

**Modeling of Older Adults' Driving Exposure and Avoidance Using Objective Driving Data in A Naturalistic Driving Study**

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## 1 ABSTRACT

2 Older adults in the United States heavily rely on driving their own vehicles to commute to work,  
3 shop for groceries and access public services. To effectively help older adults maintain mobility  
4 and independence, we need to better understand how the cognitive, visual functioning, and health  
5 declines influence their tendency to self-restrict their driving. The objective of this study is to  
6 develop a causal model to examine the effects of age, gender, household status (specifically  
7 living alone), physical, cognitive, visual abilities, and health status on older adults' driving  
8 mobility in terms of driving exposure and avoidance. Driving exposure was measured by actual  
9 driving data, whereas driving avoidance was assessed by both self-report data and actual driving  
10 exposure to challenging situations. Structural Equation Modeling (SEM) was used to analyze  
11 data collected in the Strategic Highway Research Program 2 (SHRP 2) Naturalistic Driving  
12 Study for establishing relationships between the selected factors and mobility. The SEM  
13 included a total of 794 participants aged 65 and over (367 or 46.22% females and 427 or 53.78%  
14 males). The modeling results indicate that poorer health is associated with less driving exposure;  
15 deteriorating cognitive and physical functions are associated with more self-reported driving  
16 avoidance and less actual driving in challenging situations; visual function is associated with  
17 self-reported avoidance; living alone is associated with higher driving exposure in general as  
18 well as in challenging situations; self-reported driving avoidance of challenging situations has a  
19 negative association with actual driving in those same situations. The final model could be  
20 applied to predict older adults' mobility changes according to their age, gender, living alone,  
21 visual, physical, cognitive and health status.

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1    **Keywords:** Older drivers; Driving avoidance; Driving exposure; Structural equation modeling;  
2    Naturalistic driving study  
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## 1. INTRODUCTION

The U.S. population aged over 65 is predicted to reach 83.7 million by 2050 (Ortman, Velkoff, & Hogan, 2014) and the percentage of older adults' licensed to drive is on the rise (U.S. Department of Transportation., 2017). The ability to drive is essential to independent living and quality of life for older adults in the US, where 75% of the population resides in rural and suburban areas (Carp, 1988; Kaplan, 1995; Rosenbloom & Herbel, 2009). Older adults in the US rely heavily on driving their own vehicles to commute to work, shop for groceries, or access public services. Musselwhite and Haddad (2010, 2018) formulated a hierarchical mobility model to illustrate that mobility is important not only to satisfy practical needs but also for social or affective, as well as aesthetic aspects of life. Driving reduction or cessation for older adults was associated with reduced activity outside of the home, increased dependency on others for transportation, decreased independence, loss of self-identity, reduced life satisfaction, and emergence of more depression symptoms (Chihuri et al., 2016; Harrison & Ragland, 2003).

Aging commonly leads to declines in visual, cognitive, and physical functioning in addition to the emergence of other health issues that could increase crash risks for older adults (Lombardi, Horrey, & Courtney, 2017; Pitta et al., 2021). Age-related declines or impairments not only undermine driving safety, but these are also linked to reduced mobility and can even lead to driving cessation. As older adults become more aware of their age-related declines, they tend to drive less frequently and for shorter distances, and they often avoid challenging driving situations, such as nighttime, bad weather, unfamiliar areas, and rush hour/heavy traffic (Baldock, Mathias, McLean, & Berndt, 2006; Ball et al., 1998; Braitman & Williams, 2011; Charlton et al., 2006; Molnar & Eby, 2008; Molnar et al., 2013). Given the importance of driving on mobility and thus quality of life, research has examined factors contributing to the change in driving habits of older adults.

1 Age is a very strong predictor of reduced driving due to its correlation with general  
2 health. A longitudinal interview study between 1994 and 2000 involving multiple follow ups of  
3 752 participants aged 65 years and older living in Australia found that aging increases self-  
4 regulatory behaviors, such as, limiting driving to local areas during daylight, and being 75 or  
5 older was one of the best predictors for the onset of driving behavioral modification (Unsworth,  
6 Wells, Browning, Thomas, & Kendig, 2007).

7 Health or medical problems are the most commonly cited reasons of older adults' driving  
8 reduction (Haustein & Siren, 2014) and driving cessation (Brayne et al., 2000; Campbell, Bush,  
9 & Hale, 1993). Many medical conditions are associated with driving cessation, including  
10 syncope, Parkinson's disease, stroke, macular degeneration, retinal hemorrhage, cataract, and  
11 other visual impairments (Campbell et al., 1993; Kington, Reuben, Rogowski, & Lillard, 1994;  
12 Marottoli et al., 1993). Though the influence of medical conditions on driving capabilities is  
13 complex, a cross-sectional study of a large cohort of older women found that individual medical  
14 conditions and comorbidity have a significant impact on driving frequency, driving cessation,  
15 decreased driving mileage and taking trips longer than 100 miles (Forrest, Bunker, Songer,  
16 Coben, & Cauley, 1997). From two national surveys conducted in the United States, respondents  
17 with medical conditions and taking medications often reduced their daily driving and restricted  
18 their driving to daytime hours (Rosenbloom & Santos, 2014). Further, the results showed that  
19 those over 65 with medical conditions reported fewer driving trips. The use of medications by  
20 older adults was also associated with fewer driving days per week and less nighttime driving.  
21 Thus, number of medical problems and medications taken are both good indicators of driving  
22 avoidance (Forrest et al., 1997; Vance et al., 2006). Older adults who have ceased driving or  
23 showed greater self-restriction commonly have a higher number of medical conditions

(Campbell et al., 1993; Marottoli & Drickamer, 1993). In addition, multiple studies found an association between older adults' self-rated health status and driving habits (Barrett, Gumber, & Douglas, 2018; Campbell et al., 1993; Marottoli & Drickamer, 1993; Sargent-Cox, Windsor, Walker, & Anstey, 2011). For example, Wang (2022) conducted a logistic regression on survey data on 16,049 individuals over age 65 indicating those who self-rated themselves with poor health exhibited an odds ratio of 0.306 for driving in the past month compared to those who rated their health as excellent.

Safe driving strongly depends on visual ability (Lijarcio, Useche, Llamazares, & Montoro, 2020; Owsley & McGwin Jr, 2010). Unfortunately, visual functioning tends to decline due to a variety of anatomical changes typically seen in older age groups (Owsley & Ball, 1993; Owsley & Sloane, 1990). Some of these anatomical changes include decreased size of pupil, ocular structure change, and loss of lens transparency which result in markedly less light reaching the retina. Coupled with photoreceptor loss on the retina, older drivers face difficulty in nighttime driving. In fact, older adults most commonly reported their initial self-regulation behavior to be avoidance of nighttime (Vivoda et al., 2022). Presbyopia can be noticeable as early as 40 (Melvin, 2020) and may affect the ability to monitor the instrument panel while driving. In an observational study, test scores for both the modified version of the Visual Function (mVF-14) and the Snellen Visual Acuity test were found to be significantly correlated with the composite scores of self-reported driving restriction measures (Lotfipour et al., 2010). Almost half of older adults with cataracts avoided at least one type of challenging situation (e.g., nighttime, freeway, raining, and parallel parking), and those who self-regulate have significantly lower contrast sensitivity in their worse eye than those who do not (Fraser, Meulenens, Ng, & Morlet, 2013). However, the association of driving avoidance with visual declines might only be

1 modest as poor contrast sensitivity but not acuity was associated with reduced driving exposure  
2 (Sandlin, McGwin Jr, & Owsley, 2014). Aside from visual acuity and contrast sensitivity,  
3 peripheral visual field is associated with driving cessation. In a study that followed 2,520 older  
4 adults for eight years with four data collection rounds, those experiencing two-year losses in  
5 lower peripheral visual fields were more likely to stop driving (Freeman, Munoz, Turano, &  
6 West, 2005). Poor depth perception has also been found to significantly correlate with self-  
7 restriction (West et al., 2003).

8 Physical ability in terms of strength, stamina, flexibility, and balance also tend to decline  
9 with age, possibly affecting control of the vehicle (Anstey et al., 2005). Physical declines were  
10 associated with older adults restricting their driving or avoiding challenging situations (Braitman  
11 & Williams, 2011). In a longitudinal study, lower scores on a Rapid Pace Walk task were  
12 correlated with more strategic self-regulation in driving (Molnar et al., 2014). Older adults who  
13 have ceased driving were more likely to report some physical difficulties (Campbell et al., 1993;  
14 Jette & Branch, 1992; Marottoli et al., 1993). Crowe et al. (2019) found that older adults with  
15 worse physical functioning, based on the Short Physical Performance Battery, had higher  
16 likelihood of being low-mileage drivers (less than 3,000 miles per year).

