The Pennsylvania State University

The Graduate School

EVALUATION AND MODIFICATION OF THE MULTIFACTORIAL MODEL OF DRIVING SAFETY: AN EMPIRICAL ASSESSMENT USING THE ACTIVE STUDY

A Thesis in

Human Development and Family Studies

by

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ABSTRACT

Previous research has demonstrated that cognitive, visual, and physical performance are associated with driving safety among older adults. However, there are few comprehensive models examining how all such factors jointly impact driving safety. The present study first evaluated the Multifactorial Model of Driving Safety developed by Anstey’s team (2005), then modified this model according to recent research. We used structural equation modeling (SEM) to analyze the impact of cognition, vision and physical function on older adult’s driving safety using the baseline data from the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study. Participants (n = 2391) were between 65 and 91 years old, and 73.3% of were female. While the original model had a poor fit (CFI = 0.846, TLI = 0.777), the modified model demonstrated a good fit (CFI = 0.991, TLI = 0.986). There was a negative relationship between physical function and driving avoidance, and there was a positive relationship between cognition and physical function. Visual acuity was not associated with driving safety. Additionally, in our final modified model, driving avoidance partially mediated the relationship between physical function and crashes, which indicated that only the effect of physical function on crash operated through driving avoidance. This study highlights the importance of these predictors in older adults’ safe driving. Future research should examine possible dynamic changes between these predictors and driving in a longitudinal model.
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1. Introduction

1.1 Importance of Driving in Older Adults

Older drivers’ driving safety is attracting increased interest due in part to the recent steady growth of this population. More than 16% of the total population in the United States were aged 65 or older in 2018 (U.S. Census Bureau, 2018). Approximately 45 million of them had driver licenses, which was a 69% increase from 1999 (FHWA, 2018). This trend also raises an increasing traffic facility rate in this population. From 2009 to 2018, traffic fatalities among people age 65 and older increased by 30 percent (NHTSA, 2020). A total of 5,195 drivers age 70 and older died in motor vehicle crashes in 2019 (IIHS, 2021).

Driving is essential to maintaining health and the quality of life among older adults. Declined driving capacity is closely related to negative health outcomes, such as poor general self-reported health (Kandasamy et al., 2018; Sims et al., 2007), cognitive declines (Anstey et al., 2017; Wadley et al., 2020) and increased depressive symptoms (Bulmash et al., 2006; Hill et al., 2017), and older adults’ lack of control over their lives (Al-Hassani & Alotaibi, 2014; Musselwhite & Shergold, 2013; Windsor et al., 2007). Ragland, Satariano and MacLeod (2005) found both cross-sectional and longitudinal relationships between depression and driving cessation among people aged 55 years and older after controlling for changes in physical health and cognitive function. Depressive symptoms and negative emotions are more likely to appear not only among those who cease driving, but also those who reduce driving (Bergen et al., 2017). Additionally, driving cessation is correlated with reduced social network with friends, even among older adults who feel confident in using other transportation (Mezuk and Rebok, 2008). Former and never drivers have a higher risk of entering long-term institutions (Freeman et al., 2006), and lower life satisfaction (Liddle et al., 2012) compared with current drivers.
1.2 Predictors of Driving

Driving is a complex task that requires coordination across multiple domains including vision, cognition and physical performance (Anstey et al., 2005; Anstey et al., 2012; Owsley, 2002). Although considerable research has investigated the predictors of older adults’ driving safety (Classen et al., 2008; Dawson et al., 2010; Emerson et al., 2012), there are only a few models that take a multicomponent approach (e.g., the Multifactorial Model of Driving Safety from Anstey et al., 2005; the Multilevel Older Persons Transpiration and Road Safety model from Wong et al., 2016). Accurate theoretical models are required for future research to develop effective interventions to improve older adults’ driving safety. This paper used secondary data from healthy older drivers to evaluate and modify a multifactorial model developed by Anstey and colleagues (2005). In this model, cognition, physical function and vision indirectly influence older drivers’ driving behaviors through driving capacity and self-monitoring and beliefs about driving.

1.2.1 Cognition

Cognitive abilities, including attention, processing speed, reaction time and memory, play an important role in older adult’s driving performance. Selective attention is the ability to focus on a selected information and suppress other irrelevant information, which has been shown to decline with age (Geerligs et al., 2014). Visual divided attention is the ability to focus on more than one visual field locations (Owsley & McGwin, 2004). Poorer performances on selective attention and divided attention are correlated with negative driving outcomes of both crashes and on-road test (Anstey et al., 2005). The Useful Field of View test (Edwards et al., 2005) is one such measure where poorer performance is repeatedly associated with increased crash risk (De Raedt & Ponjaert-Kristoffersen, 2000; Huisingh et al., 2017; Owsley et al., 1998), more driving
avoidance (Ross et al., 2009; Vance et al., 2006), a higher risk of driving cessation (Ackerman et al., 2008; Edwards et al., 2008; Edwards et al., 2010), and worse on-road driving behavior (Willstrand et al., 2017). A meta-analysis concluded that the UFOV test is a predictor for on-road driving, simulator driving and driving problems (Mathias & Lucas, 2009). Bélanger, Gagnon and Yamin (2010) found that compared to older people who did not crash, those who experienced a crash had poorer processing speed (UFOV subtest 1) and worse divided (UFOV subtest 2) and selective attention (UFOV subtest 3). Structural equation models demonstrated that the divided attention subscale of UFOV significantly predicted driving impairment consisting of lane position variability, missed divided attention tasks, number of crashes, stoplight violations, number of time speeding, and course time (Hoffman et al., 2005).

