Studies excluded based on title or abstract (n = 10)

Studies screened for inclusion (n = 34)

Studies excluded (n = 28):
- Disease-based (n=5)
- Not cognition (n=1)
- Not driving outcome (n=8)
- Not physical activity or exercise (n=12)
- Reviews (n=2)

Studies included in final review (n = 6)

Figure. Literature review flow diagram
**Study designs and sample characteristics.** Study designs included RCTs (n=3) and observational studies (n=3) (Table 1). The RCTs used different exercise interventions including aerobic, stretching and toning, and combinations of exercise with reaction time tasks (described further under *Exercise Interventions*), and compared intervention groups to non-exercise control groups. The observational studies measured physical activity and exercise through self-report (described further under *Physical activity and exercise self-report*). One observational study compared two exercise types (tennis and running) and non-exercisers (Marmeleira, Melo, Tlemcani, & Fernandes, 2013).
<table>
<thead>
<tr>
<th>First Author/Year/Quality Index</th>
<th>Sample: Age Mean (SD)</th>
<th>Exercise Intervention/ Duration or Self-Report</th>
<th>Outcome Measures</th>
<th>Findings</th>
<th>Summary of Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chattha, 2010 Quality Index:19</td>
<td>n=29</td>
<td>Intervention</td>
<td>Simulated driving</td>
<td>Simulated driving</td>
<td>Improved</td>
</tr>
<tr>
<td></td>
<td>Intervention n=13</td>
<td>Aerobic (brisk walking): 30-40 min</td>
<td>Two summary scores: number of collisions and number of non-collision errors in 3 driving situations (rural highway, parking lot, construction zone)</td>
<td>Control group committed less non-collision errors during rural highway situation than Intervention group: F(1,11)=14.207, p=.003, partial eta squared=.564, observed power .428</td>
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<tr>
<td></td>
<td>Gender NA</td>
<td>63.08(7.81)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Control n=16</td>
<td>Flexibility (stretches): 4 reps</td>
<td>Computer</td>
<td>Computer</td>
<td>Improved</td>
</tr>
<tr>
<td></td>
<td>Gender NA</td>
<td>62.81(6.12)</td>
<td>Three summary scores: Subtest 1 (speed of processing); Subtest 2 (divided attention); Subtest 3 (selective attention)</td>
<td>Between-group difference in summary UFOV score: F(1,21) = 5.70, p = .027, partial eta squared = .213, observed power = .624</td>
<td></td>
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<tr>
<td></td>
<td>All participants:</td>
<td>Strength training (presses, curls): 1-3 sets/10-15 reps</td>
<td></td>
<td></td>
<td>Improved</td>
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<tr>
<td></td>
<td>F:79%</td>
<td>3x week x12 weeks</td>
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<tr>
<td></td>
<td></td>
<td>Control Wait-listed (not included in intervention analysis)</td>
<td></td>
<td></td>
<td>Improved</td>
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Mean driving risk level in | Improved
Table 1. Summary of Physical Activity, Exercise, Cognitive Processes, and Driving-Related Outcome Measures

<table>
<thead>
<tr>
<th>First Author/Year/Quality Index</th>
<th>Sample: Age Mean (SD) % Female</th>
<th>Exercise Intervention/Duration or Self-Report</th>
<th>Outcome Measures</th>
<th>Findings</th>
<th>Summary of Findings</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td>Verbal/Paper-Pencil Tests</td>
<td>Intervention Group measured by UFOV remained ‘very low’ after 12 weeks while Control Group showed increase in risk, from ‘very low’ to ‘low’</td>
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<td></td>
<td></td>
<td></td>
<td>SCWT TMT-B</td>
<td>Verbal/Paper-Pencil Tests NSS</td>
<td>No change</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>First Author/Year/Quality Index</th>
<th>Sample: Age Mean (SD) % Female</th>
<th>Exercise Intervention/ Duration or Self-Report</th>
<th>Outcome Measures</th>
<th>Findings</th>
<th>Summary of Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marmeleira, (2009) Quality Index:20</td>
<td>n=32</td>
<td>Intervention</td>
<td>Simulated driving</td>
<td>Improved</td>
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<tr>
<td></td>
<td></td>
<td>Intervention</td>
<td>Reaction Time: Single-task</td>
<td>Simulated driving</td>
<td>Improverd</td>
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<tr>
<td></td>
<td></td>
<td>n=16</td>
<td>Simple RT (accelerator and brake, Movement time)</td>
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<tr>
<td></td>
<td></td>
<td>Age: 68.2(6.5) F:25%</td>
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<td></td>
<td></td>
<td>MMSE 28.6(1.1)</td>
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<tr>
<td></td>
<td></td>
<td>Control</td>
<td>Choice RT (two and three simultaneous stimuli)</td>
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<tr>
<td></td>
<td></td>
<td>n=16</td>
<td></td>
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<td></td>
<td></td>
<td>Age: 68.4(6.7) F:18%</td>
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<td></td>
<td></td>
<td>MMSE 28.4(1.5)</td>
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<tr>
<td></td>
<td></td>
<td>Intervention</td>
<td>Dual-task (Simple RT plus mental summing task)</td>
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<tr>
<td></td>
<td></td>
<td>Aerobic, dual-task, use of peripheral vision, memorization of specific walking course, responding to auditory cues, response inhibition</td>
<td>Dual-task</td>
<td>Improved</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60 min 3x week x12 weeks</td>
<td>Within-group improvement: Reaction time (-11%, p=.001), Movement time (-16%, p=.001), Response time (-13%, p&lt; .001)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Control “Normal daily activities”</td>
<td>Between-group difference: Reaction time (-11% vs. 1%; p=.018), Response time (-13% vs. -2%, p=.018)</td>
<td>Improved</td>
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</table>
Table 1. Summary of Physical Activity, Exercise, Cognitive Processes, and Driving-Related Outcome Measures

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<th>Summary of Findings</th>
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<tr>
<td></td>
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<td></td>
<td>motion tasks</td>
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<td></td>
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<td>Computer: UFOV</td>
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<td></td>
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<td></td>
<td>Subtest 1 (speed of processing; Subtest 2 (divided attention); Subtest 3 (selective attention)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>No difference within or between groups</td>
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<td></td>
<td></td>
<td></td>
<td>Computer: UFOV</td>
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<td></td>
<td></td>
<td></td>
<td>Within-group improvement: Speed of processing (-66%, <em>p</em> = .004), Divided attention (-50%, <em>p</em> = .002).</td>
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<td>Between-group difference: Speed of processing (-66% vs. 2%, <em>p</em> = .032)</td>
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<td>Improved</td>
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<td>Verbal/Paper-Pencil Tests</td>
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<td>SCWT TMT-B</td>
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<td>No change</td>
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Table 1. Summary of Physical Activity, Exercise, Cognitive Processes, and Driving-Related Outcome Measures

<table>
<thead>
<tr>
<th>First Author/ Year/ Quality Index</th>
<th>Sample: Age Mean (SD) % Female</th>
<th>Exercise Intervention/ Duration or Self-Report</th>
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<tbody>
<tr>
<td>Marmeleira, (2011) Quality Index:18</td>
<td>n=26</td>
<td>Physical exercise combined with: reaction time, dual-task, peripheral vision, response inhibition, memory of walking course, dynamic group games</td>
<td>On-road driving Reaction Time: Brake RT Peripheral RT Choice RT Dual-task</td>
<td>On-road driving Brake RT Within-group improvement: (-8%, ( p=.008 )) and response time (-7%, ( p=.045 )) Between-group difference: (-8% vs. 3%, ( p=.015 )): ( F(1,24) = 6.91, p=.015, \eta^2=.231 )</td>
<td>Improved</td>
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<td>Intervention n=13 Age: 65.5(6.9) F: 69%</td>
<td>60 min. 3x week x8 weeks</td>
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<td></td>
<td>Control n=13 Age: 63.4(6.7) F:61%</td>
<td>“Normal daily activities”</td>
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<td>Control “Normal daily activities”</td>
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<tbody>
<tr>
<td>Marmeleira (2012) Quality Index:15</td>
<td>n=38 Age: 70.2(5.0) F:42% MMSE ≥27</td>
<td>Physical Activity Self-report IPAQ-SF (seven-day recall)</td>
<td>Driving Difficulties 22-item self-report Computer: UFOV Subtest 1 (speed of processing); Subtest 2 (divided attention); Subtest 3 (selective attention) Verbal/Paper-Pencil Tests BD (WAIS-III); TMT-A and B; TOL; ROCFT-Copy and Recall</td>
<td>$p=.034$, $\eta^2=.181$ Magnitude of differences between groups in pre- to post composite score $F(1,24) = 12.80, p=.002$, $\eta^2=.358$</td>
<td>Improved</td>
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**Observational studies**

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Overall there was statistically No association

Equivocal
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<tr>
<th>First Author/ Year/ Quality Index</th>
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<tbody>
<tr>
<td>Marmeleira, (2013) Quality Index:21</td>
<td>n=36 Tennis players n=12</td>
<td>n=12 Runners</td>
<td>Sport practice self-report Years of sport activity, training sessions per week, competitions per year</td>
<td>On-road driving Brake Reaction Time: Reaction time divided into three phases: Reaction time, Movement Time and Response Time</td>
<td>On-road driving Brake reaction time: Significant between-group difference: Tennis players M=329 msec., SD=45 msec. vs. Control M=398 msec., SD=62 msec., F(2,33) = 4.09, p=.03, ES .15; post hoc analysis: p=.04, Cohen’s d = 1.27, 95% CI [0.36, 2.13]</td>
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|                                         |                                |                                |                                | significant association between physical activity and visual attention (-.48, p<.01; 95% CI [-.68, -.19]), but not executive function, visuospatial ability, or memory | No association |

Verbal/Paper-and-Pencil Tests
NSS association between physical activity and TMT, TOL, ROCFT or BD

No association
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</tr>
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<tbody>
<tr>
<td>Roth (2003) Quality Index:20</td>
<td>n=140 Age: 74.5(5.4) F:56%</td>
<td>Physical Activity Self-report EPQ (frequency, intensity, duration per week)</td>
<td>Computer: UFOV</td>
<td>Computer UFOV Statistically significant correlations between UFOV and EPQ days per week score: (r= -</td>
<td>Positive association</td>
</tr>
<tr>
<td>Control n=12 Age: 64.1(6.3) F:0%“Normal MMSE” (not specified)</td>
<td>62.7(5.7) F:0%</td>
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<tr>
<td></td>
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<td>PASE (seven-day recall)</td>
<td></td>
<td>.24, <em>p</em>&lt;.01, exercise intensity (<em>r</em>= -.17, <em>p</em>&lt;.05), aerobic activity (<em>r</em>= -.19, <em>p</em>&lt;.05) and PASE composite score (<em>r</em>= -.17, <em>p</em>&lt; .05)</td>
<td>Positive association</td>
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<td>When controlled for age, there was a statistically significant association between visual attention and EPQ days per week (<em>r</em>= -.22, <em>p</em>= .01)</td>
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<td></td>
<td>There was a significant effect of increased activity levels on UFOV scores, <em>F</em>(1,134)=6.18, <em>p</em>=.014</td>
<td>Positive association</td>
</tr>
</tbody>
</table>

Note: BD=Block Design; CI=Confidence Interval; EPQ=Exercise Participation Questionnaire; ES=Effect Size; F=Female; IPAQ-SF=International Physical Activity Questionnaire - Short Form; M=Mean; MMSE=Mini-Mental State Exam; msec=milliseconds; min=minutes; NA=Not Applicable/Not Available; NSS=Not statistically significant; PAQ-SF=Physical Activity Scale for the Elderly; Reps=repetitions; ROCFT=Rey-Osterrieth Complex Figure Task; reps=repetitions; RT=Reaction Time; SD=Standard Deviation; SCWT=Stroop Color Word Test; TMT=Trail-Making Test; TOL=Tower of London; UFOV=Useful Field of View; WAIS=Wechsler Adult Intelligence Scale
Outcome measures for the RCTs and observational studies included simulated or on-road driving, computerized measures of speed of processing and attention, and investigator-administered cognitive function tests. Additionally, one observational study measured self-reported driving difficulties.

Demographics from these studies included community-dwelling adults with an age range of 55-95 years, with nearly equal male and female participants. One study specifically included only male participants (Marmeleira, 2013). Five of the studies listed inclusion criteria of normal cognitive status, but only one reported a cut-off score of 27 or higher for the Mini-Mental State Exam (Marmeleira, 2012). Additionally, five studies listed corrected visual acuity as inclusion criteria (Marmeleira, 2009; Marmeleira, 2011; Marmeleira, 2012; Marmeleira, 2013; Roth, 2003). All but one study excluded persons with active cardiac or musculoskeletal conditions (Roth, 2003) and one study excluded individuals with sensory, motor, or language conditions that could interfere with cognitive tests (Marmeleira, 2012). All but one of the studies required participants to hold a valid driver’s license (Roth, 2003).