17 Aging is also related to declines for almost all cognitive functions, such as attention and  
18 memory (Deary et al., 2009; Hedden & Gabrieli, 2004; Wilson et al., 2002; Zaninotto, Batty,  
19 Allerhand, & Deary, 2018). These functions play a critical role in perceiving hazards in the road,  
20 processing visual cues (e.g., traffic lights, road signs, incurring traffic), focusing on driving tasks,  
21 predicting other road users' actions, and making quick decisions (Anstey et al., 2005; Breen,  
22 Breen, Moore, Breen, & O'Neill, 2007; Horswill et al., 2008; Martin, Marottoli, & O'Neill,  
23 2013; Ott et al., 2008; Withaar, Brouwer, & Van Zomeren, 2000). Increased self-restriction or

cessation of driving is associated with drivers diagnosed with mild cognitive impairment (MCI) (Davis & Owens, 2021; Feng et al., 2020; Pyun et al., 2018) or early-stage cognitive disorders, such as Alzheimer's disease (Festa, Ott, Manning, Davis, & Heindel, 2013; Paire-Ficout et al., 2018) and dementia (Adler, 2010; Drachman, Swearer, & Group, 1993; Ross et al., 2009). This association between cognitive abilities and driving also applies to healthy older adults without diagnosed cognitive impairments. Based on a five-year prospective cohort study of 928 older adults from seven U.S. cities, cognitive performance on the Trail Making part A and part B tests as well as Montreal Cognitive Assessment was correlated with level of driving restrictions (Rapoport et al., 2013). In particular, longer Trail Making A and B completion times were modestly associated with less driving exposure and greater avoidance of those driving scenarios perceived to be difficult or risky, albeit none of the associations were strong. Similar associations were also found between worse Useful Field of View (UFOV) scores and more driving avoidance behaviors (i.e., driving exposure and location familiarity) in a five-year longitudinal study (Ross et al., 2009). Slower cognitive speed of processing as measured by UFOV has been found to be a predictor of more restrictive driving habits after controlling for other factors such as vision, age, and health (Ackerman, Edwards, Ross, Ball, & Lunsman, 2008; Edwards et al., 2008).

Gender is a strong and consistent predictor of driving habits. Unsworth et al. (2007) found in a large longitudinal study that women were three times more likely to relinquish driving than a similar-aged cohort of men. Compared to older men, older women had lower average daily driving time (Shen, Koech, Feng, Rice, & Zhu, 2017) and were more likely to adopt avoidance behaviors such as avoiding high speed roads or driving at night (Choi, Adams, & Kahana, 2013; D'Ambrosio, Donorfio, Coughlin, Mohyde, & Meyer, 2008; St. Louis et al.,



2020). In addition, women tend to give up driving all together at an earlier age than do men (Marie Dit Asse, Fabrigoule, Helmer, Laumon, & Lafont, 2014).

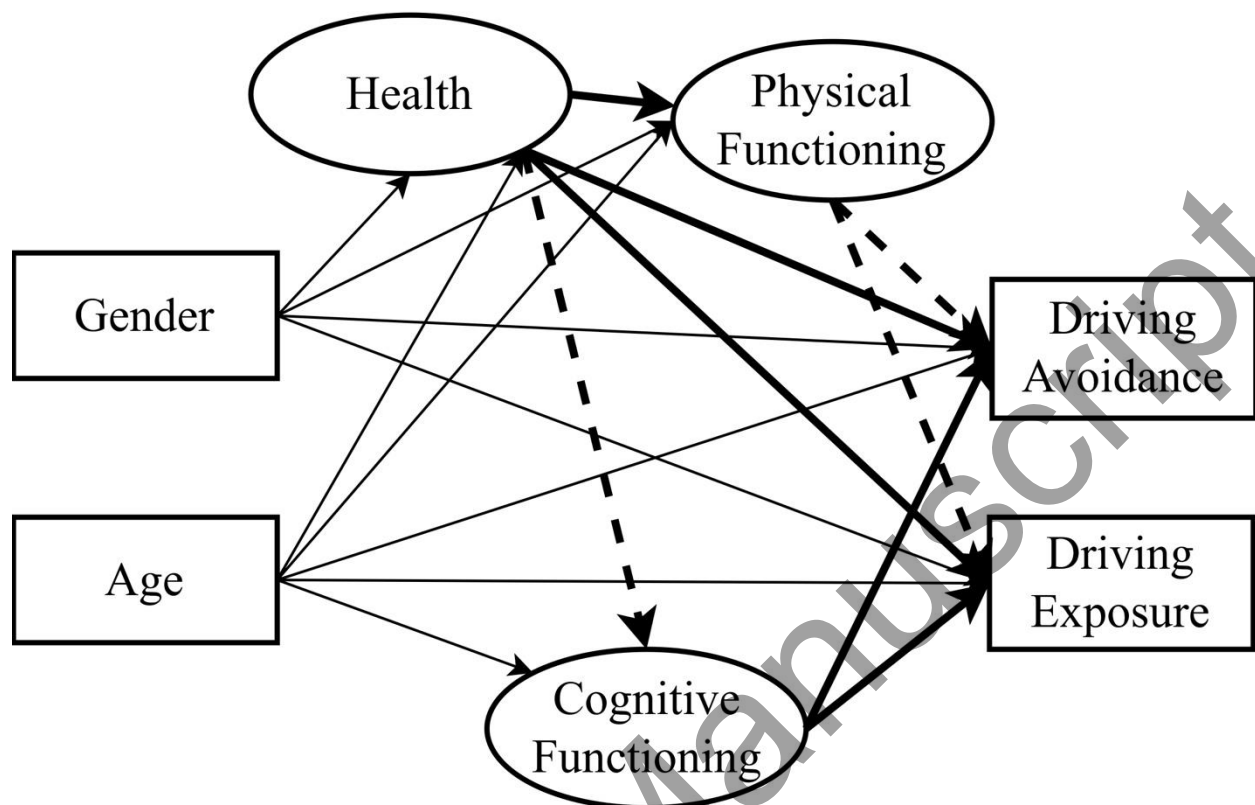
The influence of gender on driving habits could be explained by health and psychosocial factors. Women generally have worse health than men across a variety of health indicators, for instance, more cognitive, vision, and hearing problems and chronic, potentially disabling conditions, all of which consistently show associations with more self-restriction on driving (Carmel, Rechavi, & Ben-Moshe, 2014; Charlton et al., 2006; Choi et al., 2013; Choi, Mezuk, Lohman, Edwards, & Rebok, 2012; Molnar et al., 2014; Vance et al., 2006). Apart from health status, men tend to keep driving as long as their health allows, while women tend to give up driving for various, less pressing reasons (Hakamies-Blomqvist & Wahlström, 1998).

In terms of psychosocial factors, men are the principal drivers in most households, and this may have a strong influence on their decision to keep driving and minimize self-regulatory behaviors (Charlton et al., 2006). Compared to men, women reported more traffic-related anxiety, driving as less of a necessity (Hakamies-Blomqvist & Wahlström, 1998), and they also perceived lower confidence in driving (Kostyniuk, Molnar, & Eby, 2009; McNamara, Chen, George, Walker, & Ratcliffe, 2013; Meng & Siren, 2015; Molnar et al., 2014). Confidence has been found to be an important mediating factor of self-restricting driving (Charlton et al., 2006; Myers, Paradis, & Blanchard, 2008). Further, women were more likely than men to receive transportation support, such as rides from family members and friends (Choi et al., 2013; Shen et al., 2017), which facilitates their transition to driving cessation (Barrett et al., 2018).

Household status, specifically living alone, also plays a role in changes in driving behaviors. A national level random-digit-dial telephone survey in the United States found that older adults living alone reported being more than twice as likely to engage in self-regulatory

1 behaviors, such as avoiding bad weather, nighttime, traffic congestion, long trips, highways, and  
2 high-speed roads than younger respondents (Betz & Lowenstein, 2010). Choi et al. (2013) also  
3 found that older adults living alone self-reported higher likelihood of regulating their driving  
4 behaviors. Interestingly, a meta-synthesis of qualitative studies identifies a theme that older  
5 adults living alone tend to rely on their own driving for mobility (Ang, Oxley, Chen & Lee,  
6 2019). Analysis based on objective driving records would be invaluable to shed light on the  
7 differences in these findings.