Another processing speed test has also been found to be correlated with both driving safety and driving mobility in older adults. The Digit Symbol Substitution subscale from the Wechsler Adult Intelligence Scale is a commonly used measurement of processing speed (Salthouse, 1992). Chaparro, Wood and Carberry (2005) concluded that cognitive aging, measured by the Digit Symbol Substitution and trail tests, was a better predictor of on-road driving performance under dual task conditions than chronologic age. Better performance on this test was also associated with a lower composite score of unsafe driving among older drivers with or without early-stage dementia (Lafont et al., 2010), and a lower risk of driving cessation over a 5-year period (Anstey et al., 2006; Edwards et al., 2008). Older non-drivers have significant poorer performance on this test compared with current drivers (Anstey et al., 2006; Shimada et al., 2016). Therefore, the Digit Symbol Substitution test was used in this study as another indicator of cognition.
Reactions to hazard events in a timely manner are also important during driving. Reaction time measurements (simple and complex reaction time) are correlated with several unsafe driving incidents (McKnight & McKnight, 1999). Andrews and Westerman (2012) found that a slower response on simple reaction time task was associated with a higher level of mental workload after driving on a simulator, and a slower response on complex reaction time task was associated with lane position variations during driving. Older drivers’ worse complex reaction time was also correlated with collisions, traffic light violations and speed violations (Shanmugaratnam, Kass, & Arruda, 2010). As some researchers argued that complex reaction time rather than simple reaction test can better predict driving performance (Andrews and Westerman, 2012; Odenheimer et al., 1994), and there is no significant difference in simple reaction time between younger and older drivers according to Andrews and Westerman (2012), the present study used complex reaction time to predict older adults’ driving safety.

Previous studies have demonstrated the effects of impaired memory on older adults’ driving safety. Suspended drivers with crash involvement had a significantly worse performance on delayed recall of the Rey Auditory Verbal Learning Test (AVLT) and visual spatial memory (recall Rey-Osterreith complex figure) compared with suspended drivers without crash involvement (Lundberg et al., 1998). Anderson and colleagues (2005) also found that older adults’ poorer composite driving performance in a simulated drive was significantly correlated with lower AVLT abilities. Multiple regression models for older drivers’ on-road performance indicated a significant independent contribution of the Hopkins Verbal Learning Test (HVLT) for individuals with or without Alzheimer disease (Ott et al., 2008). Using the data from the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study, only worse AVLT performance was associated with driving cessation across 5 years, instead of HVLT
Even though AVLT was not a significant predictor of driving cessation, moving violation and crashes among older adults based on hazard regression models, Emerson and colleagues (2012) found that after comparing different multivariate models, AVLT was one of the predictors that could best predict moving violations and crashes. However, AVLT was not associated with older adults driving errors evaluated by a certified driving instructor in a short test drive on road (Dawson et al., 2010). Poorer Complex Figure Test recall score, which is also a visual memory test, has been correlated with more on-road errors among older adults (Dawson et al., 2010). The relationship between memory and driving safety is not limited to the measures of verbal and visual memory. Worse working memory is also correlated with poorer driving performance (Lambert et al., 2010) and a higher risk of driving cessation (Gallo et al., 1999). In the present paper, we included AVLT as the indicator of memory ability.

1.2.3 Vision

The relationships between visual impairment and driving outcomes are inconsistent in the literature (Anstey et al., 2005). Visual acuity is one of the most commonly used assessments of individuals’ visual function for licensing (Owsley, 2002). However, several studies do not find a significant association between older drivers’ visual acuity and driving exposure (Kaleem et al., 2012; Owsley et al., 2001; Sandlin et al., 2014), whereas some suggested that acuity is correlated with increased driving self-regulation (Freeman et al., 2006; West et al., 2003) and a higher risk of crashes (Ivers, Mitchell, & Cumming, 1999; Sims et al., 1998). More precisely, longitudinal data showed that worse baseline scores of visual acuity were associated with increased odds of reduced mileage driven and cessation of driving in unfamiliar areas two years later (Freeman et al., 2006). McGwin, Chapman and Owsley (2000) also concluded that decreased visual acuity was associated with self-reported driving difficulty when driving at night and on high traffic
roads. In an interactive simulator study, poor far visual acuity has been found correlated with more frequent off-road driving and longer waiting time when taking left turns among individuals aged between 18-81 (Guerrier et al., 1995). In this study, we used a large sample to investigate the relationship between visual acuity and driving safety.

1.2.4 Physical Function

Many physical functions have been associated with older adults’ driving, but results vary when different measurements tools are used to assess physical function or driving impairment. Hand grip strength is a measurement of hand muscular strength, which is a function similar to holding a steering wheel during driving. Current older drivers have a significant higher level of grip strength compared with those who ceased driving (Anstey et al., 2006; Shimada et al., 2016), and a lower grip strength is a significant predictor of driving cessation in two years (Anstey et al., 2006). However, among older drivers with dementia, there was no significant difference in grip strength between those who passed the on-road driving test and those who failed the on-road test (Carr et al., 2011). By using the ACTIVE data, worse performance on the Turn 360 test was correlated with poorer UFOV abilities (Ross et al., 2016) and driving cessation over a five-year period in a healthy population (Edwards et al., 2008; Edwards et al., 2009). Additionally, in that sample, time-varying declines in the Turn 360 test were associated with participants’ driving exposure and driving frequency changes, and time-varying declines in grip strength were associated with driving space changes across five years (Phillips et al., 2016). The physical functioning subscale of SF-36 has also been correlated with older adults’ driving cessation (Edwards et al., 2009), driving exposure and driving frequency (Phillips et al., 2016). However, no significant relationship has been found between physical function and driving safety performance, such as crash risk (Fraade-Blanar et al., 2018; Margolis et al., 2002;
Marottoli et al., 2015; Sims et al., 1998; Woolnough et al., 2013). In the present study, grip strength, Turn 360 Test and SF-36 physical functioning scale were used as indicators of older drivers’ physical functions.