**Randomized Controlled Trials**

**Exercise interventions.** Exercise interventions included aerobic exercise combined with flexing, toning, and conditioning (Chattha, 2010), and two studies had participants perform physical activities designed to increase cognitive demand and enhance reaction time while simultaneously performing aerobic exercises (Marmeleira et al., 2009; Marmeleira, Soares de Melo, Tlemcani, & Godinho, 2011). Examples of the cognitive demand and reaction time tasks included participants’ memorization of a walking course or selectively catching different colored
balloons when specific auditory cues were given, and walking in different directions while performing specific arm movements. The exercise sessions varied from 30 to 60 minutes, ranged from eight to 12 weeks in duration, conducted three times per week.

**RCT outcome measures.** Driving simulation or on-road driving assessments were used to measure reaction time including simple reaction time, choice reaction time (reacting to more than one stimulus) and reaction time under dual-task conditions (performing two tasks simultaneously (Marmeleira, et al., 2009; Marmeleira, et al., 2011). Driving simulation was also used to assess driving errors in several driving settings (Chattha, 2010). Computer-based assessments using the Useful Field of View test measured speed of processing and attention (Chattha, 2010; Marmeleira, et al., 2009). The Useful Field of View (UFOV) test assesses speed of information processing through computerized measures of visual attention under increasingly complex conditions (Edwards et al., 2006). The UFOV test is composed of four subtests that measure central vision and processing speed (subtest 1), divided attention (subtest 2), selective attention (subtest 3), and a variation on subtest 3 with a more demanding task (subtest 4) (Edwards et al., 2006). The fourth subtest was not used in the studies reviewed. Additionally, a composite score calculated from the administered subtests indicates level of driving risk. Computer-based measures of spatial awareness assessed speed and motion perception (Marmeleira, et al., 2009) and verbal or paper-and-pencil tests, specifically the Stroop Color Word Test and the Trail Making Test - Part B assessed executive function (Chattha, 2010; Marmeleira et al., 2009). (Table 1)

*Simulated driving measures.* Driving simulator technology was used to measure
collision and non-collision errors during three driving situations (rural highway, parking lot, and
construction zone) (Chattha, 2010). After a 12-week combined aerobic, flexibility, and
strengthening intervention, a significant group effect was measured, with significantly less non-
collision rural highway errors committed by the control group. Further analysis revealed that the
intervention group completed the simulated driving scenario more quickly (when compared to
their baseline assessments), possibly leading to more errors (Chattha, 2010).

Reaction time (RT) is dependent on speed of information processing and also has a motor
component, making some results jointly dependent on upper limb mobility, hand dexterity, and
lower extremity control (Ekelman, 2009). Several RT measurements were tested in computerized
simulated driving scenarios after a 12-week aerobic intervention combined with cognitive
demand tasks (described earlier) (Marmeleira et al., 2009). Measurements included braking RT,
RT during a divided visual attention task, choice RT and a dual-task condition of braking while
performing a mental calculation task. Statistically significant changes in single and dual-task RT
within-subjects in the intervention group and between the intervention and control groups were
reported. There were no statistically significant differences in choice RT or time-to-contact
(speed and motion perception).

On-road driving tests measuring RT were conducted using an instrumented vehicle after a
60 minute, three times weekly, eight-week exercise intervention combined with reaction time,
dual-task practice, and response inhibition tasks (Marmeleira et al., 2011). Statistically
significant differences were reported within- and between-groups in braking RT and dual-task
RT. For the peripheral RT, only within-group differences reached statistical significance, and
contrary to earlier results from the same research group, choice RT was statistically significant, with faster reaction times both within- and between-groups.

**Computerized measures.** Two RCTs with similar aerobic exercise interventions measured the effect of exercise on the UFOV (Marmeleira et al., 2009; Chattha, 2010) with statistically significant improvements in one or more UFOV subtests measuring speed of processing, divided attention or selective attention reported. After a 12 week combined aerobic, flexibility, and strengthening intervention a statistically significant between-group difference in UFOV summary scores was measured, as well as a significant between-subjects effect for time in selective attention measured by the UFOV (Chatta, 2010). Speed of processing as measured by the UFOV improved both within-groups and between the intervention and control groups after a 12-week exercise intervention. However, no improvement in divided or selective attention was reported (Marmeleira, 2009).

**Verbal or paper-and-pencil tests.** After 12-week exercise interventions combining aerobic, dual-task, and response inhibition exercises (Marmeleira et al., 2009), and an aerobic, flexibility, and strength training intervention (Chattha, 2010), no significant differences were found between the intervention and control groups in either the Stroop Color Word Test nor the Trail Making Test - Part B (Chattha, 2010; Marmeleira et al., 2009).

**Observational Studies**

**Physical activity and exercise self-report.** The three observational studies (Marmeleira et al., 2012; Marmeleira et al., 2013; Roth et al., 2003) measured the association between self-reported physical activity and/or exercise with several outcome measures associated with driving
including on-road measures of reaction time, the UFOV test, and/or particular paper-and-pencil or investigator-administered cognitive assessments. Additionally, one study measured self-reported driving difficulties (Marmeleira, 2012) (Table 1). Two studies used seven-day recall instruments (Marmeleira et al., 2012; Marmeleira et al., 2013), and one study used an additional questionnaire to distinguish between participants’ self-reported physical activity and exercise habits (Roth et al., 2003).

The International Physical Activity Questionnaire-Short Form (IPAQ-SF) asked participants to recall the past seven days of activity, which was then converted to estimated MET-minutes per week based on time spent walking (estimated at 3.3 METs), engagement in moderate-intensity activity (estimated at 4 METs), vigorous-intensity activity (estimated at 8 METs), and sedentary activity. Participants were then categorized into low, moderate or high levels based on these calculated MET values (Marmeleira et al., 2012). Similarly, Roth et al. (2003) used two instruments, the Exercise Participation Questionnaire (EPQ) and the Physical Activity Scale for the Elderly (PASE), allowing for a distinction to be made between exercise and physical activity. The EPQ measures regular engagement with specific exercise activities and for this questionnaire data were gathered via a phone interview and responses were coded and scored to categorize levels of exercise. Additionally, self-reported occupational, household, and leisure activities via recall of the past seven days using the PASE was reported. A single composite score was then derived from several sources including the PASE, motion sensors worn by the participants, physical activity diaries, and a global assessment of activity (Roth et al., 2003). In contrast to the use of the three validated self-report instruments (the IPAQ-SF, the
EPQ, and the PASE) a study comparing tennis players, runners and non-exercisers (Marmeleira, 2013) described self-reported years of sport practice, training sessions per week, and competitions per year of tennis players and runners. In this study MET values were not calculated. On-road reaction times were compared between the three groups.

In summary, one observational study used two different validated seven-day recall self-report instruments to distinguish between exercise participation and physical activity (Roth, 2003), one study used a validated seven-day recall instrument to quantify exercise intensity (Marmeleira, 2012), and one study reported self-reported participation in exercise, specifically tennis playing and running.

**Observational Studies Outcome Measures**

The outcome measures in the observational studies were similar to those studied in the RCTs and included on-road driving assessments of reaction time, attention, and investigator-administered paper-and-pencil cognitive measures. Additionally, a 22-item questionnaire explored the association between self-reported physical activity habits and self-reported driving difficulties.

**Driving measures.** On-road driving assessment of brake reaction time and response time showed statistically significant differences between tennis players and a sedentary control group (Marmeleira, 2013). However, no statistically significant differences were found between tennis players and runners, or between runners and the sedentary control group. Additionally, no statistically significant differences were reported in peripheral, choice, or dual-task measures between any of the three groups (Table 1).
Self-reported driving difficulties. No statistically significant correlation was measured between self-reported driving difficulties (over the preceding year) and self-reported physical activity (seven-day recall) (Marmeleira et al., 2012) (Table 1). Small sample size (n=38) and the use of self-report for both measures may partly explain the lack of significant correlation, due to biased or distorted reporting (Kazdin, 2003; Spirduso et al., 2007). Additionally, the driving difficulties questionnaire used was compiled from previous driving studies, and instrument validation was not reported.

Computerized Measures. In an observational study measuring self-reported physical activity and exercise, a statistically significant correlation between UFOV summary scores and days per week of exercise, exercise intensity, aerobic exercise and PASE scores was reported (Roth et al., 2003) (Table 1). Similarly, a positive correlation was found between self-reported physical activity intensity and processing speed, and physical activity and divided attention when measured by the UFOV (Marmeleira, 2012). However, no statistically significant correlation was measured between physical activity intensity and selective attention.

Verbal or paper-and-pencil tests. No statistically significant association was found between self-reported amount of physical activity (using seven-day recall) and the Trail Making Test, Tower of London, Rey-Osterrieth Complex Figure Test-Copy and Recall or Block Design (Marmeleira et al., 2012). These non-statistically significant results could be due to small sample size (n=38), inadequate exercise dose (frequency, duration, and intensity of exercise), or inaccurate exercise or physical activity self-reporting.
Discussion

Prior literature has established the benefit of physical activity and exercise on cognitive function in older adults (Colcombe et al., 2006; Kramer & Erickson, 2007). Also, there is evidence regarding the association between specific cognitive processes and driving ability (Anstey, Wood, Lord, & Walker, 2005; Rizzo, 2011; Trick, L. M., Enns, J. T., Mills, J., & Vavrik, J., 2004). This review examined physical activity, exercise, specific cognitive processes, and driving ability in older adults in RCTs and observational studies. Although comparing results from RCTs and observational studies is challenging, statistically significant improvements were found in several areas including simulated and on-road driving performance, measures of reaction time, visual processing speed, and attention.

The three RCTs used varying types, frequencies, and durations of exercise interventions making comparison of exercise dose difficult. For example, aerobic exercise was combined with tasks designed to increase cognitive demands including reaction time, dual-task, and memory exercises (Marmeleira et al., 2009; Marmeleira et al., 2011), and one RCT combined aerobic exercise with flexibility and conditioning activities (Chattha, 2010). These diverse exercise regimes may differentially impact cognitive and physical function making the mechanism of action of improvement difficult to explain. Although variability in the exercise interventions existed, the interventions were well-described, leading to increased reproducibility and the possibility of future intervention studies.

The observational studies measured the association between several self-report instruments including self-reported exercise and physical activity habits and self-reported driving
difficulty. Although the studies attempted to quantify actual amount of physical activity or exercise, comparison between the studies is difficult due to the use of different instruments, categorization methods, and quantification of exercise intensity. Additionally, the accuracy of self-reported measures of exercise may be unreliable, due to potential recall bias (Spirduso, Poon, & Chodzko-Zajko, 2007) or the risk of distortion due to social desirability or self-interest (Kazdin, 2003). For example, reporting more frequent or vigorous exercise habits is more socially desirable than reporting inactivity. In addition to self-report, objective measures in the observational studies also included computerized measures of attention and processing speed, verbal and paper-and-pencil tests associated with driving ability, and on-road driving performance.

A variety of reaction time measures were reported in both the RCTs and observational studies including simple, choice, dual-task measures, with statistically significant improvements reported whether reaction time was measured during driving simulation (Marmeleira et al., 2009) or on-road driving tests (Marmeleira et al., 2011). Because reaction time is composed of cognitive processes (acknowledging the stimuli) and motor capability (responding physically) (Ekelman, 2009), the improved performance could be due to better function in either cognitive or physical function, or a combination of the two.

Speed of processing, divided attention, and/or selective attention were significantly improved when measured by the UFOV test in RCTs and observational studies (Marmeleira et al., 2012; Marmeleira et al., 2009; Roth et al., 2003). However, results must be interpreted with caution due to the variability in exercise interventions used in the RCTs, some of which tested
interventions combining exercise and cognitively demanding dual-task activities, response inhibition tasks, or flexibility and strength components. Also, as previously identified, the use of self-report to measure physical activity participation and intensity in the observational studies may be inaccurate.

In contrast to the improvement in reaction time tests and UFOV tests measuring visual processing speed and attention, no statistically significant differences were demonstrated in a variety of verbal or paper-and-pencil tests. This is inconsistent with other research on exercise and cognitive function (Kramer et al., 2007) and may be partially due to small sample sizes (Chattha, 2010; Marmeleira et al., 2009; Marmeleira, 2012) (n=29, n=32, and n=38, respectively), the type of cognitive measures included, and the use of self-report measures of physical activity (Marmeleira et al., 2012). These varying results could be due to lack of sensitivity to change in the instruments used, or a disconnect between the cognitive processes assessed and driving ability, as in the case of the paper-and-pencil tests, or could be due to the positive effect of exercise on the motor component of the reaction time tests. Finally, the lack of statistically significant associations between self-reported physical activity and self-reported driving difficulties (Marmeleira et al., 2012) could be due to inaccurate self-report of physical activity or exercise habits, and the use of a non-validated driving difficulties reporting instrument.