8         Various health, functional abilities, and social factors have all been individually shown to  
9 be significant contributors to driving mobility of older adults; however, associations between one  
10 single factor and driving mobility could present an incomplete picture due co-dependence  
11 between the factors. For explaining or predicting older adults' mobility, analysis should strive to  
12 examine all contributing factors simultaneously. Causal models based on self-reported data have  
13 been developed to account for multiple factors to study driving behaviors (e.g., Labbe, Vance,  
14 Wadley, & Novack, 2014; Vance et al., 2006; Wong, Smith, & Sullivan, 2018). Vance et al.  
15 (2006) presented a structural equation model (SEM) based on self-reported data to study the  
16 influence of age, gender, physical, cognitive, and health status on driving habits in terms of  
17 avoidance and exposure (**Figure 1**). Their study investigated 815 relatively healthy older adults  
18 aged 55 and over and found that both health and cognitive measures were predictive of self-  
19 reported driving exposure and avoidance, and the magnitude of this relationship is stronger for  
20 the cognitive than health factor. Age and gender were found to have direct influence on older  
21 adults' driving habits. However, physical functioning was associated with neither driving  
22 avoidance nor exposure in their model.



**Figure 1. The trimmed causal model of driving exposure and driving avoidance presented by Vance et al. (2016). All solid lines represent significant effects; bold lines represent paths of study interest; and broken lines represent non-significant paths (investigated in the research study).**

Vance et al. (2006) contributed to our understanding of how different factors associated with aging could limit driving of older adults. In particular, their model suggests that maintaining physical health and cognitive abilities would reduce driving avoidance of older adults. However, their model lacked the factor of visual ability, which plays a critical role in driving and has been shown to be associated with changes in older adults' driving habits. Moreover, their model and most older adult mobility studies used questionnaires to collect self-reported data on driving exposure and avoidance. Self-estimations of driving distance may be inaccurate and inconsistent. Under-reporting driving exposure was found in several validation studies that compared self-reported data to actual driving data (Blanchard, Myers, & Porter, 2010; Molnar et al., 2013). The correspondence between self-reported and actual data was influenced by multiple factors, such as

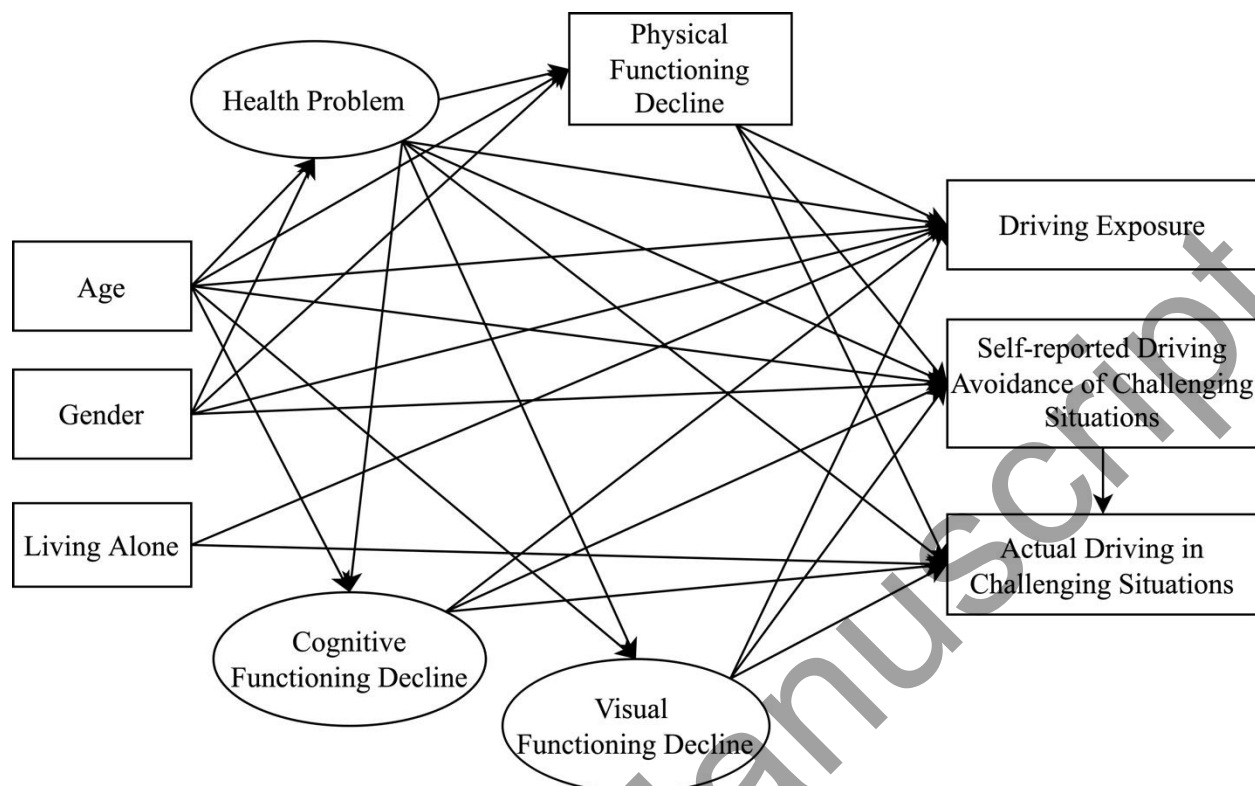
1 females being more accurate than males (Molnar et al., 2018). Though the self-reported and  
2 objective driving data generally do correspond fairly well (Molnar et al., 2018; Molnar et al.,  
3 2013; Molnar, Eby, Bogard, LeBlanc, & Zakrajsek, 2018), discrepancies still raise some validity  
4 concerns warranting research investigation.

5 In-vehicle data acquisition systems (DAS) or GPS records can provide actual vehicle trip  
6 data including the dates, duration, speed, and other information, enabling the use of objective  
7 driving records as the measurements of older adults' mobility (Marshall et al., 2007). Measuring  
8 driving habits solely by looking at actual trip data poses some interpretation challenges. In the  
9 case of measuring overall driving exposure, actual driving data are more accurate and thus  
10 preferable to self-reported mileage data. However, for driving avoidance, specific driving  
11 patterns, such as less frequent nighttime driving or fewer long-distance trips, could mean that the  
12 older drivers either intentionally avoid or do not need to drive in such situations (e.g., less  
13 driving during rush hour due to retirement). Therefore, using both self-reported and objective  
14 data is best for understanding driving habits (Molnar et al., 2015).

15 The objective of the study is to address the research gaps discussed above and advance  
16 our knowledge in older adults' driving mobility by building a causal model to examine the  
17 influences of health, visual, cognitive, and physical functioning on driving exposure and  
18 avoidance data collected from a naturalistic driving study. This model represents a unique  
19 contribution because driving exposure was measured by actual driving data, and driving  
20 avoidance was measured by actual driving in challenging situations in addition to the self-  
21 reported avoidance data. In other words, this model includes objective data on the driving habits  
22 that the literature commonly cites older drivers tend to avoid. Further, sociodemographic  
23 variables of age, gender, and living alone were included in the model as exogenous variables to

1 examine their direct influences on older adults' driving exposure and avoidance. This study  
2 employs naturalistic driving study data to evaluate our proposed model (**Figure 2**) with the  
3 following characteristics based on literature reviewed earlier:

- 4 1. Declining visual, cognitive, physical, and health/medical conditions are associated  
5 with driving exposure, self-reported driving avoidance and actual driving in  
6 corresponding challenging situations;
- 7 2. Declining visual, cognitive, physical, and health/medical conditions are *indirectly*  
8 *associated* with actual driving in challenging situations via self-reported driving  
9 avoidance; and
- 10 3. Self-reported driving avoidance is correlated with the actual driving in challenging  
11 situations.



**Figure 2 Proposed full structural model. Observed variables are shown in rectangles, latent variables are shown in ovals, the solid arrows indicate that there is relationship between the two connected variables.**

## 2. METHODS

### 2.1 Data Acquisition

The data for this modeling study were collected in the Second Strategic Highway Research Program (SHRP 2) Naturalistic Driving Study (NDS), which is currently the largest ever full scale (i.e., video-based) NDS containing comprehensive data on drivers, road environment, and trip data. Antin et al. (2019) and Dingus et al. (2015) presented details on the SHRP 2 purpose, study design, eligibility for participation, enrollment procedures, participants recruitment, training, driver assessment equipment and DAS. The SHRP 2 project completed data collection on 3,541 participants aged from 16 to 98 years, and most of them stayed in the study between

one and three years. At the beginning of the study<sup>2</sup>, participants were assessed for their cognitive, physical, and visual abilities, and they completed a wide range of questionnaires regarding their demographic characteristics, personality traits, current health status, medications, risk perception, risky taking behaviors, sensation seeking, and driving behavior. For this study we initially included all trips made by participants aged 55 and over. Our analysis also incorporated their demographic information, self-reported health conditions and medications currently in use, results from various tests of their cognitive, physical, and visual abilities. The initial pre-processed trip dataset included 1,804,716 trips driven by 1,166 participants.