1.3 Anstey’s Multifactorial Model of Driving Safety

Even though much research has examined potential predictors of older drivers’ safe driving, only a few studies incorporate all these factors and their interactions into one model. One of them is a multifactorial model developed by Anstey and colleagues (2005). They concluded that (see Figure 1): (a) “self-monitoring and beliefs about driving capacity” (p. 61) and “capacity to drive safely” (p.61) can both predict actual driving behaviors; and (b) cognitive, sensory and physical factors can all support driver safety. Self-monitoring and beliefs are the capacities of evaluating their physical and cognitive abilities, and adapting driving behaviors accordingly. Only cognitive abilities are consistently associated with self-monitoring and beliefs, compared with sensory and physical factors (Anstey et al., 2005). Capacity to drive includes off-road screening tests related to driving, such as UFOV, Hazard Perception Test, and Hazard Change Detection Test (Anstey et al., 2012). Cognition, sensory, and physical functions are intercorrelated and all related to the capacity to drive safely (Anstey et al., 2005). For instance, safe driving on road involves sensory ability to visually perceive the surrounding traffic information, cognitive ability to make a decision, and physical ability to quickly turn the steering wheel. Anstey’s team (2012) evaluated part of this model to examine the importance of cognitive and visual functions in relation to the capacity to drive safely using factor analysis and
hierarchical multiple regression. They found that cognitive factors explained a far greater proportion of variance in UFOV, Hazard Perception Test and Hazard Change Detection Test, which were all treated as the indicators of driving capacity, but visual acuity was still important in predicting these outcome variables (Anstey et al., 2012). Therefore, UFOV was used as the manifest variable of capacity to drive safely when evaluating Anstey’s original model in this study. However, to our knowledge, this model has not been fully evaluated by an empirical study, so our overarching goal of this study is to evaluate and modify it as a whole.

Older adult’s driving skills can be accessed using different off-road tests and on-road tests. As Anstey and colleagues (2012) indicated, drivers’ actual “driving behavior” can be tested using on-road designs; alternatively, off-road tests measure their capacity to drive safely. We can track individuals’ on-road performance not only by installing electronic devices in cars, but also by using driving simulators. However, recording their crash rates is the most common way to access older adults’ on-road driving performance, even though it is an infrequent event. Although self-reported and state-reported crashes were not highly correlated when measuring older drivers across five years (Ball et al., 1993; McGwin, Owsley, & Ball, 1998), there is a substantial agreement between self-reported and state-reported crashes over a 3-year period (Singletary et al., 2017). Thus, we used self-reported crashes in the last two years as an indicator of older driver’s “driving behavior” in the present study.

1.4 Goals of the present study

The first aim of the present study was to evaluate Anstey’s Multifactorial Model of Driving Safety (see Figure 1) by using the data from the ACTIVE study. Specifically, we tested the model fit and pathways proposed by this model. According to Anstey’s original model (2005): (1) older drivers’ vision and physical function positively influence their driving capacity;
(2) people with better cognitive ability have a lower-level self-monitoring and beliefs about driving capacity; and (3) both capacity to drive safely and self-monitoring and beliefs are positively correlated with their on-road driving behaviors. Anstey’s model (2005) also indicated that capacity to drive safely and self-monitoring and beliefs are mediators between various predictors and driving behaviors. Therefore, we hypothesized that in our sample, these mediation effects would be significant as outlined by Anstey’s model, namely: (1) UFOV would fully mediate the effects of cognition, visual acuity and physical function on crash; and (2) self-monitoring and beliefs would fully mediate the effect of cognition on crash.

The second aim of this study was to modify the Multifactorial Model of Driving Safety. Importantly, we proposed a new modified model based on the literature through two steps. First, we changed the variable structure in the first modified model (Model 1; see Figure 2) through: (1) the UFOV test was fitted in the latent variable of cognition instead of the capacity to drive safely, since this is a cognitive measurement of visual processing speed (Edwards et al., 2005); (2) the latent variable of “self-monitoring and beliefs about driving capacities” was separated into two different factors: self-monitoring behavior and self-beliefs about driving; and (3) the measurement of driving avoidance was used as the manifest variable of self-monitoring behavior in driving, and self-rated driving quality was treated as the manifest variable of self-beliefs about driving.

Second, we then modified the path structure as follows (Model 2; see Figure 3):

(1) Since previous research demonstrates that older drivers’ driving self-regulation is correlated with visual acuity (Freeman et al., 2006; Kaleem et al., 2012; Owsley et al., 2001; Sandlin et al., 2014; West et al., 2003), we added a
path from visual acuity to self-monitoring. We hypothesized that worse visual acuity would be correlated with more driving avoidance.

(2) There was a path from physical function to self-monitoring behaviors (e.g., Phillips et al., 2016) instead of physical function to driving performance (e.g., Sims et al., 1998). We hypothesized that better physical function would be correlated with less driving avoidance.

(3) A correlation between cognition and physical function was added based on previous research (e.g., Clouston et al., 2013). We hypothesized that there would be a positive relationship between cognition and physical functions.

(4) Studies have found that a higher level of self-monitoring driving is correlated with poorer self-reported driving abilities (e.g., Langford et al., 2013), thus a hypothesized negative correlation between these two variables was added.