The studies in this review primarily focused on older adult drivers without active cardiovascular or musculoskeletal conditions, those with intact cognitive function, and those whose visual acuity was at least 20/40. Limiting study inclusion to participants able to engage in
an exercise intervention is reasonable. However, with the exception of visual acuity tests, health conditions, including cognitive function, are not routinely assessed during initial licensing or renewal, with the exception of certain reportable conditions (such as seizure disorders), if there is a history of crashes or moving violations, or if the person’s fitness to drive is in doubt at the time of renewal (Insurance Institute for Highway Safety, 2014; National Highway Traffic Safety Administration, 2013). Therefore, the findings from this review cannot be generalized to older adult drivers with active or unstable health issues, undiagnosed or mild cognitive impairment, or poorer vision – conditions which do not necessarily preclude driving (Carr, Flood, Steger-May, Schechtman & Binder, 2006; Tuokko, Rhodes, & Dean, 2007; Wadley, et al., 2009).

Future research exploring the effect of physical activity or exercise on cognitive function related to driving ability would be strengthened by a consensus regarding specific cognitive processes to measure, selection of measures sensitive to change according to the length and type of intervention, and longitudinal studies examining long-term exercise interventions. Clear descriptions and quantification of exercise dose are needed (Spirduso et al., 2007) as are larger sample sizes, additional RCTs, and objective measures of physical activity such as accelerometer technology. Once additional well-designed objective and adequately powered RCTs from diverse research groups are available a meta-analysis would provide stronger evidence or suggest new directions for research.

Additionally, potential mediators such as sleep, energy, diseases and conditions, and mental and emotional states could be explored and potential moderators such as gender and education (Spirduso et al., 2007) could be controlled for or examined in larger, randomized trials.
Advances in understanding the influence of these variables could help guide future interventions and research.

**Conclusion**

To our knowledge, this is the first review examining the association of physical activity or exercise, cognitive processes and driving ability in older adults. Limitations to this review include the paucity of research studies obtained through the search, with four studies conducted by the same research team. Additionally, small sample sizes and the lack of reported effect sizes in the majority of the studies limits interpretation of the findings. However, the existing evidence in the physical activity and exercise research literature coupled with the need for strategies to address the growing older adult driver population make exploration of this topic timely and essential.

As the population of older adult drivers continues to grow, strategies to address driving ability will be needed to maintain safety and independence. Healthcare providers who interact with older adult drivers across the care continuum are positioned to advise and consult regarding the benefits of exercise on overall health, and on driving ability in particular. Interdisciplinary team members including primary care providers, nurses, rehabilitation therapists, and senior advocacy organizations can identify older adults who would benefit from an exercise intervention. Through these networks, the healthcare team can encourage and facilitate exercise options to meet individuals’ lifestyles to promote safety and maintain independence.
References


APPENDIX E

TAI CHI EXERCISE AND SAFE DRIVING PERFORMANCE IN OLDER ADULTS: AN
OBSERVATIONAL STUDY
Tai Chi Exercise and Safe Driving Performance in Older Adults:

An Observational Study

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Abstract

**Objective:** Age-related cognitive and physical decline impair safe driving performance (SDP). Tai Chi exercise (TCE) benefits cognitive and physical function and may influence SDP. The aims of this observational study were to 1) examine relationships between TCE habits, cognitive processes and physical function related to SDP, 2) compare cognitive processes and physical function related to SDP to normative reference values, and 3) explore potential predictors of SDP. **Method:** The DrivingHealth Inventory™, the Driving Scenes Test (DST), and other driving-related measures were collected from TCE practitioners ≥65 years (N=58; median > 3 years practice). **Results:** Several measures were significantly correlated (r=.26 to .50). Participants performed better in numerous measures compared to normative reference values, with small-to-large effect sizes. Digit span backward was the strongest predictor of SDP, accounting for 11% of the variability in DST. **Discussion:** TCE is associated with cognitive processes and physical function related to SDP.

**Indexing keywords:** Tai Chi, exercise, physical activity, automobile driving, older adults
Tai Chi Exercise and Safe Driving Performance in Older Adults: 
An Observational Study

Introduction

In 2009 there were 33 million licensed drivers over the age of 65 in the United States. As the population continues to age, this number is expected to nearly double to approximately 60 million older adult licensed drivers by 2030 (Centers for Disease Control and Prevention, [CDC] 2011a; National Highway Traffic Safety Administration, 2013). Many older adults prefer private vehicles for transportation due to lifelong driving habits, the lack of public transportation options due to growth of suburbs, and the desire to maintain independence (American Association of Retired Persons, 2010). Driving individual automobiles is a necessary and often critical mode of transportation (Burkhardt, 2000), which has been termed a ‘global instrumental activity of daily living’ necessary for carrying out other essential activities such as shopping, accessing medical care, and engaging in social interactions (Wieland, 2013).

Safe driving performance is a complex and integrated process of attention, memory, decision-making, and planning, along with the physical ability to respond and adjust to ever-changing driving conditions. However, common age-related changes in cognitive processes and physical function can impact safe driving performance. Declines in executive function, that is, those cognitive processes necessary for attentional capacity, information processing, working memory, judgment, inhibition of responses, and increased distraction, can impair appropriate monitoring of, and reaction to the driving environment (Anstey et al., 2012; Dawson at al., 2010; Emerson et al., 2012; Park et al., 2011). Declines in motor control, strength, flexibility, and health-related symptoms such as stiffness, pain, and fatigue can affect the ability to carry out
planned actions (Ekelman, Stav, Baker, O'Dell-Rossi, & Mitchell, 2009; Tuokko, Rhodes, & Dean, 2007). The combined age-related cognitive and physical changes can impact safe driving performance leading to premature or precipitous driving cessation and loss of independence, social isolation, depression, and reduced quality of life (Harrison & Ragland, 2003; Marottoli et al., 2000).

Although older adult drivers drive less miles annually than their younger counterparts, the miles driven are often conducted in city driving, increasing cognitive demand for navigating traffic, and interacting with other road users, thereby increasing the risk for of crashes. When older adults are involved in crashes they are at heightened risk of injury and death due to comorbidities and frailty. In addition to the individual impact of being involved in a crash, significant economic and societal implications also exist: the total lifetime costs of fatal and nonfatal injuries for adults 65 and older accounted for over $2 billion of the $70 billion cost among drivers or passengers of all ages (Naumann, Dellinger, Zaloshnja, Lawrence, & Miller, 2010).

Current methods to improve safe driving performance include driver education programs to increase self-awareness and safety information from organizations such as the Safety Foundation of the Automobile Association of America (Marmoleira, Godinho, & Vogelaere, 2009). However, while these programs are valuable for educating drivers, raising awareness of driving habits, and helping drivers compensate for deficits; they do not influence the underlying decline in cognitive processes and physical function impacting safe driving performance.

One less-explored intervention with positive effects on driving-related cognitive measures is physical activity and exercise. Traditional forms of exercise such as brisk walking,
Flexion and strengthening exercises show promise for improving cognitive processes and physical function related to driving (Marmeleira, Godinho, & Vogelaere, 2009; Miller, Taylor-Piliae, & Insel, 2015). The proposed mechanisms of action of physical activity and exercise are increased neuroelectric activity, preservation of brain volume, increased cerebral blood volume, enhanced factors responsible for growth and function of neurons, heightened synaptic activity, and angiogenesis (Ratey & Loehr, 2011). These structural and functional changes are evidence of neural plasticity and are consistent with lifespan development theory and the ability of continued growth and development in older adults, regardless of advancing age and common age-related changes (Willis, Shaie, & Martin, 2009).

Another form of exercise, Tai Chi, has become increasingly popular in the United States and is offered at many fitness and wellness centers serving older adults. Tai Chi is considered a moderate aerobic exercise similar to brisk walking with recognized cognitive and physical benefits (Compendium of Physical Activities, 2015; NCCIH, 2015; Miller & Taylor-Piliae, 2014; Wayne, 2013). Tai Chi is performed with slow, choreographed movements, mental concentration, attention to balance, and meditative breathing. Because it is a gentle form of exercise with low impact on joints, Tai Chi has been endorsed as an appropriate form of exercise for older adults, and for chronic disease management (Chodzko-Zajko et al., 2009; NCCIH, 2015). Eight “active ingredients” (Wayne, 2013, p. 29) have been proposed as essential elements of Tai Chi practice and include 1) awareness, 2) intention, 3) structural integration, 4) active relaxation, 5) strengthening and flexibility, 6) natural, freer breathing, 7) social support, and 8) embodied spirituality. These distinct cognitive and physical components, interactions, and complexities distinguish Tai Chi exercise from traditional forms of aerobic exercise.
While there is substantial evidence regarding the cognitive and physical benefits of Tai Chi exercise, including improved mood, sleep, cognitive function, balance, decreased falls, and aerobic capacity (Chang, Nien et al. 2010; Li et al. 2004; Taylor-Piliea, Haskell, Waters, & Froelicher, 2006; Taylor-Piliea, 2008; Wayne et al., 2014) to our knowledge, the association between Tai Chi exercise and safe driving performance has not been explored. Thus, the aims of this study among older adult Tai Chi practitioners were to 1) examine relationships between Tai Chi exercise habits, cognitive processes and physical function related to safe driving performance, mindfulness, and overall perceptions of wellness, 2) compare cognitive processes and physical function related to safe driving performance to normative reference values for adults aged 65 and older, and 3) explore potential predictors of safe driving performance.

Methods

Study Design

An observational study design was used to measure cognitive processes and physical function associated with safe driving performance among older adult Tai Chi practitioners. Norm-referenced values from the Model Driver Screening and Evaluation Program (National Highway Traffic Safety Administration, 1999; National Highway Traffic Safety Administration, 2003; National Highway Traffic Safety Administration, 2012), other driving-related research (Brown et al., 2005), cognitive aging studies (Bopp & Verhaeghen, 2005), and self-report measures of mindfulness (Brown & Ryan, 2003), and overall well-being (Myers et al. 1999) were used to compare study participants’ performance relative to established values.
Setting and Sample

A purposive sample of community-dwelling adults aged 65 and over was recruited from Tai Chi classes and Tai Chi events in the Middle Tennessee area. Recruitment strategies included face-to-face personal contact with Tai Chi instructors and students and obtaining permission to recruit from organizations where Tai Chi classes were held. Recruitment sites included but were not limited to adult fitness programs, parks and recreation departments, the YMCA organization, local wellness centers, and local Tai Chi events. In addition, “snowball sampling” methods (Trochim, 2012) were used to identify other potentially eligible Tai Chi practitioners, particularly those not currently involved in organized Tai Chi classes or attending group practice.

Recruitment, enrollment, and data collection occurred between September 2014 and June 2015.

Participants and eligibility criteria. The goal of the recruitment strategy was to accurately represent older adult Tai Chi practitioners from the community setting. Eligibility criteria for the study included persons aged 65 years or older at the time of data collection, the ability to speak, understand, and read English, having received formal instruction in Tai Chi (e.g. not self-taught), having practiced Tai Chi for at least three months, currently practicing Tai Chi either independently and/or in group sessions for at least 30 minute each week, and the ability to transport themselves to the study site. Persons with unstable medical conditions or those who had used a computerized driving assessment program within the past year were ineligible to participate in the study.

Study sample size. Prior meta-analyses on the effects of Tai Chi on cognitive and physical function have reported small-to-large effect sizes (Park & Song, 2013; Taylor-Piliae, 2008; Wayne et al., 2014; Wu, Wang, Burgess, & Wu, 2013). Therefore, a medium effect size
was used to calculate sample size. Power calculation (two-tailed test, alpha = .05, power = .80, effect size .40) yielded a sample size of 52 participants needed to detect a difference between the study group and the normative reference value (G*Power, 2013). Due to the possibility of attrition an additional six participants were enrolled for a final sample size of 58.

**Informed Consent.**

The study was approved by the Institutional Review Boards of The University of Arizona and Vanderbilt University. Written informed consent was obtained from each participant. Participants were assured that the results of their individual performance would remain confidential.

**Benefits and Compensation.**

Participants received a personalized DrivingHealth Inventory™ and individual results of other measures associated with safe driving performance, a list of local Tai Chi offerings, and two brochures from the Automobile Association of America (AAA) Foundation for Traffic Safety (*The Older And Wiser Driver*, and *Drivers 65 Plus: Check Your Performance*) (AAA Foundation for Traffic Safety, 2014).