## 2.2 Data Processing

Trips with moving durations of “null” and mean speeds of zero were removed from the dataset. Then, trips with moving distance less than 0.5km (i.e., around 0.31miles, such as moving a vehicle in a parking lot) were also deemed inappropriate and removed from the data set. These two steps resulted in 1,411,803 trips driven by 1,166 participants (aged 55 and over). We further eliminated all participants who reported using their vehicles for business purpose. The dataset was further narrowed down to those aged 65 and older to minimize work commutes dictated by the need to earn a living rather than personal desire. The final dataset included 794 participants of 367 women (46.22%) and 427 men (53.78%). Of all participants, 23.55% were between aged 65-69, 20.40% between aged 70-74, 29.97% between aged 75-79, 18.26% between aged 80-84, 6.80% between aged 85-89, and 1% aged 90 and over.

Table 1 outlines the variables in the model and their measurements.

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<sup>2</sup> As a result of a variety of factors that could not be predicted before the study, a small number of participants took some of the assessments at the end of their participation.

**TABLE 1 Variables in model, definitions of variables and their measurements**

Variable	Measurement		Objective/ Self-reported
Visual functioning decline	Visual acuity	Visual acuity is the ability of how well you discern the shapes and details of the object from a specific distance. Binocular visual acuity test was administered using the Optec 6500p and assessed under photopic and distance settings. During the test, participants were asked to read all letters in the row on Snellen chart. The last line (smallest letters) the participant could read was recorded as a Snellen fraction and transformed to log mini angle resolvable (logMAR) for better analysis. For this measure, zero indicates average acuity and higher values represent poorer vision. The range in our sample is from -0.2 (good vision) to 0.8 (bad vision).	Objective
	Contrast sensitivity	Contrast sensitivity is a visual ability to tell the difference between an object and the background. Also using the Optec 6500p, contrast sensitivity was tested individually for each eye under photopic conditions (85 cd/m) for a 6 cycles per degree grating. Participants started read from the top of the chart until they can no longer see any letters. The last patch the participant correctly identified before missing two consecutive patches was recorded as the test result and converted to log for the purpose of analysis. Noted that a score of 0.78 was assigned to the individuals who were unable to see the target even at the highest contrast level (1.08 log contrast sensitivity) for purpose of analysis. The range is 0.78 (cannot see) to 2.1 (good vision).	Objective



	Depth perception	Depth perception is a visual ability to perceive objects in three dimensions and the distance of the object. Depth perception was assessed for both eyes under photopic and far settings using the Optec 6500p. This measure ranged from 1 (cannot see) to 10 (good vision).	Objective
	Peripheral vision	Peripheral vision is a visual ability to see objects and movement outside the point of fixation without the need of turning head or moving the eye. Using the Optec 6500p, peripheral vision was assessed by the test that asked the participant to detect the target appearing nasally at 45 degree and at 55, 70, 85 degrees from center. The target at the most extreme degree that the participant can see was coded for analysis. The range for this measure is from “nasal” (coded as 1) up to 85 degree (coded as 4). The larger score represents the better peripheral vision.	Objective
Cognitive functioning decline	*UFOV- subtest 2 (ms)	UFOV subset 2 is designed to measure processing speed under divided attention. Participants were asked to identify an object (a car or truck) appear in the center of the screen for varying lengths of time and localize a simultaneously presented target displayed in the periphery of the screen. Test scores are the display duration.	Objective
	*Trail making test A (TMA; min)	Trail Making Tests assesses the cognitive domains of processing speed that incorporates sequencing, mental flexibility and visual-motor skills (Bowie & Harvey, 2006). In part A, participants were asked to start with the number one and draw lines connecting all encircled numbers in numerical order. The time (min) the participant taken to complete the task was recorded as the test result.	Objective

	*Trail making test B (TMB; min)	The part B task is similar to part A, the difference is that part A uses only numbers while the part B use letters and numbers. Participants were asked alternate between numbers and letters (e.g., 1, A, 2, B, 3, C...). The time (min) the participant taken to complete the task was recorded as his test result.	Objective
	*Visualizing missing information (VMI) test (No. of incorrect)	Spatial ability was measured by VMI test. The total number of errors in the test was recorded as the test result ranged from 0 - 11. Lower scores (fewer incorrect answer) indicate better functional performance.	Objective
Health problem	Number of health conditions	The total number of high level medical conditions selected by participants. One listed condition chosen, or “other”, is worth one point. The possible range for this measure is 0-16.	Objective
	Number of medications	The total number of medications were presently taken as self-reported by participants. (Supplements, such as vitamins, fish oil, were not counted as medications.)	Objective
Physical functioning decline	Rapid pace walk test (s)	The time took for the participant to complete a 20-ft rapid pace walk (ten feet in one direction and ten ft back to the starting point) was recorded as the test score. Taking less time to complete the test indicates better physical functioning.	Objective
Living alone/household status		Participants’ household status was used to indicate whether or not they lived alone. The response “living alone” was coded 1. Other responses “one parent household” and “two parent household” were both coded 0.	Self-reported
Actual driving in challenging situations	Percentage of trips at night	Percent of all trips taken during nighttime (local time 9pm-5am).	Objective
	Percentage of trips on freeways	Percent of trips driven at least 80% on freeways (rural freeway, rural freeway < 4	Objective

composite score (z-score)		lanes, urban freeway, urban freeway < 4 lanes).	
	Percentage of trips during rush hour	Percentage of trips taken during rush hours on weekdays (local time 6am - 10am or 3pm - 7pm from Monday to Friday). Used as a proxy for high traffic volumes.	Objective
	Percentage of trips with low frequency destination	Percentage of trips with destination being classified as a “low frequency”, which occurred in less than 5% of the given participants’ trips. Used as a proxy for driving in unfamiliar areas.	Objective
Driving exposure composite score (z-score)	Trips per week	Total number of trips taken divided by total number of weeks participated in study.	Objective
	Driving days per week	Total number of days with at least one trip taken divided by total number of weeks participated in study.	Objective
	Distance driven in kilometer per week	Total distance in kilometers driven divided by total number of weeks participated in study.	Objective
	Distance in kilometer per trip	Total distance in kilometers driven divided by total number of trips driven during study participation.	Objective
Self-reported driving avoidance of challenging situations (number of situations self-reported being avoided)		Driving avoidance was based on the total number of situations that the participants selected being avoided. The given situations were at night, highway or interstate travel, high traffic volumes, unfamiliar areas, and other. One condition chosen, or “other” that was not being listed, is worth one point. The possible range is 0-5. (Note. The selection “left turn” was dropped from the analysis.)	Self-reported

\*The UFOV, TMA, TMB, and VMI visuo-cognitive tests is part of the DrivingHealth® Inventory (Crisler et al. 2013).

## 2.3 Data Analysis

### 2.3.1 Missing Data

Missing data can affect the model fitting and parameter estimation (Vaske, 2019). Within the 794 participants, 74 participants did not respond to the questions on health status, and their data were missing one or all the visual, cognitive, and physical tests. The 74 participants with missing data did not differ from the remaining 720 participants in gender ( $\chi^2 (1, n=718) = 0.18, p=0.67>0.05$ ) but did differ in age group ( $F (1, 718) = 6.55, p=0.01 <0.05$ ), as the older groups were more likely to have missing data. Of the 720 participants, 224 cases have between one and three missing values for the measurements of the various variables in Table 1, 496 had complete data. For these 224 cases, we imputed their missing data using multiple imputation (MI) method (Rubin, 1988). After imputation, the final sample size for analysis is 720 participants, which can be analyzed using SEM based on the recommendation of at least 20 responses per variable in the model (Schumacker & Lomax, 2004). Our model has three latent variables and 17 observed variables, thus the sample size 720 satisfied their criterion.

### 2.3.2 Test for Normality

A Multivariate Royston test ( $H=1682.68, p < 0.001$ ) indicated the presence of multivariate non-normality. The sample dataset includes both categorical and continuous variables. The two issues both influence the model fitting and parameter estimation. Thus, diagonally weighted least squares (DWLS) was selected as the estimation method. Compared to the default estimator, maximum likelihood estimation (MLE), DWLS provides more accurate parameter estimates and more robust model fit against departures from scale types of the variables and normality (Hart & Conn, 1992; Hoyle, 1995; Mindrila, 2010).