In terms of the mediation effects of the modified model, (1) driving avoidance was hypothesized to partially mediate the effect of cognition and visual acuity on crash; (2) driving avoidance was hypothesized to fully mediate the effect of physical function on crash; and (3) self-reported driving quality was hypothesized to partially mediate the effect of cognition on crash. We also hypothesized that the Model 2 would be significantly improved in terms of its fit with the data compared with the Model 1.
Figure 1. *Original Model - Multifactorial Model of Driving Safety (Anstey et al., 2005)*

![Diagram](image1.png)

Figure 2. *Modified Model 1 - Change in Variable Structure*

![Diagram](image2.png)

Note. Changes are highlighted in yellow.
Note. Changes are highlighted in red.

2. Method

2.1 Participant

This paper used the baseline data from the ACTIVE study, which was a randomized controlled trial designed to assess how different types of cognition interventions (speed of processing, memory, and reasoning) can improve cognition, health and everyday functions among older adults across years (Jobe et al., 2001). Participant recruitment started from 1998, and a total of 2832 persons were enrolled in the trial. Participants were excluded if they: (a) already had symptoms of cognitive decline (score of 23 or less out of 30 points on the Mini-Mental State Examination); (b) self-reported that they needed assistance for their daily activities, such as dressing; (c) had severe sensory losses; (d) had medical conditions that may influence their cognitive functioning; (e) recently had taken other cognitive training; or (f) had communication difficulties that may influence their training progress. 2802 of them fulfilled the
screening criteria, and were required to finish all the baseline measurements. 400 participants were excluded because they were not current drivers or did not report their driving status at baseline, 1 participant was excluded because he reported 10 crashes in the past two years, which was an outlier, and 10 participants were excluded because they did not report their crash history at baseline. The final sample consists of 2391 drivers (age range from 65-91, $M_{\text{age}} = 73.28$, $SD = 5.70$), 73.3% were female, and 75.7% were Caucasians. Their average years of education were 13.75 ($SD = 2.69$). Table 1 displays the sociodemographic characteristics of this sample.

Table 1 – Sample Characteristics ($N = 2391$)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percentage</th>
<th>Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td></td>
<td>73.28 (5.70)</td>
<td>65-91</td>
</tr>
<tr>
<td>Years of education</td>
<td></td>
<td>13.75 (2.69)</td>
<td>4-20</td>
</tr>
<tr>
<td>Sex, female</td>
<td></td>
<td>73.3</td>
<td></td>
</tr>
<tr>
<td>Race</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td></td>
<td>75.7</td>
<td></td>
</tr>
<tr>
<td>African American</td>
<td></td>
<td>23.5</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>0.8</td>
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</table>

2.2 Measures

2.2.1 Cognition

Reaction time. The Complex Reaction Time (CRT; Ball & Owsley, 2000) test measures how quickly they can recognize, react to, or ignore the changing of one of four possible traffic signs (pedestrian, bicycle, right and left turn arrows). Participants are required to identify these signs without a red slash. When there are bicycle and pedestrian signs without a slash on the
screen, participants are asked to press a button by using the mouse. When the arrow signs
without a slash show on the screen, they should move the mouse to the direction indicated by the
arrow. An average score of these trials was calculated. Lower scores signify better reaction time
speed performance.

*Memory*. The Rey Auditory Verbal Learning Test (AVLT; Schmidt, 1996) is a measure
of verbal memory ability by counting numbers of words recalled across five trials. For each trial,
they are asked to recall as many words as they can from the audiotape of 15 words. Tester code 1
if they can recall the word, and code 0 if they can’t recall the word. A composite score across
five trials was calculated, and higher scores correlate with better verbal memory.

*Processing speed*. Digit Symbol Substitution test (Wechsler, 1981) measures how fast
participants can pair a number between 1 and 9 with it associated nonsense symbol according to
a key. In 90 seconds, the total number of correct substitutions was recorded for each participant.
The score range is from 0 to 100, and higher scores associate with better processing speed
performance.

### 2.2.2 Vision

*Far visual acuity (Rubin & Salive, 1995)*. It was measured with the Good-Lite LD-10
Chart in a Good-Lite Model 600A light box. Participants were allowed to wear their usual indoor
glasses. The score range of this test is from 0 (approximate logMAR score of 0.8) to 90
(approximate logMAR score of -0.1); the higher the score the better the performance. A logMAR
score of 0.3 is a cutoff score for driving licensure in most states of the USA (Prevent Blindness,
2020).
2.2.3 Physical Function

**Turn-360 Test** (Steinhagen-Thiessen & Borchelt, 1999). This task is used to test lower-limb physical function. Participants are asked to make two complete turns quickly and safely from a standing position. Their average steps of the two turns are recorded, and less steps prove their better physical functions. Since the steps of the two turns were highly correlated in this sample ($r = 0.84$), we used the complete one as the average score if they only finished one turn.

**Grip Strength** (Ferrucci et al., 1995). It is an instrument to test the strength in their hands by squeezing two pieces of metal together. The value (in kg) on the dynamometer is recorded across two trials, and the average score was calculated. The complete one was used as the average score if they only finished one trial, since their scores on these two trials were highly correlated ($r = 0.95$). Higher scores mean better performance.

**SF-36 Physical Functioning scale.** SF-36 is a self-reported survey of health status, which consists of eight different scales (Ware and Sherbourne, 1992). The scale used in this study was the Physical Functioning scale. It includes 10 items measuring how health influences participants’ activities, such as lifting or carrying groceries, climbing stairs and walking. The score range of this scale is from 0 to 100, higher scores reflecting better physical functioning.