**Study Procedures**

**Recruitment, enrollment, and data collection.** At each recruitment site a study overview was verbally provided to potential participants. Interested persons were invited to complete the initial screening. After initial screening eligible persons received a study packet and consents, and arrangements for study appointments were made. To decrease the risk of attrition, an attempt was made to confirm study appointments within a two-week period after first contact. Once a study appointment was made participants were contacted 2-3 days prior to their study
date with reminders to bring their study materials, wear comfortable walking shoes, and bring glasses if used for distance, driving, or reading (Figure).

**First face-to-face:** Meet with potential study participants at recruitment sites.

Screen potential study participants for inclusion criteria.

Provide consent form and study packet to eligible individuals. Consent can be read and signed at this time or taken home. Study packet taken home. Schedule testing date, time, and location. Provide reminder card.

**Second face-to-face.** Study assessment day. Review consent. Screen consented individuals for cognitive impairment and depression.

Review study packet for completeness. Collect cognitive and physical function measures.

Provide study participants with personal results, Tai Chi and driving-related materials.

Remind by phone call, email, or text one-to-two days prior to study assessment day.

Refer to Primary Care Provider or give list of providers if screened positive for cognitive impairment or depression.

Figure. Study flow.
Printed study materials were optimized for older adults including font type (serif typeface, Times New Roman), size (at least 12 point), and adequate contrast (National Institute on Aging, 2012). The all-in-one computer touchscreen (Dell XPS 1810, www.dell.com) used for the computerized DrivingHealth Inventory™ was adjusted for proper ergonomics, glare reduction, ease of use, and was regularly calibrated and cleaned. A stylus was used to facilitate touchscreen use.

Study appointments were held in locations convenient to the recruitment sites and were scheduled to avoid periods of high traffic, such as rush hours, dusk or dark. Participants received detailed instructions to the study sites and room locations and site staff or receptionists were alerted to the study room location. Study site rooms were chosen to provide privacy and a quiet, non-distracting environment. A 10-foot tape measure and colored tape was used to mark distances in each study room to provide consistency for the three study measures requiring accurate distances (Rapid Walk Test, Head/Neck Flexibility, and Visual Acuity/Contrast Sensitivity).

One researcher (SM) collected all data. A checklist and pre-written instructional scripts were used to ensure operational fidelity (Sidani & Braden, 2011). Written consent was obtained and participants were screened for cognitive impairment and depression. If screened out, appropriate referrals to primary care providers or mental health providers were made. The study packet was then reviewed for completeness to decrease the chance of missing self-report data and to clarify any questions the participant might have. The computerized DrivingHealth Inventory™ and additional investigator-administered measures were collected. Once all cognitive and physical measures were collected the participant received their personal results and
incentive materials. Access to restrooms, bottled water, and stretch breaks were provided for participants during the study to increase comfort and decrease fatigue (McHenry et al., 2012).

**Study Measures**

**Cognitive measures.** Once participants were consented and enrolled, baseline cognitive function was established with the Mini-Cog (Doerflinger, 2007) and participants were screened for depression using the five-item Geriatric Depression Scale (Rinaldi et al., 2003). Nine measures assessed cognitive function known to be associated with safe driving performance. Measures included computer-based and researcher-administered tests of specific cognitive processes: recall (digit span forward [DSF] and three word recall), working memory (digit span backward [DSB]), planning (a maze test), visual speed of processing and divided attention (the Useful Field of View, subtest 2 [UFOV]), a visual perception and closure task (visualizing missing information [VMI]), and two computerized versions of the Trail Making Tests A and B (TMT A and TMT B); visual search (VSA) and visual search and attention switching (VSB), respectively. Lastly, the Driving Scenes Test (DST) (Brown et al., 2005), a composite instrument measuring visual scanning, attention, and working memory was used as the driving outcome for multiple regression. A description of the measures, their relationships to safe driving performance and scoring are presented in Table 1. All cognitive measures were reliable and valid for use in the study population.
<table>
<thead>
<tr>
<th>Test Name/Description</th>
<th>Cognitive Processes Measured</th>
<th>Relationship to Driving</th>
<th>Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digit span backward</td>
<td>Working memory</td>
<td>Retaining and manipulating information including awareness of traffic situations, and the ability to recall positions of other vehicles.</td>
<td>Number of digits repeated in correct order. Longer correct spans indicate better working memory.</td>
</tr>
<tr>
<td>Digit span forward</td>
<td>Immediate serial recall</td>
<td>Remembering driving directions, addresses, and obeying traffic warnings.</td>
<td>Number of digits repeated in correct order. Longer correct spans indicate better immediate serial recall.</td>
</tr>
<tr>
<td>Driving Scenes test</td>
<td>Visual scanning, Visual attention, Attention to detail, Selective attention, Working memory</td>
<td>Correlated with on-road driving performance.</td>
<td>One point given for each detail identified. Scores range from 0 (worst) to 70 (best) for all six Driving Scenes. Higher scores indicate better visual attention.</td>
</tr>
<tr>
<td>Maze navigation*</td>
<td>Judgment, Planning, Visual attention, Forethought</td>
<td>Route planning, judgment, attention</td>
<td>Completion time and errors Faster times to completion indicate better executive function.</td>
</tr>
<tr>
<td>Test Name/Description</td>
<td>Cognitive Processes Measured</td>
<td>Relationship to Driving</td>
<td>Scoring</td>
</tr>
<tr>
<td>-----------------------</td>
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<td>-------------------------</td>
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</tr>
<tr>
<td>Three-word recall*</td>
<td>Simple recall</td>
<td>Remembering addresses, driving instructions, and upcoming road hazard warnings.</td>
<td>More words recalled (such as three-out-of-three) indicate better delayed recall.</td>
</tr>
<tr>
<td></td>
<td>Memory</td>
<td></td>
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<tr>
<td></td>
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<tr>
<td>After several minutes of intervening activities participant is asked to recall as many of the three words as possible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Useful Field of View (subtest 2)*</td>
<td>Visual speed of processing</td>
<td>Visual attention to activity in the central field of view while simultaneously monitoring activity in the peripheral fields.</td>
<td>Response times and error rates.</td>
</tr>
<tr>
<td></td>
<td>Divided attention</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>The participant is presented a central object to identify and must also identify the location of an additional target object briefly presented in the peripheral field</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inference</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outcome prediction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visual perceptual ability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The participant is asked to match 11 partially completed line drawings to a complete target object</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual Search and Attention (computerized Trail Making Test A)*</td>
<td>Information processing speed, visual search, attention</td>
<td>Scanning, searching, and monitoring the driving environment.</td>
<td>Completion time, accuracy.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screen with scattered numbers (1-25)</td>
<td></td>
<td>Maintaining attention</td>
<td>Shorter times and better accuracy indicate better visual search and information processing.</td>
</tr>
<tr>
<td>Test Name/Description</td>
<td>Cognitive Processes Measured</td>
<td>Relationship to Driving</td>
<td>Scoring</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------------------</td>
<td>-------------------------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>Visual Search with Divided Attention</strong> <em>(computerized Trail Making Test B)</em></td>
<td>Information processing speed, visual search, attention, and attention-switching</td>
<td>Scanning, searching, and monitoring the driving environment. Maintaining attention to sequencing. Mental flexibility.</td>
<td>Completion time, accuracy. Shorter times and better accuracy indicate better visual search and sequencing, information processing, and attention-switching.</td>
</tr>
</tbody>
</table>

Note: *Component of the DrivingHealth Inventory. All measures are valid and reliable for use in the study population.
Table 1 (continued). *Relationship of physical measures to safe driving performance*

<table>
<thead>
<tr>
<th>Test Name/ Description</th>
<th>Physical Function Measured</th>
<th>Relationship to Driving</th>
<th>Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right Foot Tap test</strong></td>
<td>Lower extremity control, flexibility, and proprioception</td>
<td>Moving between the brake and gas pedal</td>
<td>Completion time.</td>
</tr>
<tr>
<td>The participant taps their right foot alternately five times on each side of a 2 inch 3-ring binder as quickly as possible for a total of 10 taps</td>
<td></td>
<td>Shorter times indicate better right lower extremity control, flexibility, and proprioception.</td>
<td></td>
</tr>
<tr>
<td><strong>Rapid Walk test</strong>*</td>
<td>Lower extremity strength and mobility</td>
<td>General lower extremity strength and mobility; moving the leg and foot between the brake and gas pedals, and entering and exiting the vehicle</td>
<td>Completion time.</td>
</tr>
<tr>
<td>The participant walks as quickly and safely as possible for a distance of 10 feet around a cone or other marker, and returns to their starting place (total distance walked is 20 feet)</td>
<td></td>
<td>Shorter times indicate better general mobility and lower extremity strength.</td>
<td></td>
</tr>
<tr>
<td><strong>Head/neck flexibility</strong>*</td>
<td>Head and neck flexibility</td>
<td>Visualizing traffic, pedestrians and other objects when changing lanes, at intersections, or when backing up</td>
<td>Pass/fail indicating head/neck flexibility and range of motion.</td>
</tr>
<tr>
<td>The participant is seated in a chair and must look over their shoulder without moving their hips and identify a shape on the computer screen 10 feet directly behind them</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High and low contrast visual acuity/ contrast sensitivity</strong>*</td>
<td>Visual acuity</td>
<td>Read traffic signs, see road markings, and for safe navigation in low-light situation such as dusk, fog, or rain</td>
<td>Less errors indicate better visual acuity and/or contrast sensitivity.</td>
</tr>
<tr>
<td>The participant is presented with a series of progressively smaller and less contrasted “E” symbols and must detect the E with a different orientation than the others</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: *Component of the DrivingHealth Inventory. All measures are valid and reliable for use in the study population.*
Physical and Perceptual Measures Related to Driving Performance

The DrivingHealth Inventory™. Physical and perceptual components of the DrivingHealth Inventory™ include tests of leg strength/general mobility, head and neck flexibility, and high and low contrast visual acuity. A description of the DrivingHealth Inventory™ measures, plus one additional physical measure (the Right Foot Tapping test), the measures’ relationships to safe driving performance, and scoring are presented in Table 1. All physical measures were reliable and valid for use in the study population.

Self-report Measures

Self-report measures included 1) self-reported Tai Chi exercise habits, 2) exploratory questions regarding engagement with the eight active ingredients of Tai Chi, 3) the Rapid Assessment of Physical Activity (RAPA) Scale (Topolski et al., 2006) to distinguish between participants’ Tai Chi exercise and other types of physical activity and exercise, 4) the Automobile Association of America Foundation for Traffic Safety 15-item Drivers 65 Plus Self-Rating Tool, 5) a 6-item researcher-developed driving habits questionnaire, 6) the Mindful Attention Awareness Scale (MAAS) (Brown & Ryan, 2003), and 7) the Vitality Plus Scale (VPS) (Myers et al., 1999) for perceived psychological and physical benefits of exercise.

Statistical Methods

Study packet data were hand-entered into SPSS, compared for accuracy, scanned for outliers, and reviewed for proper coding (Polit & Beck, 2008; Roberts, Anthony, Madigan, & Chen, 1997). Data from the DrivingHealth Inventory™ touchscreen program were imported into SPSS as comma separated files. Once all data were entered into SPSS each file was double-
checked for completeness and accuracy. A final random check of 15% of files resulted in no errors found in the entered data.

Data were analyzed according to the level of measurement of the specific variable. Parametric tests were used for normally distributed data and non-parametric tests were used for non-normally distributed data. All significance levels were set at $p < 0.05$. Version 22 of International Business Machines-SPSS (IBM-SPSS) software was used for data analysis (International Business Machines, 2014). For non-normally distributed data Spearman’s correlation was conducted and biserial correlation coefficients were calculated for dichotomous variables. Median tests and binomial tests were conducted depending on the type of data, and an r effect size calculated. For normally-distributed data an independent samples t-test was used to compare the difference between the means of the Tai Chi study participants and norm-referenced values and Cohen’s $d$ effect size calculated. The DST was used as the dependent variable for the hierarchical multiple regression to predict safe driving performance.

In an attempt to quantify Tai Chi exercise doses from self-reported Tai Chi exercise habits, High exercise dose and Low exercise dose were estimated by multiplying the number of times the participant practiced per month by the minutes per session practiced per month. Because the times per month and minutes per session were recorded as ranges, the dose is an estimate. The midpoint of each range was used for computing. Due to a skewed distribution in the number of hours practiced the median was used to determine Low Tai Chi Dose and High Tai Chi Dose.

Using the nomenclature from the RAPA scoring instruction (Topolski et al., 2006) the designations of Sedentary, Underactive, Underactive-Regular Light Activity, Underactive-
Regular Moderate Activity, and Underactive-Vigorous were categorized as “Underactive”; the RAPA designations of Active-Moderate and Active-Vigorous were categorized as “Active”.

This research report conforms to the *Strengthening the Reporting of Observational Studies in Epidemiology* (STROBE) guidelines for observational cross-sectional studies (Vandenbroucke et al., 2007).