### 2.3.3 Analysis

SEM was used to examine the proposed causal model (**Figure 2**). SEM is a multivariate quantitative technique used to depict the relationships among observed variables, which can be measured directly by existing data, and latent variables, which cannot be measured directly but are modeled on the basis of the observed variables. The present study followed the two-stage approach recommended by Anderson & Gerbing (1988). First, the measurement models were specified and tested to assess the validity and reliability of the constructs. Second, the proposed model was tested by data. The final trimmed model was constructed by eliminating the non-significant paths from the full model. The analysis mainly used R (“Lavaan” package for model fitting (Rosseel, 2012), “mice” package for multiple imputation Buuren & Groothuis-Oudshoorn (2010)). The following model fit indices were computed: Chi-square test, Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA) and Standardized Root Mean Square Residual (SRMR).

### 3. RESULTS

#### 3.1 Sample Statistics

The descriptive statistics of 720 drivers are presented in **Table 2**.

**TABLE 2 Descriptive statistics (N = 720)**

	N	%	Range	Mean	SD	Skew	Kurtosis
Age group							
65-69	162	22.50					
70-75	141	19.58					
76-79	222	30.83					
80-84	137	19.03					
84-90	51	7.08					
Over 90	7	0.97					
Gender							
Female	325	45.14					
Male	395	54.86					
Living alone							

Living alone	290	40.28					
Not living alone	430	59.72					
Rapid pace walk time (s)			3.06 -15.69	6.28	1.84	1.76	5.00
No. of health problems			0 -16	4.72	2.67	0.72	0.70
No. of meds			0 -17	3.81	2.99	1.49	2.77
Visual acuity under day and far conditions, logMAR (both eyes)			-0.20 - 0.80	0.08	0.15	0.79	1.21
Depth perception			1-10	4.68	2.72	0.38	-0.95
Peripheral vision (worse eye)							
1	12	1.67					
2	51	7.08					
3	108	15.00					
4	549	76.25					
Contrast sensitivity under day condition, log sensitivity (worse eye)			0.78 - 2.11	1.46	0.37	-0.64	-0.55
Trials A (min)			0.23 - 5.44	0.69	0.32	5.61	68.01
Trials B (min)			0.61 - 5.98	1.73	0.69	2.03	7.23
VMI test (No. of incorrect)			0 -10	2.55	2.06	1.45	2.23
UFOV subset2 (ms)			100-500	210.88	121.65	0.51	-0.96
Self-reported driving avoidance of challenging situations			0-5	0.79	0.95	1.40	1.94
Actual driving in challenging situations (composite z-score)			-6.56 - 5.63	-0.37	1.82	0.06	0.04
Driving exposure (composite z-score)			-6.31 - 9.29	0.007	2.65	0.29	-0.01

### 3.2 Measurement Models

The measurement model was examined first to assess the fitness of the latent variables of health (number of health problems, number of medications), cognition (Trails A, Trails B, VMI, and UFOV), and vision (visual acuity, contrast sensitivity, depth perception, and peripheral vision).

This step aimed to reduce measurement error by only retaining significant indicators. Items with

factor loadings below 0.3 were removed from subsequent model development for parsimony (Kline, 2005).

The fitting indices in **Table 3** indicate a general good fit between the proposed measurement model and the sample data. However, for visual functioning decline latent variable, peripheral vision has low factor loading ( $0.15 < 0.3$ ) and thus was removed from subsequent model development (Kline, 2005). The re-specified model has improved fit performance compared with the initial one (see Table 3).

**TABLE 3. Measurement model**

		<b>Initial Model</b> ( $\chi^2$ (df) = 50.78 (32), p-value = 0.02, CFI= 0.99, RMSEA= 0.03, SRMR= 0.04, GFI=1.00, NNFI= 0.99, AGFI=1.00)				<b>Re-specified Model</b> ( $\chi^2$ (df) = 22.38 (24), p-value= 0.56, CFI=1.00, RMSEA= 0, SRMR=0.03, GFI=0.99, NNFI=1.00, AGFI=1.00)			
<b>Statistics</b>		<b>B</b>	<b>SE</b>	<b>Z</b> (p> Z )	<b>Beta</b>	<b>B</b>	<b>SE</b>	<b>Z</b> (p> Z )	<b>Beta</b>
<b>Health problem</b>	No. of health conditions	1	-	-	0.37	1			0.37
	No. of meds	3.59	0.31	11.69 (0.00)	1.20	3.55	0.40	9.04 (0.00)	1.19
<b>Cognitive functioning decline</b>	Trials A	0.14	0.01	14.33 (0.00)	0.44	0.14	0.02	8.92 (0.00)	0.43
	Trails B	0.39	0.04	11.22 (0.00)	0.57	0.39	0.04	10.79 (0.00)	0.56
	VMI test	0.65	0.06	11.32 (0.00)	0.32	0.69	0.08	9.17 (0.00)	0.33
	UFOV subset2	0.64	0.05	14.34 (0.00)	0.53	0.63	0.06	11.50 (0.00)	0.52
<b>Visual functioning decline</b>	Visual acuity	0.09	0.01	16.25 (0.00)	0.64	0.09	0.01	15.43 (0.00)	0.61
	Contrast sensitivity	-0.23	0.02	-14.93 (0.00)	-0.63	-0.25	0.02	-16.08 (0.00)	-0.67

	Depth perception	-1.81	0.11	-15.91 (0.00)	-0.67	-1.88	0.12	-16.29 (0.00)	-0.69
	Peripheral vision	-0.15	0.04	-3.88 (0.00)	-0.15	-	-	-	-

*Note:* CFI: Comparative fit index; GFI: Goodness-of-fit index; SRMR: Standardized Root Mean Squared Residual; RMSEA: Root mean square error of approximation; AGFI: Adjust GFI; NNFI: Non-Normed Fit Index Criteria of acceptable fit: CFI, GFI, AGFI, NNFI  $\geq 0.90$ ; RMSEA, SRMR  $\leq 0.08$  (Hu & Bentler, 1999; Schermelleh-Engel, Moosbrugger, & Müller, 2003; Wan, 2002)

### 3.3 Structural Equation Model

The hypothesized model (**Figure 2**) was tested with a number of goodness-of-fit indices to identify non-significant paths (**Table 4**). A trimmed model was then created by removing the least significant path one at a time (based on least z value) and recalculating model fit. The process was iterated until only statistically significant paths ( $p < 0.05$ ) remained in the model.

**TABLE 4 Goodness-of-fit for full and trimmed model**

Goodness-of-fit Measures	Full model	Trimmed model
$\chi^2$ (df)	180.56 (79)	185.81 (88)
p-value $\chi^2$	0.00	0.00
RMSEA	0.04	0.04
SRMR	0.04	0.04
CFI	0.95	0.95
TLI	0.92	0.93
NNFI	0.92	0.93
GFI	0.99	0.99
AGFI	0.99	0.99

*Note:* CFI: Comparative fit index; GFI: Goodness-of-fit index; SRMR: Standardized Root Mean Squared Residual; RMSEA: Root mean square error of approximation; AGFI: Adjust GFI; NNFI: Non-Normed Fit Index Criteria of acceptable fit: CFI, GFI, AGFI, NNFI  $\geq 0.90$ ; RMSEA, SRMR  $\leq 0.08$  (Hu & Bentler, 1999; Schermelleh-Engel et al., 2003; Wan, 2002)