2.2.4 Self-Monitoring and Beliefs about Driving Capacity

**Driving avoidance** was measured by the Driving Habits Questionnaire (Owsley et al., 1999), which reflects the number of driving situations a driver avoids in the last 2 months. Situations include driving in the rain, driving alone, making left-hand turns, merging in traffic while entering a highway, driving on high traffic roads, driving in rush-hour traffic, driving at night and making lane changes. Higher scores indicate more driving avoidance behaviors.
*Self-reported driving quality* is examined by a five-point Likert scale, from “excellent” to “poor” (Owsley et al., 1999). Participants are asked to report “how would you rate the quality of your own driving”. Higher scores mean they have poorer self-rated driving quality.

### 2.2.5 Capacity to Drive Safely

*Useful Field of View (Ball et al., 1993).* The UFOV test measures older adult’s change of information processing speed, proficiency in dividing attention and selecting attention (Edwards et al., 2005). It consists of four subtests, processing speed (central identification task), divided attention (adding a peripheral location task to the central identification task), divided attention and inhibition (similar with the second subtest), and selective attention (central discrimination task along with the simultaneous peripheral localization task with distractors). A composite score across these four subtests was calculated and converted to Z score. Lower scores indicate better performance on speed of processing.

### 2.2.6 Driving Behavior

*Crash.* Participants were asked to self-report how many accidents they had involved in over the past two years, including all accidents regardless of fault. 82.3% of them (n = 1967) reported no crash, 15.3% (n = 365) reported one crash, 2.5% (n = 59) reported more than one crashes. In this study, participants’ crash number was recoded as a binary variable: if they reported no crash, they got a score of 0; if they had reported any crashes, they got a score of 1.
2.3 Analysis

Descriptive analyses were conducted first to explore older adults’ cognitive, visual, physical and driving characteristics, and correlations among these measurements. Pearson correlations were estimated between pairs of continuous variables, and Spearman correlations were estimated when one or both variables are ordinal. Then, to evaluate Anstey’s Multifactorial Model of Driving Safety, we used Structural Equation Modeling (SEM) to determine how cognition, visual acuity and physical factors can influence older adults’ crash number through self-monitoring and beliefs about driving safety and UFOV (see Figure 1). A good model fit was determined by the likelihood ratio chi-square statistic ($\chi^2; p > .05$), Bentler’s Comparative Fit Index (CFI; > .95), the Tucker-Lewis Index (TLI; > .90), and the Steiger-Lind Root Mean Square Error of Approximation (RMSEA; < .08). To investigate the mediation effects of this model, the total, direct and indirect effects of cognition, visual acuity and physical function on crashes were tested. To test our second aim, separate SEM models were conducted to test the modified Model 1 (see Figure 2) and Model 2 (see Figure 3). A chi-square difference test was conducted to compare these two modified models. Since the original model and the modified models were not nested, we used the CFI and TLI (higher is better) to compare the original model and the final modified model. The total, direct and indirect effects of cognition, visual acuity and physical function on crashes were also be tested in the modified models to investigate the mediation effects of driving avoidance and self-reported driving quality. All models in this study were estimated using the lavaan package in R (Rosseel, 2020). We used the diagonally weighted least squares (DWLS) estimation since there were ordinal variables included in the models (Jia & Wu, 2019).
3. Results

Results of descriptive statistics and bivariate correlations between the variables in this study are present in Table 2. Pearson correlations were estimated between pairs of continuous variables, and Spearman correlations were estimated when one or both variables were ordinal. Only cognitive predictors (memory, processing speed and reaction time) and some physical predictors (Turn 360 and SF-36 physical functioning) are significantly correlated with self-reported crashes in older drivers. All the predictors are significantly correlated with their driving avoidance and self-reported driving quality.
Table 2 - Means, Standard Deviations, Score Range, and Correlations between Variables.

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<th>Measures</th>
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<td>1. Age</td>
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<tr>
<td>2. Complex Reaction Time</td>
<td>0.31*</td>
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<tr>
<td>3. AVLT</td>
<td>-0.35*</td>
<td>-0.33*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Digit Symbol Substitution</td>
<td>-0.31*</td>
<td>-0.39*</td>
<td>0.45*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5. UFOV</td>
<td>-0.44*</td>
<td>0.41*</td>
<td>-0.37*</td>
<td>-0.49*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Visual acuity</td>
<td>-0.31*</td>
<td>-0.15*</td>
<td>0.14*</td>
<td>0.19*</td>
<td>-0.27*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Turn-360</td>
<td>0.30*</td>
<td>0.19*</td>
<td>-0.22*</td>
<td>-0.23*</td>
<td>0.24*</td>
<td>-0.14*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>8. Grip strength</td>
<td>-0.17*</td>
<td>-0.13*</td>
<td>-0.08*</td>
<td>0.00</td>
<td>-0.16*</td>
<td>0.11*</td>
<td>-0.18*</td>
<td>-</td>
<td></td>
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<tr>
<td>9. SF-36 Physical Functioning</td>
<td>-0.16*</td>
<td>-0.16*</td>
<td>0.14*</td>
<td>0.24*</td>
<td>-0.18*</td>
<td>0.10*</td>
<td>-0.29*</td>
<td>0.16*</td>
<td>-</td>
<td></td>
<td></td>
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<tr>
<td>10. Driving avoidance</td>
<td>0.19*</td>
<td>0.14*</td>
<td>-0.10*</td>
<td>-0.16*</td>
<td>0.22*</td>
<td>-0.13*</td>
<td>0.13*</td>
<td>-0.19*</td>
<td>-0.21*</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Self-reported driving quality (o)</td>
<td>0.12*</td>
<td>0.12*</td>
<td>-0.04*</td>
<td>-0.09*</td>
<td>0.16*</td>
<td>-0.13*</td>
<td>0.04</td>
<td>-0.13*</td>
<td>-0.13*</td>
<td>0.21*</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>12. Self-reported crashes (o)</td>
<td>0.04</td>
<td>0.05*</td>
<td>-0.05*</td>
<td>-0.04*</td>
<td>0.04</td>
<td>-0.02</td>
<td>0.06*</td>
<td>0.01</td>
<td>-0.08*</td>
<td>-0.02</td>
<td>0.08*</td>
<td>-</td>
</tr>
</tbody>
</table>