**Results**

Fifty-eight participants recruited from the community completed the study. The mean age was 73 (range 65-87); 72% were female. The majority of participants were Caucasian (90%). Ninety-one percent of participants had completed 13 or more years of education and the median annual household income was greater than $50,000 (Table 2). The two most frequently reported health conditions were hypertension/heart disease (57%) and arthritis/degenerative joint disease (41%). Twenty-six percent of study participants reported a fall within the past 12 months.
Table 2. *Participant Demographics, N=58*

<table>
<thead>
<tr>
<th>Age</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>65-69 years</td>
<td>22</td>
<td>37.90</td>
</tr>
<tr>
<td>70-74 years</td>
<td>15</td>
<td>25.90</td>
</tr>
<tr>
<td>75-79 years</td>
<td>11</td>
<td>19.00</td>
</tr>
<tr>
<td>80-84 years</td>
<td>8</td>
<td>13.80</td>
</tr>
<tr>
<td>≥85 years</td>
<td>2</td>
<td>3.40</td>
</tr>
</tbody>
</table>

**Gender**

<table>
<thead>
<tr>
<th>Gender</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>42</td>
<td>72.40</td>
</tr>
</tbody>
</table>

**Marital status**

<table>
<thead>
<tr>
<th>Marital status</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never married</td>
<td>4</td>
<td>6.90</td>
</tr>
<tr>
<td>Presently married/domestic partner</td>
<td>26</td>
<td>44.80</td>
</tr>
<tr>
<td>Divorced or separated</td>
<td>17</td>
<td>29.30</td>
</tr>
<tr>
<td>Widowed</td>
<td>11</td>
<td>19.00</td>
</tr>
</tbody>
</table>

**Race**

<table>
<thead>
<tr>
<th>Race</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caucasian</td>
<td>52</td>
<td>89.70</td>
</tr>
<tr>
<td>Black or African-American</td>
<td>2</td>
<td>3.40</td>
</tr>
<tr>
<td>Asian</td>
<td>4</td>
<td>6.90</td>
</tr>
<tr>
<td>American Indian or Alaskan Native</td>
<td>3</td>
<td>5.20</td>
</tr>
<tr>
<td>Native Hawaiian or Other Pacific</td>
<td>1</td>
<td>1.70</td>
</tr>
<tr>
<td>Islander</td>
<td>2</td>
<td>3.40</td>
</tr>
<tr>
<td>Unknown/Not reported</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Ethnicity**

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Hispanic or Latino</td>
<td>50</td>
<td>86.20</td>
</tr>
</tbody>
</table>

**Highest education level in years**

<table>
<thead>
<tr>
<th>Highest education level in years</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary (7-12)</td>
<td>5</td>
<td>8.60</td>
</tr>
<tr>
<td>Tertiary (13+)</td>
<td>53</td>
<td>91.40</td>
</tr>
</tbody>
</table>

**Current employment status**

<table>
<thead>
<tr>
<th>Current employment status</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-time</td>
<td>5</td>
<td>8.60</td>
</tr>
<tr>
<td>Part-time</td>
<td>10</td>
<td>17.20</td>
</tr>
<tr>
<td>Retired/Unemployed</td>
<td>43</td>
<td>74.10</td>
</tr>
</tbody>
</table>

**Self-reported health problems**

<table>
<thead>
<tr>
<th>Self-reported health problems</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthritis/Degenerative joint disease</td>
<td>24</td>
<td>41.40</td>
</tr>
<tr>
<td>Hypertension/Heart disease</td>
<td>33</td>
<td>56.90</td>
</tr>
<tr>
<td>Eye conditions (cataracts, glaucoma, etc.)</td>
<td>17</td>
<td>29.30</td>
</tr>
<tr>
<td>Cancer</td>
<td>7</td>
<td>12.10</td>
</tr>
<tr>
<td>Diabetes</td>
<td>6</td>
<td>10.30</td>
</tr>
<tr>
<td>Respiratory disease</td>
<td>3</td>
<td>5.20</td>
</tr>
<tr>
<td>Sleep apnea</td>
<td>1</td>
<td>1.70</td>
</tr>
<tr>
<td>Kidney disease</td>
<td>14</td>
<td>20.30</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Driving Habits

Study participants drove an average of 6 days per week (M = 6.17; SD 1.2) and averaged nearly 2 trips per day (M=1.8; SD .88). Self-reported driving habits elicited from the AAA Foundation for Traffic Safety documented 47% (n = 27) of participants in the “Safe” range, 50% (n = 29) in the “Caution” range, and 3% (n = 2) in the “Unsafe” range. Nineteen percent (n = 11) of participants reported one or more collisions in the past two years.

Tai Chi and Other Physical Activity/Exercise Habits

Tai Chi exercise. Participants had been practicing Tai Chi from three months to less than one year (12%), one-to-three years (35%) and greater than three years (53%). On average, participants practiced more as a group than alone, and for longer duration when in a group, with 74% of participants practicing in a group one or two times a week for 45-60 minutes duration (79%). Several Tai Chi styles were represented with Yang (41%) and Sun/Sun for Arthritis (40%) being the most popular. Thirty-three percent of participants did not know the style of Tai Chi practiced. Tai Chi activity intensity was light-to-moderate based on 86% of participants selecting “My heart beats faster but I can talk or sing” when practicing Tai Chi, a measure of self-reported physical activity exertion based on the ‘talk test’ (CDC, 2015).

The exploratory eight-item self-report scale containing four Likert-type items (Strongly Agree to Strongly Disagree) based on Wayne’s (2013) eight active ingredients of Tai Chi revealed a high level of agreement with statements regarding engagement with the Eight Active Ingredients of Tai Chi (possible range 8-32, Mean=27, SD 3). On average, participants Agreed or Strongly Agreed with statements such as “Because of my Tai Chi practice, I feel I am more
aware, mindful, and have better focus”. The scale had a high level of internal consistency as determined by a Cronbach’s alpha of 0.81.

**Non-Tai Chi physical activity and exercise.** In addition to Tai Chi exercise, participants’ physical activity and exercise habits were recorded using the RAPA scale (Topolski et al., 2006). Nearly half (52%) reported Moderate-to-Vigorous weekly activity, and 43% performed both strengthening and flexibility activities weekly.

**Relationships between study measures.** Spearman’s correlation coefficients revealed weak-to-strong statistically significant relationships between several cognitive processes, physical measures, mindfulness, and vitality (Table 3). Several measures with moderate to strong correlations between cognitive processes included DSF and DSB ($r_s = .47, p < .001$), the DST and DSB ($r_s = .31, p < .05$), VSA and DSB ($r_s = -.38, p < .001$), and VSB and DSB ($r_s = .40, p < .001$). Statistically significant correlations were also observed between the Rapid Walk test and DSB ($r_s = -.39, p < .001$), the Rapid Walk test and Foot Tapping test ($r_s = .50, p < .001$) and between the MAAS and VPS ($r_s = .36, p < .001$). A biserial correlation coefficient was calculated to determine the strength of the relationship between Tai Chi dose (High versus Low) and the study measures. Visualizing Missing Information was the only measure with a statistically significant correlation between High Tai Chi dose and performance, ($r_b = .35, p = .03$).
Table 3. *Spearman’s correlation coefficients among study measures (N=58)*

<table>
<thead>
<tr>
<th>Cognitive Measures</th>
<th>Physical Measures</th>
<th>Self-report Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DSB</td>
<td>DSF</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>DSB</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>DSF</td>
<td>.47**</td>
<td>--</td>
</tr>
<tr>
<td>DST</td>
<td>.31*</td>
<td>.24</td>
</tr>
<tr>
<td>Maze test</td>
<td>-.12</td>
<td>-.07</td>
</tr>
<tr>
<td>Three Word Recall</td>
<td>.27*</td>
<td>.12</td>
</tr>
<tr>
<td>UFOV</td>
<td>-.13</td>
<td>-.26</td>
</tr>
<tr>
<td>VMI</td>
<td>-.25</td>
<td>-.39**</td>
</tr>
<tr>
<td>VSA</td>
<td>-.38**</td>
<td>-.39**</td>
</tr>
<tr>
<td>VSB</td>
<td>-.40**</td>
<td>-.42**</td>
</tr>
<tr>
<td>Foot Tap Test</td>
<td>-.15</td>
<td>-.37**</td>
</tr>
<tr>
<td>Rapid Walk</td>
<td>-.39**</td>
<td>-.11</td>
</tr>
<tr>
<td>Mean MAAS Score</td>
<td>.05</td>
<td>.09</td>
</tr>
<tr>
<td>VPS Total Scores</td>
<td>.25</td>
<td>.12</td>
</tr>
</tbody>
</table>

Note: DSB = Digit Span Backward; DSF = Digit Span Forward; DST = Driving Scenes Test; MAAS = Mindful Attention Awareness Scale (Mean); UFOV = Useful Field of View (subtest 2, divided attention); VSA = Visual Search and Attention- A; VSB=Visual Search and Attention-B; VMI = Visualizing Missing Information; VPS = Vitality Plus Scale

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).
Comparison of cognitive measures to normative values. Study participants performed statistically significantly better in several of the cognitive measures compared to normative reference values. Participants scored higher (noticed more new, different or missing items) on the DST, recalled more serial digits for the DSF test, had faster completion times on the Maze test, had shorter UFOV times, made less errors on the VMI test, and had faster completion times on the VSA. Study participants did not perform statistically significantly differently from normative reference values on the DSB or VSB (Table 4).
Table 4. Cognitive function, physical function, and self-reported benefits of Tai Chi Exercise compared to normative reference values (N=58)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Non-parametric</th>
<th>Parametric (t-test)</th>
<th>95% CI</th>
<th>df</th>
<th>p</th>
<th>Effect Size</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hypoth.</td>
<td>Observed Median</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>LL</td>
</tr>
<tr>
<td>Cognitive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSB</td>
<td>5.34</td>
<td>5.00</td>
<td>5.34</td>
<td>0.96</td>
<td>5.02</td>
<td>1.30</td>
<td>NA</td>
</tr>
<tr>
<td>DST</td>
<td>NA</td>
<td>NA</td>
<td>43.79</td>
<td>8.18</td>
<td>54.74</td>
<td>4.80</td>
<td>10.95</td>
</tr>
<tr>
<td>MZ</td>
<td>NA</td>
<td>NA</td>
<td>39.18</td>
<td>16.92</td>
<td>35.21</td>
<td>12.30</td>
<td>10.95</td>
</tr>
<tr>
<td>UFOV</td>
<td>206</td>
<td>100</td>
<td>206</td>
<td>122</td>
<td>147.88</td>
<td>92.13</td>
<td>NA</td>
</tr>
<tr>
<td>VMI (MVFT)</td>
<td>3.40</td>
<td>2.00</td>
<td>3.40</td>
<td>2.39</td>
<td>1.84</td>
<td>1.60</td>
<td>NA</td>
</tr>
<tr>
<td>VSA (TMT-A)</td>
<td>45.20</td>
<td>34.41</td>
<td>45.19</td>
<td>24.98</td>
<td>36.17</td>
<td>11.93</td>
<td>NA</td>
</tr>
<tr>
<td>VSB (TMT-B)</td>
<td>95.45</td>
<td>96.76</td>
<td>95.50</td>
<td>50.78</td>
<td>98.90</td>
<td>29.21</td>
<td>NA</td>
</tr>
<tr>
<td>Physical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*Head/Neck Flexibility</td>
<td>77% pass</td>
<td>28% pass</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Rapid Walk Test Right</td>
<td>7.97</td>
<td>5.70</td>
<td>7.97</td>
<td>3.43</td>
<td>5.96</td>
<td>1.08</td>
<td>NA</td>
</tr>
<tr>
<td>Foot Tap Test</td>
<td>4.80</td>
<td>3.52</td>
<td>4.80</td>
<td>1.56</td>
<td>3.63</td>
<td>0.70</td>
<td>NA</td>
</tr>
<tr>
<td>Perceived benefits of Tai Chi Exercise</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAAS</td>
<td>NA</td>
<td>NA</td>
<td>4.20</td>
<td>.69</td>
<td>4.70</td>
<td>.64</td>
<td>.50</td>
</tr>
<tr>
<td>VPS</td>
<td>NA</td>
<td>NA</td>
<td>35</td>
<td>7</td>
<td>37.52</td>
<td>5.80</td>
<td>2.52</td>
</tr>
</tbody>
</table>

Note: *Binomial test, CI = confidence interval; DSB = Digit Span Backward; DSF = Digit Span Forward; DST = Driving Scenes Test; LL = lower limit; MAAS = Mindful Attention Awareness Scale (Mean); MVFT = Motor-free Visual Perception Test; MZ = Maze Test; NA = Not Applicable; TMT-B = Trail Making Test Part-B; UL = upper limit; UFOV = Useful Field of View (subtest 2, divided attention); VSA-A = Visual Search and Attention-Part A; VSB=Visual Search and Attention-Part B; VMI = Visualizing Missing Information; VPS = Vitality Plus Scale (Total Scores) *Cronbach’s alpha=.87. 1 Cronbach’s alpha=.78
Comparison of physical and perceptual measures to normative values. The majority of participants had adequate visual acuity of 20/80 and 20/40 at high contrast and 20/80 at low contrast with no errors on the “tumbling E” chart (97%, 88%, and 91% respectively). However, at 20/40 low contrast only 66% (n = 38) of participants had no errors, with 35% (n = 20) having from one to four errors. Visual acuity and contrast sensitivity are perceptual components of the DrivingHealth Inventory™ and are important for safe driving performance. However, in this study they are used for descriptive purposes only and were not compared to normative reference values. Study participants performed better on the Rapid Walk test and Right Foot Tapping test when compared to normative reference values, but not on the Head/Neck Flexibility measure (Table 3).