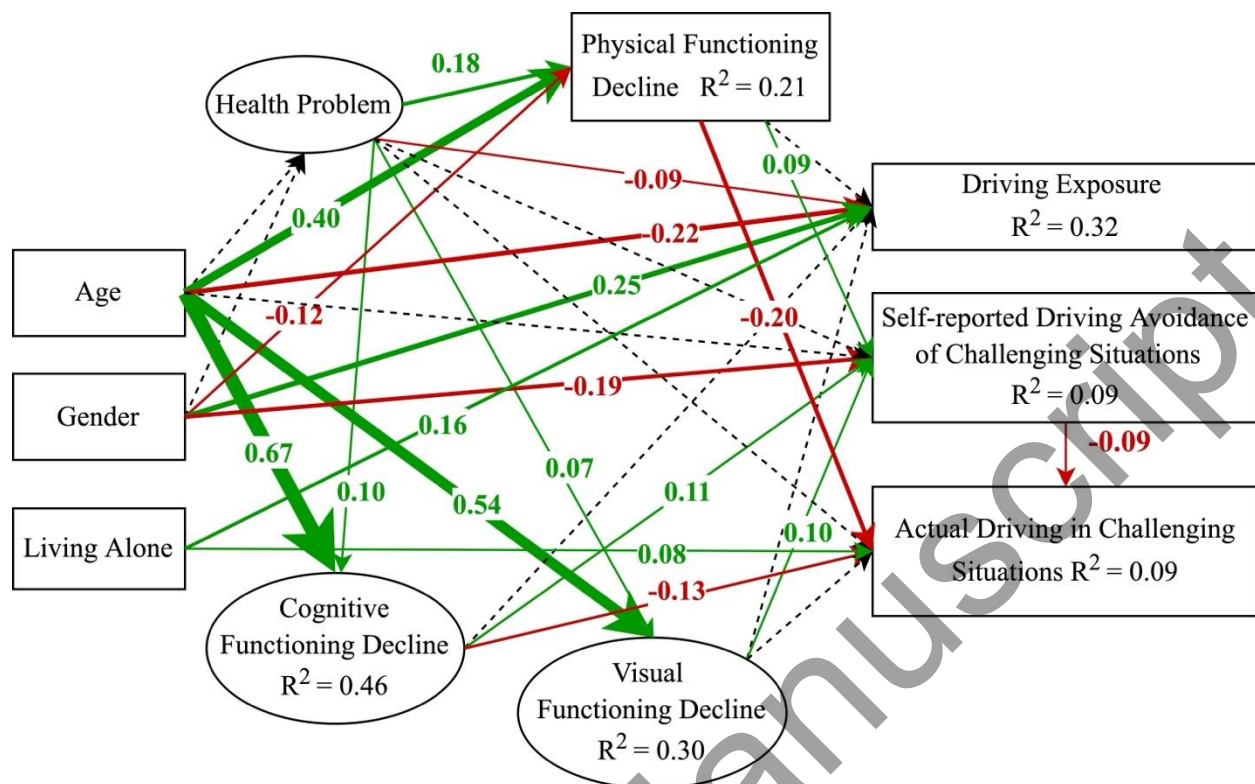
Standardized and unstandardized path coefficients are listed in **Table 5**.

**TABLE 5 The estimation results of the trimmed model SEM (All paths are statistically significant with p-value < 0.05)**

	Est.	SE	Z-value	Standardized Coefficient
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<b>Latent Variables</b>					
Health problem ~	No. of health problem	1	-	-	0.37
	No. of meds	3.25	0.38	8.58	1.09
Visual functioning decline ~	Visual acuity	0.08	0.01	15.67	0.65
	Contrast sensitivity	-0.20	0.01	-16.04	-0.66
	Depth perception	-1.51	0.09	-16.03	-0.67
Cognitive functioning decline ~	Trails A	0.10	0.01	8.18	0.40
	Trials B	0.27	0.03	9.18	0.53
	VMI test	0.46	0.06	8.43	0.31
	UFOV subset 2	0.51	0.05	9.91	0.57
<b>Regressions</b>					
Visual functioning decline ~	Age	0.56	0.05	11.52	0.54
	Health problem	0.08	0.03	2.69	0.07
Cognitive functioning decline ~	Age	0.79	0.10	7.83	0.67
	Health problem	0.13	0.05	2.69	0.10
Physical functioning decline ~	Age	0.63	0.05	12.09	0.40
	Gender	-0.43	0.13	-3.21	-0.12
	Health problem	0.33	0.08	4.14	0.18
Driving exposure ~	Age	-0.50	0.08	-6.51	-0.22
	Gender	1.34	0.25	5.43	0.25
	Health problem	-0.24	0.09	-2.67	-0.09
	Living alone	0.89	0.28	3.19	0.16
Self-reported driving avoidance of challenging situations ~	Gender	-0.36	0.07	-5.26	-0.19
	Visual functioning decline	0.08	0.03	2.26	0.10
	Cognitive functioning decline	0.07	0.03	2.19	0.11
	Physical functioning decline	0.05	0.03	1.97	0.09
Actual driving in challenging Situations ~	Self-reported driving avoidance of challenging situations	-0.18	0.08	-2.27	-0.09
	Cognitive functioning decline	-0.17	0.06	-2.93	-0.13
	Physical functioning decline	-0.20	0.06	-3.61	-0.20
	Living alone	0.28	0.14	1.97	0.08



**Figure 3 Final trimmed causal model (standardized estimates). Solid line = significant effects ( $p < 0.05$ ); broken lines = non-significant proposed paths. Line widths are proportional to coefficient values.**

The full model (Figure 2) and final trimmed model (Figure 3) both showed good fit to the sample data. The final trimmed model (Figure 3) shows that age, gender, health problems, and living alone status are directly associated with driving exposure. Gender, visual, physical functioning decline and living alone status can be directly related to self-reported driving avoidance, as well as actual driving in challenging situations. Age is a predictor of declines in visual (standardized coefficient = 0.54), cognitive (standardized coefficient = 0.67), physical functioning (standardized coefficient = 0.40) and driving exposure (standardized coefficient = -0.22). Therefore, older adults tend to have declining visual, cognitive, and physical capabilities, and drive less as they age.

Health problems have association with older adults' declines in visual functioning (standardized coefficient = 0.07), cognitive functioning (standardized coefficient = 0.10), and

1 *physical functioning* (standardized coefficient = 0.18). Additionally, *health problems* are  
2 predictive of *driving exposure* (standardized coefficient = -0.09). *Genders* exhibit different  
3 *physical functioning decline* (standardized coefficient = -0.12), *driving exposure* (standardized  
4 coefficient = 0.25), and *self-reported driving avoidance of challenging situations* (standardized  
5 coefficient = -0.19). Results showed that older females have worse physical performance, and  
6 they are more likely to self-restrict their driving through less exposure and report greater  
7 avoidance of challenging situations.

8 Both *cognitive* and *physical functioning declines* were found to be directly related to  
9 driving avoidance as reflected by self-reported measurements (standardized model coefficients of  
10 0.11 and 0.09 respectively) and actual driving measurements (standardized model coefficients of  
11 -0.13 and -0.20 respectively). Older adults with cognitive and physical functioning declines self-  
12 reported to avoid more and exposed less to challenging situations. In addition, *visual functioning*  
13 *decline* is associated with more *self-reported driving avoidance* but is not linked to *actual*  
14 *driving in challenging situations* according to our model. Lastly, *living alone* is predictive of  
15 *driving exposure* (standardized coefficient = 0.16) and *actual driving in challenging situations*  
16 (standardized coefficient = 0.08). Older adults who live alone tend to drive more and expose  
17 themselves to challenging situations to a greater extent.

#### 19 **4. DISCUSSION**

20 A causal model was built to predict driving exposure and driving avoidance according to age,  
21 gender, living alone, and functional capabilities. This model includes self-reported as well as  
22 actual driving data collected during naturalistic driving observation. Using SEM, the relationship  
23 between the factors and driving exposure, self-reported driving avoidance and actual driving in  
24 corresponding challenging situations were examined. The final model presents several important

findings: (1) poorer health is predictive of less driving exposure; (2) living alone is associated with greater driving exposure in general (i.e., higher mileage) as well as greater exposure to challenging driving situations; (3) self-reported driving avoidance is inversely related to observed exposure to challenging driving situations, and (4) worsening cognitive and physical functioning have a direct association with more driving avoidance as reflected in both self-reported and objective measurements.

Our model revealed a small association between health conditions and observed driving exposure, indicating that older adults with poorer health status tend to drive less. This relationship is logical and consistent with previous studies that relied on self-reported driving exposure (Campbell et al., 1993; Marottoli et al., 1993; Rosenbloom & Santos, 2014; Vance et al., 2006). However, age and gender in our model showed no relationship with health and no links to driving avoidance. Health measurement in this study may not fully reflect the health status of older adults because quantifying health by merely adding up self-reported diseases without accounting for severity and the integrative nature of some disorders; thus, this metric may not reflect fully practical health status as it relates to driving. Future work ideally should include more measurements or indicators of health status, including health status rated by participating drivers and their health providers.

The model shows that older adults who live alone tend to drive more and in more challenging situations. This finding is contrary to some previous studies indicating that older adults who reported living alone also self-reported more restrictions in their own driving (Betz & Lowenstein, 2010; Choi et al., 2013). This discrepancy may be attributed to the fact that previous studies employed self-reported data for measuring driving mobility, while the current study used observed driving data. How much a driver drives or how frequently the individual is exposed to

1 potentially hazardous situations is determined by many factors, such as work status, schedule  
2 flexibility, and the environment in which the individual lives. Additionally, household status or  
3 living alone is a sociodemographic factor intricately tied to transportation support and  
4 dependency on others, which can influence older adults' driving behaviors. Older adults living  
5 with families can easily access transportation support; however, those who live alone, even if  
6 they may want to restrict their driving as the earlier studies suggested, those intentions might not  
7 be easily carried out and develop to the actual behavior due to lack of the driving alternative  
8 options available to them (Barrett et al., 2018). Hassan, King, and Watt (2015) concluded that  
9 relying on a spouse or other family members for transportation facilitated the transition to non-  
10 driving, whereas living alone led to extended driving. In addition to transportation support, older  
11 adults living with families are more likely to make decisions about self-regulating behaviors  
12 collectively or at least with more inputs or concerns for their safety and well-being (Kostyniuk,  
13 Molnar, & Eby, 2009).