**Mean (SD)**

<table>
<thead>
<tr>
<th></th>
<th>73.28</th>
<th>1.98</th>
<th>48.98</th>
<th>41.39</th>
<th>913.03</th>
<th>73.96</th>
<th>6.79</th>
<th>24.58</th>
<th>70.95</th>
<th>4.66</th>
<th>1.89</th>
<th>0.2</th>
</tr>
</thead>
</table>

| Score Range    | 65-91 | 0.87-15.63 | 0-73 | 0-92 | 312-2000 | 31.8-90 | 1-20 | 1.5-63 | 0-100 | 0-62.5 | 1-5 | 0-3 |

Note. (o) = ordinal variable; *p < .05
3.1 Measurement model

The two-step approach suggested by Anderson and Gerbing (1988) was used to examine the mediation effects in these models. In the first step, the measurement model was tested by using confirmatory factor analysis to show the relationships between measurements and their latent factors. It included eight observed variables and three latent variables. The measurement model did not fit well ($\chi^2 (17) = 151.360, p < 0.001, CFI = 0.918, TLI = 0.864, RMSEA = 0.063$) according to cutoff scores suggested by Smith and McMillan’s review paper (2001). A good model fit was determined by the likelihood ratio chi-square statistic ($\chi^2; p > .05$), Bentler’s Comparative Fit Index (CFI; > .95), the Tucker-Lewis Index (TLI; > .90), and the Steiger-Lind Root Mean Square Error of Approximation (RMSEA; < .08). We included the covariation between memory and grip strength to the measurement model after inspecting the modification indices (MI), then the model was acceptable ($\chi^2 (16) = 92.167, p < 0.001, CFI = 0.953, TLI = 0.918, RMSEA = 0.049$). Previous research also indicated the relationships between memory and grip strength in older adults (Sternäng et al., 2016). All the factor loadings of indicators on latent variables were significant ($p < .001$), which indicated that the latent variables were well represented by their indicators.

3.2 Structural model

In the second step, the full structural models were tested. Our model testing Anstey’s original structure had poor fit after adding the covariation from the measurement model ($\chi^2 (38) = 2209.308, p < 0.001, CFI = 0.846, TLI = 0.777, RMSEA = 0.171$). As Figure 4 displayed, all the pathways were significant ($p < .001$), except for the regression between self-monitoring and
beliefs about driving capacity and crashes ($\beta = 0.02, p = 0.784$). We first tested the total effects between cognition, visual acuity, physical function and crashes. The results indicated that only the total effect between visual acuity and crashes was not significant ($\beta = 0.07, p = 0.093$). We then tested the standardized direct and indirect effects between predictors and crashes. We found that all the direct effects were not significant, but the indirect effects between cognition ($\beta = 0.21, p = 0.005$), physical function ($\beta = 0.10, p = 0.007$) and crashes through UFOV were significant. Therefore, UFOV fully mediated the relationships between cognition and crashes, and physical function and crashes.

Figure 4. Anstey’s Original Model

Note. Significant pathways are represented by solid lines, and non-significant pathways are represented by dotted lines.

To investigate our second aim of modifying the Multifactorial Model of Driving Safety, we first tested the Modified Model 1 (Figure 2). We treated UFOV as an observed variable of cognition, and treated driving avoidance and self-reported driving quality as two separate
variables. Overall, this structural model also revealed a poor fit to the data: $\chi^2 (38) = 2487.538, p < 0.001$, CFI = 0.826, TLI = 0.749, RMSEA = 0.182. Even though the Modified Model 1 and the original model are not nested, the CFI and TLI indicated the Model 1 was worse than Anstey’s original model. In the Model 1 (see Figure 5), the relationship between visual acuity and crashes was not significant ($p = 0.099$).

Figure 5. Modified Model 1

[Diagram of the Modified Model 1]

Note. Significant pathways are represented by solid lines, and non-significant pathways are represented by dotted lines.

In the Modified Model 2 (Figure 6), we re-specified the Modified Model 1 by adding correlation between cognition and physical function, correlation between driving avoidance and self-reported driving quality, relationship between visual acuity and driving avoidance, and relationship between physical function and driving avoidance; and by deleting the relationship between physical function and crashes. Even though the Chi-square test of this model was still significant ($\chi^2 (35) = 158.931, p < 0.001$) because of the large sample size, other indices
indicated a good fit to the data: CFI = 0.991, TLI = 0.986, RMSEA = 0.043. All the pathways were significant (see Figure 6), except for the relationships between visual acuity and driving avoidance \( (p = 0.068) \), visual acuity and crashes \( (p = 0.428) \), and cognition and driving avoidance \( (p = 0.074) \). As we hypothesized, more physical function barriers were correlated with more driving avoidance \( (\beta = -0.27, p < 0.001) \), more driving avoidance was associated with poorer self-reported driving quality \( (\beta = 0.19, p < 0.001) \), and there was a positive relationship between cognition and physical function \( (\beta = 0.61, p < 0.001) \).