Comparison of perceived benefits of Tai Chi exercise to normative values. Results for mindfulness and attention as measured by the MAAS, and self-perceived health benefits associated with exercise measured by the VPS were significantly higher in the study participants than normative reference values (Table 3). Both the MAAS and VPS had high levels of internal consistency in this study (Cronbach’s alphas = .87 and .78, respectively).

Predicting safe driving performance. A four-stage hierarchical multiple regression was conducted with DST as the dependent variable. The DST was chosen as the dependent variable because it is composed of several cognitive processes including visual search and scanning, attention, and working memory, and due to its strong correlation with on-road driving outcomes (r = .55) (Brown et al., 2005) (Table 5). Predictor variables were entered into the equation based on past driving research evidence and theoretical considerations: the Useful Field of View (UFOV, a measure of visual speed of processing and divided attention) and the DSB, a measure
of working memory were entered at the first and second stages of the model, respectively. Tai Chi Exercise Dose and RAPA Activity Category were then added in the third and fourth blocks, respectively. Applicable assumptions for multiple regression were met.

Table 5. *Hierarchical Multiple Regression Predicting Driving Scenes Test Scores*

<table>
<thead>
<tr>
<th>Model</th>
<th>b</th>
<th>SE b</th>
<th>β</th>
<th>R²</th>
<th>Adjusted R²</th>
<th>ΔR²</th>
<th>F</th>
<th>ΔF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>54.43</td>
<td>1.17</td>
<td></td>
<td>0.05</td>
<td>0.03</td>
<td>0.05</td>
<td>2.89</td>
<td>2.89</td>
</tr>
<tr>
<td>Useful field of</td>
<td>-0.01</td>
<td>0.01</td>
<td>-.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>49.75</td>
<td>2.71</td>
<td></td>
<td>0.16</td>
<td>0.13</td>
<td>0.11</td>
<td>5.24*</td>
<td>7.28*</td>
</tr>
<tr>
<td>Useful field of</td>
<td>-0.01</td>
<td>0.01</td>
<td>-.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit span backward</td>
<td>1.236</td>
<td>0.46</td>
<td>.34*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Model 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>48.97</td>
<td>2.81</td>
<td></td>
<td>0.18</td>
<td>0.13</td>
<td>0.02</td>
<td>3.89*</td>
<td>1.16</td>
</tr>
<tr>
<td>Useful field of</td>
<td>-0.01</td>
<td>0.01</td>
<td>-.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit span backward</td>
<td>1.30</td>
<td>0.46</td>
<td>.35*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tai Chi Exercise Dose</td>
<td>1.30</td>
<td>1.17</td>
<td>.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Model 4</strong></td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Constant</td>
<td>48.21</td>
<td>2.98</td>
<td></td>
<td>0.19</td>
<td>0.13</td>
<td>0.01</td>
<td>3.05*</td>
<td>.61</td>
</tr>
<tr>
<td>Useful field of</td>
<td>-0.01</td>
<td>0.01</td>
<td>-.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit span</td>
<td>1.30</td>
<td>0.46</td>
<td>.35*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tai Chi Exercise Dose</td>
<td>1.10</td>
<td>1.20</td>
<td>.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RAPA Category</td>
<td>0.96</td>
<td>1.22</td>
<td>.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: N=58; *p < 0.01
Useful Field of View ($\beta = -0.22, p = 0.095$) as the first predictor of DST scores (Model 1) did not produce a statistically significant model, $R^2 = 0.049, F(1,56) = 2.89, p = 0.095$; adjusted $R^2 = 0.032$. The addition of DSB ($\beta = 0.34, p = 0.009$) when controlling for UFOV to the prediction of DST (Model 2) led to a statistically significant increase to the prediction of DST scores, $R^2 = 0.179, F(1,55) = 5.24, p = 0.009$. The addition of Tai Chi Exercise Dose ($\beta = 0.13, p = 0.286$) when controlling for both UFOV and DSB to the prediction of DST scores (Model 3) did not improve the predictive ability of the model, $R^2 = 0.178, F(1,54) = 3.89, p = 0.286$. Finally, the addition of RAPA Exercise Category ($\beta = 0.10, p = 0.438$) when controlling for UFOV, DSB and Tai Chi Exercise Dose did not improve the predictive ability of DST scores, $R^2 = 0.187, F(1,53) = 3.05, p = 0.438$. Digit Span Backward was the variable most strongly predictive of DST scores and accounted for 11% of the variability in DST scores.

**Discussion**

To our knowledge this is the first study examining the associations between specific cognitive processes and physical function related to safe driving performance among Tai Chi practitioners aged 65 and over. Tai Chi exercise has many known cognitive and physical benefits, and is an increasingly popular activity appropriate for older adults. As a form of aerobic exercise, Tai Chi shares the same mechanisms of action of traditional forms of exercise. The additional active ingredients including the multi-faceted elements and integration of physiological and structural systems specific to Tai Chi exercise (Wayne, 2013) may enhance cognitive processes, specific physical functions, mindfulness, and overall well-being.
Tai Chi exercise, physical activity, and exercise habits. Tai Chi exercise includes muscle strengthening, joint flexibility, anatomic alignment, use of the core, weight shifting, and emphasis on balance and postural control and is a moderate-intensity aerobic physical activity (Compendium of Physical Activities, 2015). Our results indicate the potential contribution of Tai Chi exercise to the recommended physical activity dose of 150 minutes of moderate-intensity aerobic activity weekly (CDC, 2015) when combined with other forms of physical activity or exercise, and are consistent with the upward trend of Tai Chi practice in the United States (National Center for Complementary and Integrative Health, 2015). The exploratory scale examining participants’ engagement with Tai Chi’s active ingredients demonstrated a high level of engagement. These results indicate a rich area to investigate the eight active ingredients as a framework for teaching and researching Tai Chi exercise (Wayne, 2013).

Driving habits. The importance of driving to this study population was evident through the finding that on average, study participants drove almost daily. From a lifespan development perspective, this suggests that driving plays an important role in maintaining engagement in the community and of individual independence. Of concern are the number of participants (29%) whose self-reported driving habits placed them in the “Caution” category, and 19% reporting one or more major or minor collisions in the past two years. Affirmative responses to questions regarding problems merging with traffic or difficulty negotiating intersections place this vulnerable population at increased risk of injury or death from motor vehicle crashes.

At the conclusion of each study session when study participants received the results of their DrivingHealth Inventory™ and driving-related incentive materials many participants shared how their driving habits had changed as they grew older, such as not driving on the highway,
driving only during daylight, and only driving local familiar routes. During this discussion strategies to compensate for age-related changes impacting safe driving performance were explored. For example, in addition to changes in driving habits, equipment such as adaptive mirrors and the use of new safety technology were discussed.

**Relationships among study measures.** Several study measures revealed statistically significant correlations. Several possible explanations exist, including shared cognitive processes or physical abilities measured. For example, VSA and VSB are computerized versions of the TMT-A and TMT-B, respectively. Visual Search and Attention-Part A measures visual search and VSB measures visual search, attention and also mental flexibility. These two measures were moderately correlated, a finding consistent with existing research using the paper-and-pencil version of the TMT-A and TMT-B (Strauss, Sherman, & Spreen, 2006). Also, the DST, which includes a working memory component, was significantly correlated with the DSB, a measure of working memory.

Two measures of physical function, the Rapid Walk test and Foot Tapping Test rely on lower extremity strength and control and were significantly correlated. Interestingly, a statistically significant correlation between the Rapid Walk test, a measure of general mobility, and working memory measured by DSB was also found, exemplifying the potential link between physical activity and exercise and executive function. This correlation is possibly explained by exercise promoting better mobility, and the effects of exercise on cognitive function. The self-reported measures of vitality and mindfulness were significantly correlated, demonstrating a possible relationship between overall well-being and dispositional mindfulness. While cause and effect cannot be determined, higher dispositional mindfulness may influence a person’s attention.
to feelings and sensations and lead to better self-care; on the other hand, a person who has more energy and feels better may have more capacity to be attentive to the moment.

**Cognitive measures.** There is existing evidence of enhanced global cognition, executive function (including working memory and measures of attention), and increased speed of information processing associated with Tai Chi exercise (Miller & Taylor-Piliae, 2014; Wayne et al., 2014). In the current study the DST, a measure of visual scanning, selective attention, and working memory revealed statistically significantly higher scores. And although the DSF test showed better immediate serial recall, the DSB test, a measure of working memory, was not statistically significantly different than normative reference values. This finding is similar to inconsistent results from other research measuring digit span tests (Kasai et al., 2010; Lam et al., 2012; Taylor-Piliae et al., 2010; Wayne et al., 2014).

Faster visual speed of processing times and divided attention were measured by the UFOV (subtest 2) and although the UFOV has not been studied as an outcome in Tai Chi research, other measures of visual speed of processing and attention, such as the Trail Making Tests and Digit Symbol tests have also shown improvement (Chang, et al., 2011; Matthews & Williams, 2008; Reid-Arndt, Matsuda, & Cox, 2012). In the current study a statistically significant difference was found in the VSA; however, no difference was seen in the VSB, a measure of divided attention. These results are consistent with other studies, some of which reported improvement in TMT A and TMT B, or both (Matthews & Williams, 2008; Nguyen & Kruse, 2012; Reid-Arndt, Matsuda, & Cox, 2012). The VMI, a computerized test similar to the Motor-free Visual Perception Test/Visual Closure Subtest resulted in fewer errors committed
when compared to normative reference values, indicating better visual perceptual and spatial relationship skills.

**Physical and perceptual measures.** Tai Chi has many known physical benefits including improved strength, endurance, and balance (Rogers, Larkey, & Keller, 2009). In the current study, faster Rapid Walk test times likely indicates better lower limb strength, balance, and general mobility, consistent with other studies measuring similar variables (Fong & Ng, 2006; Jacobson, Ho-Cheng, Cashel, & Guerrero, 1997; Taylor-Pilie, Haskell, Stotts, & Froelicher, 2006). Also, faster Right Foot Tapping Test times may reflect the control, specific lower extremity/foot placement, and proprioceptive awareness required while performing Tai Chi postures and is consistent with other studies measuring somesthesis and proprioception (Fong & Ng, 2006; Jacobson, Ho-Cheng, Cashel, & Guerrero, 1997; Liu et al., 2012; Xu, Hong, Li, & Chan, 2004). In the current study, Tai Chi practitioners had poorer head/neck flexibility compared to normative reference values, a finding consistent with other research measuring upper body flexibility (Day et al., 2012; Taylor-Pilie, Haskell, Stotts, & Froelicher, 2006). Tai Chi postures focus on unified ‘core’ movements and do not require twisting of the upper body or looking over the shoulder and may partially explain the lack of significant findings in the present study. Additionally, 41% of study participants reported arthritis/degenerative joint disease, which may in part explain our head/neck flexibility findings.

**Perceived benefits of exercise.** The findings of increased dispositional mindfulness and overall well-being are consistent with evidence from recent meta-analyses conducted on psychological and overall health benefits of Tai Chi exercise (Jahnke, Larkey, Rogers, Etnier & Lin, 2010; Wang Bannuru, Ramel, Kupelnick, Scott, & Schmid, 2010) where moderate to large
effect sizes in psychological health and improved health-related outcomes in a diverse range of health conditions were reported in Tai Chi practitioners. The association between safe driving performance, mindfulness, and overall well-being can be conceptualized through several mechanisms including decreased distractibility, attention to surroundings, improved mood, less physical discomfort, and more vigor.