14 A modest inverse association between self-reported driving avoidance and actual driving  
15 in challenging situations is also observed in our model, lending some support to our  
16 interpretation of the model result on household status or living alone. The discrepancy between  
17 self-reported driving avoidance and actual driving in challenging situations is consistent with  
18 prior research (Molnar et al., 2013). Self-reported driving avoidance, which was collected from  
19 the questionnaire items asking participants if they tried to avoid certain driving situations, may  
20 reflect drivers' intention to limit their behavior. There are many factors in real life interfering  
21 with carrying out the intention or translating it to actual behavior. For example, as was discussed  
22 above, the lack of alternatives to driving would hinder the transition to not driving. Developing  
23 self-regulatory practice is about having the ability to adjust the behavior if one so chooses.

1 Baldock et al. (2006) defined self-regulation as an ability to harmonize driving ability and  
2 avoidance. The imperfect association in our model may be best interpreted as how much of the  
3 intention matches with, or translates to, the actual behaviors. Future work should examine how  
4 certain social, demographic, or environment factors (e.g., population density, public  
5 transportation in the area, income...) influence this transition.

6 Worsening cognitive, physical, and visual functioning are associated with more self-  
7 reported driving avoidance. These relationships are consistent with findings from earlier studies  
8 with the exception of work by Vance et al. (2006) who did not find a relationship between  
9 physical functioning and driving habits. In our model, the magnitudes of the influences are  
10 nearly equivalent for visual, physical, and cognitive functions on self-reported driving avoidance.  
11 The magnitude of the direct association between actual driving in challenging situations and  
12 physical capability function is slightly greater than that of cognitive ability. The reason for this  
13 finding may be that cognitive ability is less easily self-monitored compared to physical ability;  
14 thus, older adults with mild cognitive declines may not have sufficient metacognitive ability to  
15 sense the change or any need of avoiding driving in challenging situations. In a longitudinal  
16 study, cognitive function was identified as a better predictor of driving cessation than physical  
17 performance (Anstey, Windsor, Luszcz, & Andrews, 2006). However, driving cessation is  
18 different from avoidance. Driving cessation could be seen as the final stage of self-restricted  
19 driving. Those who gave up driving entirely in Anstey et al.'s study were more likely to have  
20 poor health or severe impairment. Participants in our study were active and legally licensed with  
21 good cognitive status. A naturalistic study with early-stage dementia participants suggested that  
22 driving mobility might not be affected at the early stage of cognitive impairment (Eby,  
23 Silverstein, Molnar, LeBlanc, & Adler, 2012). According to an interview study, older drivers

with cognitive impairments were aware of the problems but did not feel their driving was affected (Meng, Siren, & Teasdale, 2013). However, research has shown that driving could deteriorate before cognitive impairment can be detected using standard instruments (Roe et al., 2017). There appears to be a lot of nuances in the relationship between cognitive and physical functioning in the contexts of driving avoidance and cessation, and further research is needed to explain these relationships.

#### 4.1 Limitation

This study has a restricted range of sample in terms of visual, physical, cognitive, and health status, which might explain those paths/associations that were not statistically significant. Participants in SHRP 2 were required to be active drivers who held valid driver licenses, thus this sampling method inherently favored healthier older adults. Those who had severe illnesses or functional impairments may have been less likely to volunteer (or be considered eligible) for a driving study even though they were still driving.

The measurement of self-reported driving avoidance is incomplete. Our model only accounted for self-ratings (on a six-point scale) of their driving avoidance in four situations<sup>3</sup> - freeway, nighttime, unfamiliar areas, and rush hour. This measurement approach may not have been sufficiently sensitive to subtle changes in the intention of avoiding certain driving situations. Many other situations commonly mentioned in previous studies about older adults' driving mobility were not included in the SHRP 2 questionnaires, such as, inclement weather (e.g., foggy or rainy conditions), and long-distance traveling.

The raw data collected by the DAS is not able to be directly applied to examine driving patterns in challenging situations. Deriving the measures for studying the patterns from the raw

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<sup>3</sup> Participants were presented five situations, but the selection of avoiding "left turn" was dropped and not counted for analysis. So, four situations were considered in this study.

1 data needs triangulation of various supporting datasets (e.g., vehicle speed, time of day, location,  
2 weather). For example, precisely defining “nighttime” or “daytime” should consider the local  
3 solar angle, as in the Molnar et al. (2013)’s study which characterized “nighttime” as the solar  
4 angle greater than 96° and “daytime” less than 90°. However, our dataset does not include  
5 latitude/longitudinal coordinates and GPS time for each trip, which are required to calculate the  
6 solar angle. Thus, this study employed the simplification of defining trips between 9pm and 6am  
7 as nighttime driving even though the solar angles could be less than 90° after 9pm or greater than  
8 96° after 6 am depending on the season. However, this limitation is somewhat ameliorated by the  
9 relatively large dataset which contains enough cases either way to render these exceptions as  
10 having negligible influence on the results. Similarly, the definitions of unfamiliar areas and high  
11 traffic volume were also simplification based on distance and time, respectively. Defining  
12 driving patterns in simpler, though well-accepted, terms may limit the degree of association  
13 between self-reported driving avoidance and actual driving patterns in challenging situations.

14 Finally, the SHRP 2 study administered functional assessments at the outset only; thus,  
15 significant changes (e.g., a sharp decline in vision due to a disease or an accident) would be  
16 missed, resulting in potential over or under estimation the influence of the various factors on  
17 mobility.

## 18 **4.2 Practical Implications**

19 The findings of the study offer several implications for developing early detection and  
20 intervention programs to help older adults who are relatively healthy, active, and legally licensed  
21 drivers. A major goal of transportation policies and measures are to ensure older adults’ safety on  
22 the road as well as maintaining their mobility and avoiding unnecessary driving cessation



(O'Neill, Walshe, Romer, & Winston, 2019). Routine screenings for cognitive, visual, and physical functioning may be effective in detecting a change in driving habits, especially physical functioning, which has larger association with elders' avoidance driving pattern. The local government should also offer older adults some incentives encouraging them to take the screening tests regularly and advise older adults who are at risk to access alternative transportation methods. Special attention should be given to older adults living alone and experiencing physical, cognitive, and visual declines.

Educational intervention has demonstrated effectiveness in promoting self-regulatory practices, though the program examined only visually impaired older adults (Owsley, Stalvey, & Phillips, 2003). Our model supports the continuation of educating older adults on how to monitor all aspects of their driving function (e.g., vision, health, cognition) and to appropriately reduce exposure to hazardous situations. Further research is necessary to investigate whether cognitive training could be a potential remedy to delay declines and driving avoidance with older drivers. Speed of processing training has been found to increase responsiveness to road signs in driving simulators and reduce dangerous driving maneuvers in on-road tests (Roenker, Cissell, Ball, Wadley, & Edwards, 2003), and UFOV training has been shown to reduce the risk of driving cessation (Edwards, Delahunt, & Mahncke, 2009). However, other studies have not found such positive effects (Antin, Owens, Foley, Ebe, & Wotring, 2016). A recent literature review suggests an overall effectiveness in training and educating older drivers but discrepancies between studies challenge comparison between techniques and methods (Castellucci, Bravo, Arezes, & Lavallière, 2020).

Timely access to medical interventions is effective in improving mobility and reducing crash risk. For example, Agramunt et al. (2018) found that 47.3% of 55 older adults self-reported to

1 regulate their driving behaviors while waiting for cataract surgery but the percentage dropped to  
2 29.1% after first eye surgery and further to 18.2% after second eye surgery. The crash rate for  
3 those who underwent cataract surgery was half that of those who didn't but needed such  
4 operation (Owsley et al., 2002).

5 Advancing vehicle technology might play a role in maintaining mobility and enhancing  
6 safety as some researchers have suggested that Advanced Driver Assistance Systems (e.g.,  
7 adaptive cruise control, lane-keeping assist, etc.) have the potential to assist older drivers in  
8 compensating for declining abilities (Caird, 2004; Davidse, 2006). Though less accepting of new  
9 technology, older adults have also shown some positive attitude towards some advanced  
10 technology in supporting their driving and road safety (Liang, Lau, & Antin, 2019; Liang, Lau,  
11 Baker, & Antin, 2020) and such technology might affect their driving habits and thus mobility.  
12 As our model affirms that multiple factors contribute to driving avoidance, a comprehensive  
13 approach involving many techniques and solutions would be necessary to extend mobility while  
14 maintaining road safety of senior drivers.