In order to investigate the mediation effects in this model, we first tested the total effects of predictors (cognition and physical function) on the dependent variable (crashes) without mediators. Since the relationship between visual acuity and driving avoidance was not significant, the total effect of visual acuity on crashes was not tested again. The total standardized path coefficient between cognition and crashes \( (\beta = -0.02, p = 0.727) \) was not significant, but the coefficient between physical function and crashes was significant \( (\beta = -0.14, p = 0.033) \). In the next step, we found that the direct effect between physical function and crashes \( (\beta = -0.157, p = 0.030) \), and the indirect effect through driving avoidance \( (\beta = 0.035, p = 0.015) \) were both significant. Therefore, there were no mediation effects of driving avoidance and self-reported driving quality between cognition, visual acuity and crashes, but driving avoidance partially mediated the relationship between physical function and crashes.
3.3 Model comparison

The model fit indices of the three structural models (Anstey’s original model, Modified Model 1 and Modified Model 2) are displayed in Table 3. According to CFI and TLI, the Modified Model 2 was the most parsimonious model among the three models. Additionally, the chi-square difference test indicated that the Model 2 was significantly better than the Model 1 ($\Delta \chi^2 = 2328.6$, $p < 0.001$).

Table 3 – Model fit indices of all models and model comparison result between Modified Model 1 and Modified Model 2.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$ (df)</th>
<th>CFI</th>
<th>TLI</th>
<th>RMSEA</th>
<th>$\Delta \chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original model</td>
<td>2209.308 (38)</td>
<td>0.846</td>
<td>0.777</td>
<td>0.171</td>
<td>-</td>
</tr>
<tr>
<td>Modified Model 1</td>
<td>2487.538 (38)</td>
<td>0.826</td>
<td>0.749</td>
<td>0.182</td>
<td></td>
</tr>
<tr>
<td>Modified Model 2</td>
<td>158.931 (35)</td>
<td>0.9991</td>
<td>0.986</td>
<td>0.043</td>
<td>2328.6***</td>
</tr>
</tbody>
</table>

Note. *** $p < 0.001$. 

Note. Significant pathways are represented by solid lines, and non-significant pathways are represented by dotted lines.
4. Discussion

Anstey’s Multifactorial Model of Driving Safety (2005) was a comprehensive model of
driving safety for older adults that included relationships among cognition, vision, physical
function, perceptions, and driving safety. The purpose of this study was first to evaluate this
model with a large sample (Aim 1), and then to modify this model to better present the pathways
between the predictors and safety driving (Aim 2). To our knowledge, this is the first study to
empirically test the full Multifactorial Model of Driving Safety. To test Anstey’s original model,
we used reaction time, memory and processing speed as the manifest variables of cognition;
visual acuity as the indicator of vision; turn-360, grip strength and SF-36 physical function scale
as the manifest variables of physical function; and driving avoidance and self-reported driving
quality as the manifest variables of self-monitoring and beliefs about driving capacity. Aim 1
found that Anstey’s original model had a poor model fit (CFI < .95 and TLI < .90) in this
sample. Additionally, only UFOV has been found fully mediate the relationships between
cognition, physical function and crashes as originally proposed. It is important to note that the
original model was developed based on the literature through 2004; however, it had not been
fully evaluated by an empirical study. More evidence about the pathways between cognition,
vision, physical function and driving has been published since 2004. For instance, the
relationship between physical function and self-monitoring in driving has been found in previous
research (Anstey et al., 2006; Edwards et al., 2008; Edwards et al., 2009; Phillips et al., 2016;
Shimada et al., 2016). Some recent research also indicated that there is no significant association
between physical function and driving performance (Fraade-Blanar et al., 2018; Marottoli et al.,
2015; Woolnough et al., 2013). Additionally, visual acuity has been found correlated with
driving self-regulation (Freeman et al., 2006; Kaleem et al., 2012; Sandlin et al., 2014).
Therefore, aim 2 expanded Anstey’s model (2005) based on recent findings to better comprehensively represent the relationships between cognition, physical function, vision and driving safety. First, the UFOV test was fitted in latent construct of cognition; and self-monitoring and beliefs about driving capacity was separated into driving avoidance and self-reported driving quality. As the model did not fit well (CFI < .95, TLI < .90 and RMSEA > .08), adjustments were made according to previous findings with the inclusion of a path between cognition and physical function, a path between driving avoidance and self-reported driving quality, a path from visual acuity to driving avoidance, and a path from physical function to driving avoidance. Moreover, the path from physical function to driving avoidance was deleted. We found a good model fit of this modified model (CFI > .95, TLI > .90 and RMSEA < .08).

Some relationships are consistent with previous research. First, individuals with worse physical function tend to have more driving avoidance behaviors (Edwards et al., 2009; Phillips et al., 2016). Second, the positive relationship between cognition and physical function has also been reported previously (Auyeung et al., 2008; Clouston et al., 2013; Fitzpatrick et al., 2007). In other words, the three predictors of older adults’ driving safety, cognition, vision and physical function, were all correlated with each other. Third, more driving avoidance was also correlated with poorer self-reported driving quality (Langford et al., 2013; Ross et al., 2012). This evidence suggests that healthy older drivers are able to limit their driving according to their perceived driving abilities.