**Predictors of safe driving performance.** Prior research has shown the predictive ability of speed of information processing (UFOV), attention, and working memory on driving outcomes (Anstey et al. 2012; Dawson et al., 2010, Emerson et al., 2012; Wood, Anstey, Kerr, Lacherez, & Lord, 2008). In the current study working memory as measured by the DSB test revealed the highest predictive ability of the DST scores. This finding is consistent with evidence linking working memory to driving-related measures (Anstey et al., 2012; Mäntylä, Karlsson, & Marklund, 2009). However, the UFOV, a measure highly predictive of high-risk driving did not add significant predictive ability to the model, a finding inconsistent with other research (Ball et al. 2006). This finding is possibly due to a floor effect (72% of participants scored 100 milliseconds, the fastest time possible). Neither Tai Chi exercise dose nor exercise level measured by RAPA categories were predictive of Driving Scenes scores, potentially from imprecise estimates derived from self-reported exercise behavior.

In summary, study participants performed better on several tests of cognitive processes and physical function measures associated with safe driving performance when compared to normative reference values. In addition, participants demonstrated increased dispositional mindfulness and overall well-being which may further contribute to better attention, decreased distraction, and improved physical function while driving.
**Study Strengths and Limitations**

Strengths of this study include recruitment from a wide variety of Tai Chi offerings, study measures with adequate psychometric properties, and providing participants with their results. Although several threats to external validity exist including a purposive sample and self-selection bias, the study population was drawn from currently driving older adults recruited from a wide variety of community settings offering Tai Chi exercise classes. The majority of study participants were Caucasian, female, and well-educated, leading to underrepresentation of males, minorities, or older adults with less education.

The observational study design aligns with an ecologically valid approach for the study of Tai Chi exercise’s multiple components (Wayne & Kaptchuk, 2008) and describes authentic and contextual Tai Chi exercise practice. A variety of Tai Chi forms, Tai Chi exercise doses, and class settings were represented in this study, reflecting a common challenge in Tai Chi research (Wayne & Kaptchuk, 2008). Although no control over these dissimilarities was possible, these variations are representative of the variety of community Tai Chi offerings, increasing generalizability to the larger population.

**Conclusion**

Although age-related changes in cognition and physical function will continue to challenge older adult drivers, accessible and appropriate methods to enhance specific cognitive processes and physical function necessary for safe driving performance are needed. Tai Chi exercise may be one form of exercise that can positively impact age-related changes by enhancing factors predictive of safe driving performance through aerobic exercise mechanisms, cultivation of mindfulness, and increased overall vitality. For those cognitive processes and
physical functions not amenable to improvement, compensatory strategies such as use of adaptive mirrors or modified driving behaviors can be employed toward the goal of increased safety and continued community mobility.

**Future Research**

Future Tai Chi interventional research on the effect of Tai Chi exercise on safe driving performance in older adults could include randomized controlled trials with a structured Tai Chi intervention and control group. Use of the eight active ingredients as a framework would ensure essential components of Tai Chi exercise were included in the intervention. Study measures could consist of both cognitive processes and physical function similar to those used in the current study, or could expand to driving simulator or on-road driving tests. The results of this study demonstrate that further exploration of Tai Chi exercise as a potential strategy to maintain safe driving performance in older adults is warranted.

**Funding**

This study was funded in part by the *Lange Doctoral Dissertation Research Award*, University of Arizona, College of Nursing, (Sally Miller, PI).
References


https://www.aaafoundation.org/


http://www-01.ibm.com/software/analytics/spss/


*Complementary Therapeutics in Clinical Practice, 18*(1), 26-30. doi: 10.1016/j.ctcp.2011.02.005


APPENDIX F

CONNECTING EAST AND WEST BY A DEVELOPMENTAL THEORY FOR OLDER ADULTS: APPLICATION OF BALTES’ SELECTION, OPTIMIZATION, AND COMPENSATION MODEL
Permissions email from Elsevier Publications for Manuscript #4, in press, received October 2, 2015.

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Connecting East and West by a Developmental Theory for Older Adults: Application of Baltes’ Selection, Optimization, and Compensation Model

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Assistant Professor of Nursing, Vanderbilt University School of Nursing

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Acknowledgments:
I would like to thank Pamela Reed, PhD, RN, FAAN and Ruth Taylor-Piliae, PhD, RN, FAHA for their helpful review of this manuscript, and Vanderbilt University School of Nursing for its support of my doctoral studies.
Abstract

Age-related changes in cognitive and physical function can affect safe driving performance. As the population of older adults increases in the United States there will be a simultaneous rise in the number of older adult drivers. Tai Chi, a non-traditional form of exercise with both physical and cognitive benefits may enhance driving performance. A lifespan developmental theory (Baltes’ Selective Optimization with Compensation model) is used to study the relationship between Tai Chi exercise and driving performance in older adults. Application of this theory was pivotal in building a bridge between a non-traditional practice and Western-based research to study an intervention that can be used to promote and sustain well-being in older adults.

Keywords: Lifespan development, driving, Tai Chi, exercise intervention, older adults
Connecting East and West by a Developmental Theory for Older Adults: Application of Baltes’ Selection, Optimization, and Compensation Model

Driving is an important instrumental activity of daily living for ‘community mobility’ and allows individuals to maintain independence, connect with family and friends, engage with spiritual communities, and complete necessary activities such as shopping, banking, and accessing healthcare (Wieland, 2013). Driving reduction or cessation results in loss of community mobility and can lead to isolation, depression, and dependence (National Academy on an Aging Society, 2005). Although various methods such as driver self-assessment and classroom or on-line driving education courses are frequently used to promote safer driving performance, these methods do not address the underlying changes in cognitive and physical function contributing to driving performance problems. In this article, I discuss application of a developmental theory used for an observational study exploring driving performance in older adults.

Increasing Numbers of Older Adult Drivers

As the population of older adults increases in the United States there will be a simultaneous rise in the number of older adult drivers (Centers for Disease Control and Prevention, 2013). Age-related changes in cognitive and physical function can affect safe driving performance leading to increased risk of automobile crashes or driving cessation (Centers for Disease Control and Prevention, 2013). Although there is much variability in the aging process, several cognitive processes and physical abilities are universally affected by aging and can impact safe driving performance. Cognitive changes include declines in memory, attention, and processing speed. Physical changes include decreased strength, reaction time, and flexibility.
When older adults are involved in crashes they are at increased risk of morbidity and mortality due to frailty, comorbidities, and decreased resilience thus leading to catastrophic personal and societal costs (Insurance Institute for Highway Safety, 2014). Physical activity and exercise have the potential to enhance driving performance in older adults.

**Physical Activity and Exercise**

Physical activity is defined as any bodily activity beyond resting baseline (such as yard or housework), while exercise is defined as a structured and routine activity with the goal of improved fitness (National Heart Lung and Blood Institute, 2013). Although the benefits of physical activity and exercise are well-documented (Agency for Healthcare Research and Quality, 2012) little research exists on their effects on driving performance (Miller, Taylor-Piliae, & Insel, 2015). One form of exercise becoming increasingly popular is Tai Chi, an ancient Chinese martial art incorporating slow, intentional movements with imagery and meditative breathing (National Center for Complementary and Integrative Health, 2015).

**Tai Chi exercise.**

Tai Chi is moderate-intensity aerobic exercise comparable in energy consumption to brisk walking (Lan, Chen, & Lai, 2008). Tai Chi is offered at many recreational and health facilities serving older adults and is an appropriate form of exercise for older adults due to its gentle movements and low impact on joints. While there is growing evidence of the cognitive and physical benefits of Tai Chi exercise (National Center for Complementary and Integrative Health, 2015) the potential connection between Tai Chi exercise, cognitive and physical function related to driving performance has not been studied.
With this gap in mind, my research is exploring the association between Tai Chi exercise and driving performance in adults aged 65 and older. Using an observational, cross-sectional study design I am collecting measures of cognitive and physical function related to driving performance in Tai Chi practitioners 65 years and older and am also exploring associations between Tai Chi exercise, mindfulness, well-being, vitality, and driving habits.

Tai Chi’s origins are in Eastern philosophies, and its underlying concepts such as energy (qi), opposites (yin and yang), intentional movement, and its meditative components are less-studied and not well-established or well-understood as mechanisms of action in biomedical-based Western research. Tai Chi is listed as a complementary and alternative medicine (CAM) by the National Center for Complementary and Integrative Health (NCCIH) and is embraced by integrative nursing as a form of movement therapy (Kreitzer & Koithan, 2014). One of the NCCIH’s objectives, which nursing shares, is to “increase understanding of ‘real world’ patterns and outcomes of use of complementary and integrative interventions and their inclusion in health care and health promotion” (National Center for Complementary and Integrative Health, 2015, About NCCIH). Although research on Tai Chi is becoming more popular and evidence of its many benefits is growing, Tai Chi is not a mainstream intervention and subject to criticism from the scientific community (Polich, Dole, & Kaptchuk, 2010; Wayne & Kaptchuk, 2008). Therefore, it was important for me to base my research in a theory that would help communicate my findings and bridge the gap between Eastern and Western ways of knowing. Likewise, important to me was finding a theory congruent with my beliefs regarding the individuality of aging and the ability of older adults to change, grow, and adapt over the course of their lifetime.
Finally, the theory I sought needed to be flexible enough to sustain not only my current doctoral work, but one that would support future research as well.

**Building Bridges**

Doctoral coursework introduced me to many theories to “try on” and I explored theories of aging and theories of self-regulation, self-efficacy and health beliefs. I sought a theory that would be useful whether my study aims required objective, biophysiological measures such as cognitive or physical function, subjective measures of a psychological or social nature such as those regarding vitality or mindfulness, or societal issues related to automobile driving.

While studying cognitive plasticity and the theory of lifespan development I discovered Baltes’ Selective Optimization with Compensation (SOC) model (Baltes et al., 2005; Freund, 2008). The foundation of lifespan development theory is the ability of individuals to change, grow and transform over the entire course of their lifetime. The SOC model’s concepts and language are intuitive and logical to me, and its theoretical underpinnings are consistent with my beliefs. The model provides a framework of interrelated, testable links between concepts to describe and communicate my research. It is concise enough to lend focus to my doctoral work, yet broad enough to sustain a future program of research.

In the SOC model antecedent conditions set into motion three adaptive processes: selection, optimization, and compensation followed by transformative outcomes that provide feedback to the antecedent conditions. Antecedent conditions refer to reductions in general capacity or specific functional abilities, such as age-related declines in cognitive or physical function. These changes stimulate the three processes of selection, optimization, and compensation. First, selection refers to an individual’s choice to pursue a goal, often due to
reductions in choices, for example due to decreasing functional abilities. However, it is important to note that selection of a goal is not always deficit-driven: goal selection can also be elective. Second, optimization denotes methods to maximize function or capacity toward the selected goal. The third process, compensation, consists of enlisting new resources toward the selected goal. Finally, outcomes demonstrate the transformation occurring due to the processes of selection, optimization, and compensation, and provide feedback to the individual. The processes of selection, optimization, and compensation are flanked by the descriptive antecedent conditions and measurable outcomes and provide a robust model from which to work. My doctoral research is particularly focused on the process of optimization, and specifically on Tai Chi exercise as a means to optimize cognitive and physical function related to automobile driving.

Application of the SOC Model to Driving Health in Older Adults

Universal age-related changes in cognitive and physical function are antecedent conditions for at-risk driving performance in older adults. In my study antecedent conditions are represented through demographic, health history, and vitality questions. The three processes, selection, optimization and compensation are being measured and demonstrated through several methods. First, study questions regarding driving exposure (trips per day, miles driven, and duration of trips) and driving habits (safety, awareness, and driving practices) demonstrate driving as an elective selection. Second, optimization of driving performance through Tai Chi exercise is explored by measuring the association between Tai Chi practice and driving performance measures. Instruments and questionnaires are used to distinguish between physical activity, exercise, and Tai Chi practice. Mindfulness, a meditative component associated with Tai Chi is also measured. Third, methods of compensation per se are not being measured; however,
when study participants receive their individualized computerized driver screening results, we
discuss adaptive driving techniques or equipment to counteract any deficits. Additionally, study
participants receive literature on safe driving practices for older adults, including suggestions for
compensating for age-related changes in driving ability.

Driving performance as an outcome is measured using a computerized driver screening
instrument along with neurocognitive and physical measures related to driving performance.
These measures are compared to normative reference values for older adults. In summary, the
SOC model is providing a framework for exploring Tai Chi exercise as a strategy to optimize
cognitive and physical function related to driving performance. The SOC model’s components
provide logical links to describe associations, test propositions, and communicate research
findings.