However, we did not find significant relationships between visual acuity and driving avoidance and crashes. As Anstey and colleagues (2005) mentioned, there was no consistent conclusion between visual acuity and crash risk. Near and far visual acuity tests are most commonly used in research. Huisingh and colleagues (2017) concluded that both near and far
visual acuity scores were not correlated with different types of crash and near-crash involvement. Another study found that except for near visual acuity, far visual acuity and contrast sensitivity were all not associated with driving safety errors (Dawson et al., 2010). Emerson et al. (2012) found near visual acuity and contrast sensitivity can predict older adults’ time to driving cessation, but not their moving violations on road and risk of crashes, and far visual acuity was not significantly correlated with any results. One possible explanation is that older adults’ driving safety is not correlated with far visual acuity tested by Early Treatment Diabetic Retinopathy Study measurement (Dawson et al., 2010; Emerson et al., 2012; Kaleem et al., 2012; Sandlin et al., 2014), but its relationship with near visual acuity is not clear since they used different measurements of near visual acuity. Another explanation could be we only included participants without severe sensory losses in this study. Future research should investigate the driving safety in the sample of older adults with various levels of visual ability. Visual acuity is an integrate measurement of visual function, but individuals with impaired contrast sensitivity may have normal visual acuity (Appavoo & Chacko, 2005). Contrast sensitivity measures the ability to identify luminance differences between an object and its background (Amesbury & Schallhorn, 2003). Visual acuity sometimes is not a good measure of visual function because many objects in the real world do not have the same small size and contrasts (Ginsburg, 2003). Sandlin, McGwin and Owsley (2014) have concluded that impaired contrast sensitivity was associated with reduced driving mileage and exposure, but visual acuity deficit was not associated with driving exposure. It is possible that contrast sensitivity might be a good predictor of older adults’ self-regulation on road. Future research should also compare how visual acuity and contrast sensitivity influence their driving in different scenarios, and their underlying mechanisms when dealing with these visual scenarios.
This study also highlighted the mediation effects within these driving safety models. In the Multifactorial Model of Driving Safety, older adults’ driving behaviors were not directly influenced by these factors, but through the paths of self-monitoring and beliefs about driving capacity and capacity to drive safely (Anstey et al., 2005). According to their definitions, the two mediators cannot be tested on road, but are based on the self-report and off-road test. We found in Anstey’s original model, UFOV fully mediated the relationships between cognition, physical function and crashes, and in our final modified model, only driving avoidance partially mediated the relationship between physical function and crashes. Future research should choose measurements which can directly measure these two mediators.

4.1 Limitations and future directions

This study still has some limitations. First, we only included visual acuity as the indicator of vision, and we did not find any significant relationships between visual acuity and driving outcomes (driving avoidance and crash). One way to improve this study is to use diverse manifest measurements of vision, such as contrast sensitivity and visual field. Previous research has demonstrated the relationships between contrast sensitivity, visual field and driving avoidance in older adults (Emerson et al., 2012; Freeman et al., 2006; Sandlin et al., 2014). For instance, worse baseline contrast sensitivity and central and peripheral visual field have been found correlated with a higher risk of driving avoidance in mileage and night driving with odds ratios of more than 2.1 (Freeman et al., 2006). West and colleagues (2003) concluded that visual tests which contribute to binocularity, such as stereoscopic vision and central visual field, were associated with nonvision-related driving avoidance; but measures of spatial vision were associated with vision-related driving avoidance. Another way to improve this study is to remove
this visual factor or combine it with other sensory factors, such as hearing. Models without the latent variable of vision should be tested to keep only useful factors in the model.

Second, additional metrics of driving safety should be examined. Even though crash data is one of the best ways to investigate a large population, sometimes it is not sensitive enough to detect individuals’ potential driving risk on road. Some studies now are using digital cameras installed in car or using a driving simulator to obtain participants’ time-to-time changes on road (e.g., Lee et al., 2003; Michaels et al., 2017; Wang & Xu, 2019). Simulated driving, but not self-reported crash, has been found highly correlated with on-road driving performance in older drivers with or suspected of diminished driving abilities (Urlings et al., 2018). As Anstey and colleagues (2009) discussed in the paper, using self-reported crashes over a 5-year period had some validity to evaluate older adults’ driving safety, but it was subject to memory bias, especially for people with cognitive impairment. Future studies should also include older adults’ driving behaviors on road or on a driving simulator as the manifest variables of driving behavior.

Third, there are some other important factors that play an important role in older adults’ driving performance. To develop a more comprehensive model, future studies could include other factors to better explain their driving behaviors. For instance, advancing age is more likely to bring a higher risk of crash. Drivers age 70 and older had more crashes per mile driven than middle-aged drivers (IIHS, 2019). In addition, some research suggested that there is a gender difference in driving behaviors. More men died in motor vehicle crashes than women (IIHS, 2019), but female drivers were more likely to self-regulate driving under certain adverse conditions, such as at night or during rush hour (Bauer et al., 2003). Therefore, it is also important to include some demographic factors to the model. Last but not least, the present study
only included baseline data. Future research should explore the dynamic change between predictors and driving safety in a longitudinal model.

4.2 Implications

In conclusion, our study provides insights into the relationships between cognition, vision, physical function and crash, through the paths of capacity to drive safely and self-monitoring and beliefs about driving capacity. Even though Anstey’s original Multifactorial Model of Driving Safety did not fit well with our data, we figured out a better modified model based on previous findings. Our findings indicate that cognition and physical function are significant predictors of driving safety, and cognition, vision and physical function predictors are correlated with each other. Additionally, driving avoidance and self-reported driving quality are correlate with each other, and both have an impact on the crash risk among older adults. The modified model facilitates us to better understand these relationships with synthetic results. Future research could improve this model and develop interventions that aim towards improving older adults’ driving safety.
References


among older drivers using naturalistic driving data. *Investigative ophthalmology & visual science, 58*(7), 2959-2967.