**Use of the Model for Future Research**

Future research could include study of at-risk drivers, for example those who have had a
-crash or who have specific conditions affecting driving performance (loss-based selection) or,
alternately, healthy community members who are interested in enhancing their driving
performance (elective selection). A study would begin with baseline measures of cognitive and
physical function related to driving performance (antecedent conditions). The desire of study
participants to continue driving would be assessed (selection). A Tai Chi exercise intervention
would then be provided (optimization), and for non-modifiable deficits, adaptive driving
techniques or equipment would be recommended or implemented (compensation). Post-
intervention cognitive and physical function related to driving performance would again be
measured, and community mobility assessed (outcomes).
Conclusion

As the population of older adult drivers continues to grow, optimizing driving performance will be an increasingly important personal and public health concern. As a non-traditional form of exercise Tai Chi has potential to impact safe driving performance. Connecting theory to my research enables me to bring a potentially significant Eastern-based intervention approach into nursing to support older adults’ driving performance and add to nursing’s fund of evidence-based practice. Use of a robust theoretical model to test links between concepts is one strategy I have employed to bring two worlds together to contribute to enhanced safety and quality of life of older adults.
References


Polich, G., Dole, C., & Kaptchuk, T. J. (2010). The need to act a little more ‘scientific’: biomedical researchers investigating complementary and alternative medicine. Sociology of Health & Illness, 32(1), 106-122. doi:10.1111/j.1467-9566.2009.01185.x


APPENDIX G

HUMAN SUBJECTS REVIEW
**Date:** June 30, 2014  
**Principal Investigator:** Sally M Miller  
**Protocol Number:** 1406376382  
**Protocol Title:** Tai Chi for Driving Health: Cognitive and Physical Function Related to Safe Driving Performance among Older Tai Chi Practitioners  
**Level of Review:** Exempt  
**Determination:** Approved  
**Documents Reviewed Concurrently:**  
- **Data Collection Tools:** Miller-CeriatricDepressionScreen.docx  
- **Data Collection Tools:** Miller-Mini-Cog.docx  
- **Data Collection Tools:** Miller-Screening.docx  
- **Data Collection Tools:** Miller-StudyPacket-rev-6-20-2014.docx  
- **HSPP Forms/Correspondence:** Miller-F107-v2014-01.doc  
- **HSPP Forms/Correspondence:** Miller-F200-v2014-02-06-23-2014.doc  
- **HSPP Forms/Correspondence:** Signature page.pdf  
- **Informed Consent/PHI Forms:** Miller-T502a-ICP-Consent-Form-v2014-01-rev-6-23-2014.pdf  
- **Other:** Miller-RailProtocol-rev-6-20-2014.docx  
- **Other:** Miller-References.docx  
- **Other:** Miller-MentalHealth-TN-KY-rev-6-20-2014.docx  
- **Participant Material:** Miller-AppointmentReminder.docx  
- **Participant Material:** Miller-Driver55-PlusBookletAAAFTSPdf  
- **Participant Material:** Miller-MentalHealth-TN-KY-rev-6-20-2014.docx  
- **Participant Material:** Miller-OlderWiserDriver-AAAFTSPdf  
- **Participant Material:** Miller-ProviderList-TN-KY.docx  
- **Recruitment Material:** Miller-RecruitmentFlyer-rev-6-20-2014.docx  

This submission meets the criteria for exemption under 45 CFR 46.101(b).  
- The University of Arizona maintains a Federalwide Assurance with the Office for Human Research Protections (FWA #00004218).  
- All research procedures should be conducted in full accordance with all applicable sections of the Investigator Manual.  
- Exempt projects do not have a continuing review requirement.  
- Amendments to exempt projects that change the nature of the project should be submitted to the Human Subjects Protection Program (HSPP) for a new determination. See the
Investigator Manual, 'Appendix C Exemptions,' for more information on changes that affect the determination of exemption. Please contact the HSPP to consult on whether the proposed changes need further review.

- All documents referenced in this submission have been reviewed and approved. Documents are filed with the HSPP Office. If subjects will be consented the approved consent(s) are attached to the approval notification from the HSPP Office.

Your proposal is in compliance with Federalwide Assurance 00004218. This project should be conducted in full accordance with all applicable sections of the IRB Investigators Manual and you should notify the IRB immediately of any proposed changes that affect the protocol. You should report any unanticipated problems involving risks to the participants or others to the IRB.

This project has been reviewed and approved by an IRB Chair or designee.
September 2, 2014

Sally M. Miller, RN MS
College of Nursing, The University of Arizona
Godchaux Hall 315  37240-1119

RE: IRB# 141269  "Tai Chi for Driving Health: Cognitive and Physical Function Related to Safe Driving Performance among Older Tai Chi Practitioners"

Dear Sally M. Miller, RN, MS:

A sub-committee of the Institutional Review Board reviewed the research application identified above. The sub-committee determined the study poses minimal risk to participants, and the application is approved under 45 CFR 46.110 (f)(4) and (f). Approval is extended for the Protocol dated 7/18/2014.

Please be reminded that this approval extends only to research activities conducted at Vanderbilt. Please submit documentation of IRB approval/letters of cooperation for non-Vanderbilt sites when it becomes available.

The Consent Forms have been stamped with the approval and expiration date and this copy should be used when obtaining the participant’s signature. Federal regulations require that the original copy of the participant’s consent be maintained in the principal investigator’s files and that a copy be given to the subject at the time of consent. An additional record (i.e., case report form, medical record, database, etc.) of the consent process should also be maintained in a separate location for documentation purposes.

As the Principal Investigator, you are responsible for the accurate documentation, investigation and follow-up of all possible study-related adverse events and unanticipated problems involving risks to participants or others. The IRB Adverse Event reporting policy may be found on the IRB website at http://www.mc.vanderbilt.edu/irb/.

If this trial requires registration as a clinical trial, accrual cannot begin until this study has been registered at clinicaltrials.gov and a National Clinical Trial Number (NCT) provided. Please provide the NCT# to the IRB as soon as it is obtained. If an approval is required from an additional source other than the Vanderbilt IRB, this must be obtained prior to study initiation. These approvals may include, but are not limited to, CRC, SRC, IND, IDE.

Please note that approval is for a 12-month period. Any changes to the research study must be presented to the IRB for approval prior to implementation.


Sincerely,
Richard A. Epstein, Ph.D., M.P.H., Vice-Chair
Institutional Review Board
Health Sciences Committee #1

RAE:ct
Electronic Signature: Richard AEpsm innovate
Signed On: 09/03/2014 05:17:34 PM CDT
APPENDIX H

DESCRIPTIVE STATISTICS
### Cognitive Measures – Descriptive Statistics

<table>
<thead>
<tr>
<th>Measure</th>
<th>Normative Reference Value M (SD)</th>
<th>Results M (SD)</th>
<th>Med</th>
<th>Min</th>
<th>Max</th>
<th>Interquartile Ranges</th>
<th>Skewness</th>
<th>Kurtosis</th>
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<tbody>
<tr>
<td>Digit Span Backward</td>
<td>5.34 (0.96)</td>
<td>5.02 (1.30)</td>
<td>5.00</td>
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<td>9</td>
<td>4.0</td>
<td>5.0</td>
<td>6.0</td>
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<td>7.53 (1.17)</td>
<td>8.0</td>
<td>5</td>
<td>9</td>
<td>7.0</td>
<td>8.0</td>
<td>9.0</td>
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<td>Driving Scenes Test</td>
<td>43.79 (8.18)</td>
<td>54.74 (4.80)</td>
<td>55</td>
<td>43</td>
<td>66</td>
<td>51</td>
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<tr>
<td>Maze Test (seconds)</td>
<td>39.18 (16.92)</td>
<td>35.21 (12.30)</td>
<td>34.22</td>
<td>16.47</td>
<td>66.62</td>
<td>25.48</td>
<td>34.22</td>
<td>44.51</td>
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<td>Useful Field of View, (subtest 2) (milliseconds)</td>
<td>206 (122)</td>
<td>147.88 (92.13)</td>
<td>100.00</td>
<td>100.00</td>
<td>417.00</td>
<td>100</td>
<td>100</td>
<td>135</td>
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<td>Visual Search and Attention – Part B (seconds)</td>
<td>95.45 (50.78)</td>
<td>98.90 (29.21)</td>
<td>96.77</td>
<td>55.78</td>
<td>181.44</td>
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<td>Visualizing Missing Information (items)</td>
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<td>1.84 (1.60)</td>
<td>2.00</td>
<td>0</td>
<td>8</td>
<td>1</td>
<td>2</td>
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Note: Max=Maximum; M=Mean; Med=Median; Min=Minimum; M; SD=Standard Deviation
Physical Measure, Categorical Variable – Descriptive Statistics

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<tr>
<th>Measure</th>
<th>Normative Reference Value Scoring</th>
<th>Results</th>
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<tr>
<td></td>
<td>n=265</td>
<td>N=58</td>
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<td>Head/Neck Flexibility</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td></td>
<td>n 204</td>
<td>n 28</td>
</tr>
<tr>
<td></td>
<td>% 77</td>
<td>% 48.30</td>
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<tr>
<td>Flexibility (pass/fail)</td>
<td>Fail</td>
<td>Fail</td>
</tr>
<tr>
<td></td>
<td>n 61</td>
<td>n 30</td>
</tr>
<tr>
<td></td>
<td>% 23</td>
<td>% 51.70</td>
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Physical Measure, Continuous Variables – Descriptive Statistics

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<th>Med</th>
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<th>Max</th>
<th>Interquartile Ranges</th>
<th>Skewness</th>
<th>Kurtosis</th>
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<tr>
<td>Rapid Walk Test (seconds)</td>
<td>7.97 (3.43)</td>
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<td>5.70</td>
<td>4.11</td>
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<td>5.25 6.38</td>
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<td>Right Foot Tapping Test</td>
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<td>6.07</td>
<td>3.13 3.94</td>
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Note: Max=Maximum; M=Mean; Med=Median; Min=Minimum; M; SD=Standard Deviation

Perceived Benefits of Tai Chi and Exploratory Eight Active Ingredients - Descriptive Statistics

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<th>M (SD)</th>
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<th>Kurtosis</th>
<th>Cronbach's alpha</th>
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<tr>
<td>Mindful Attention Awareness Scale (mean)</td>
<td>4.20 (.69)</td>
<td>4.70</td>
<td>3</td>
<td>6</td>
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<td>4.70 5.20</td>
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<td>.87</td>
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<tr>
<td></td>
<td>Possible range 1-6</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Vitality Plus Scale (total)</td>
<td>35 (7)</td>
<td>37.52</td>
<td>37</td>
<td>20</td>
<td>49</td>
<td>33 37 42</td>
<td>-0.24</td>
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<td>.78</td>
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<td></td>
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<td>37</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Eight Active Ingredients (exploratory)</td>
<td>26.66 (3.00)</td>
<td>27</td>
<td>19</td>
<td>32</td>
<td>24</td>
<td>27 29</td>
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<td>Possible range 8-32</td>
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Note: Max=Maximum; M=Mean; Med=Median; Min=Minimum; M; SD=Standard Deviation
APPENDIX I

SOURCES OF NORMATIVE REFERENCE VALUES
Sources of Normative Reference Values

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<tr>
<th>Measure</th>
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<th>Source</th>
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<td>Delayed Three Word Recall</td>
<td>.41 (.75)</td>
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<td>Digit Span Backward</td>
<td>5.34 (.96)</td>
<td>Bopp &amp; Verhaeghen (2005)</td>
</tr>
<tr>
<td>Driving Scenes Test</td>
<td>43.79 (8.18)</td>
<td>Brown, et al. (2005)</td>
</tr>
<tr>
<td>Maze Test</td>
<td>39.18 (16.92)</td>
<td>L. Staplin, personal communication, August 28, 2015</td>
</tr>
<tr>
<td>Useful Field of View (subtest 2)</td>
<td>206 (122)</td>
<td>NHTSA DOT HS 811 630 (August 2012)</td>
</tr>
<tr>
<td>Visual Search and Attention –Part B</td>
<td>95.5 (50.78)</td>
<td>NHTSA DOT HS 811 630 (August 2012)</td>
</tr>
<tr>
<td>Visualizing Missing Information</td>
<td>3.4 (2.39)</td>
<td>NHTSA DOT HS 811 630 (August 2012)</td>
</tr>
<tr>
<td><strong>Physical Measures</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head/Neck Flexibility</td>
<td>.77 (0.42) (Pass)</td>
<td>NHTSA DOT HS 809 583 (May 2003)             (residential sample)</td>
</tr>
<tr>
<td>Rapid Walk Test</td>
<td>7.97 (3.43) (active drivers, age 71+)</td>
<td>Staplin et al. (1999)</td>
</tr>
<tr>
<td>Right Foot Tapping Test</td>
<td>4.80 (1.56) (drivers only, age 72+)</td>
<td>NHTSA DOT HS 809 583 (May 2003)</td>
</tr>
<tr>
<td><strong>Self-report Measures</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitality Plus Scale</td>
<td>35 (7)</td>
<td>Myers, et al. (1999)</td>
</tr>
</tbody>
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