## 16 5. CONCLUSION

17 This study developed a novel causal model to examine the influences of health, visual, cognitive,  
18 physical functioning and sociodemographic factors on older adults' driving exposure and  
19 avoidance. The study analyzed both self-reported as well as actual driving data to examine older  
20 adults' driving habits. Results indicate that health is a reliable predictor of driving exposure, and  
21 cognitive and physical functioning are predictive of their intention and actual driving in  
22 challenging situations.

## Conflict of interest

None.

## Authors' contribution

Dan Liang: Conceptualization; Methodology; Data curation; Formal analysis; Validation; Writing-original draft. Nathan Lau: Conceptualization; Funding acquisition; Reviewing and editing; Jon Antin: Conceptualization; Reviewing and editing; Funding acquisition.

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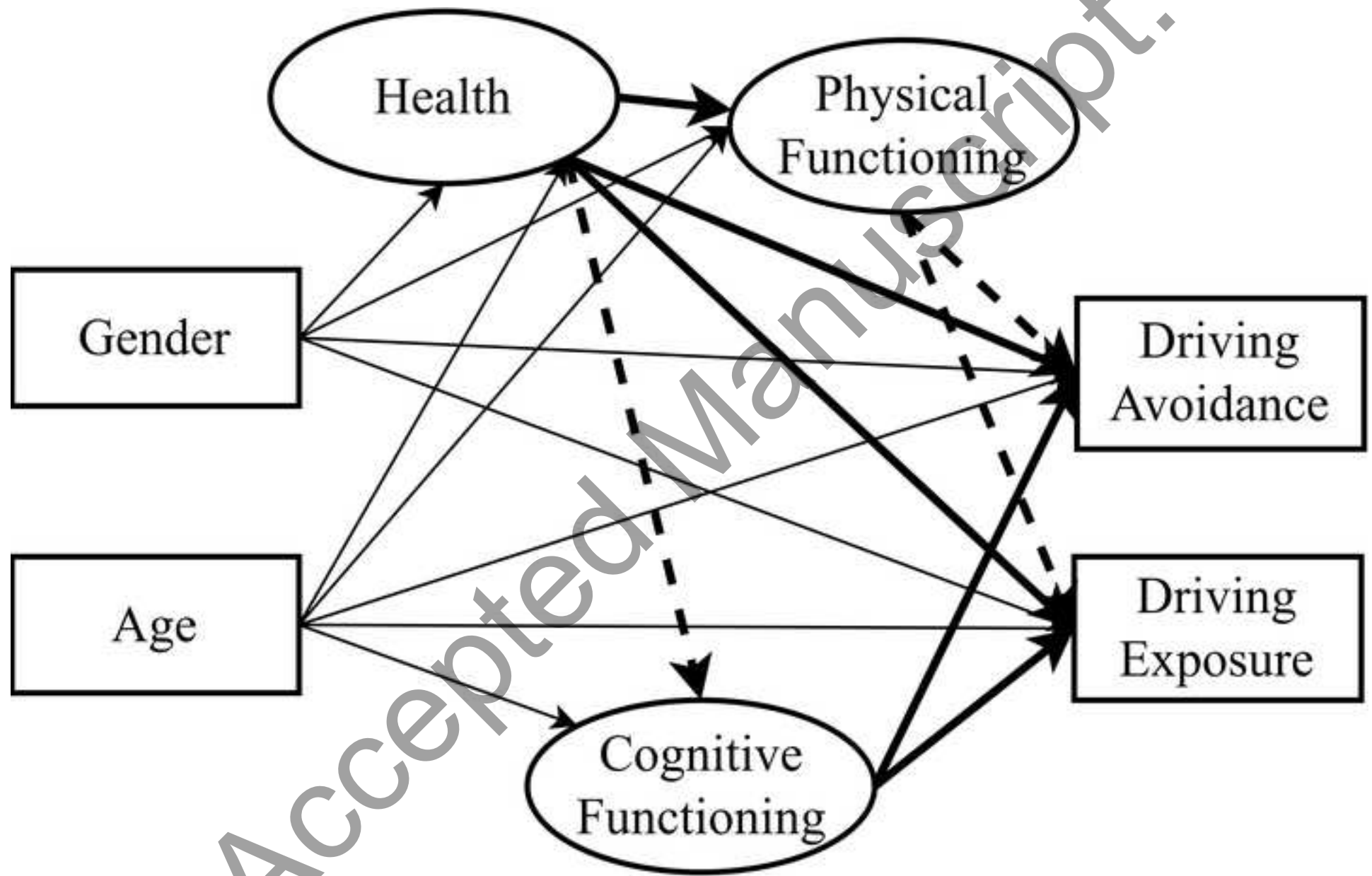


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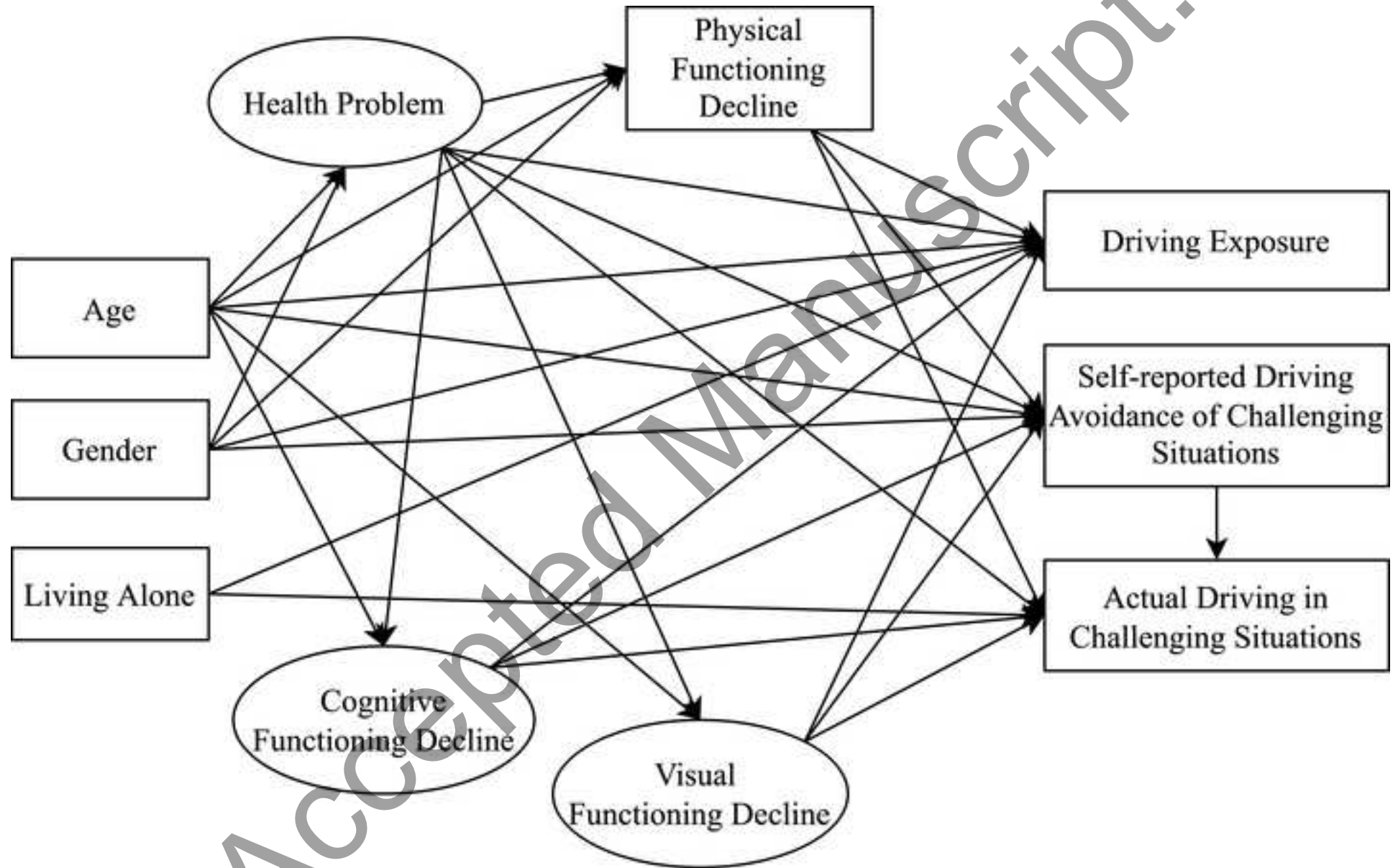
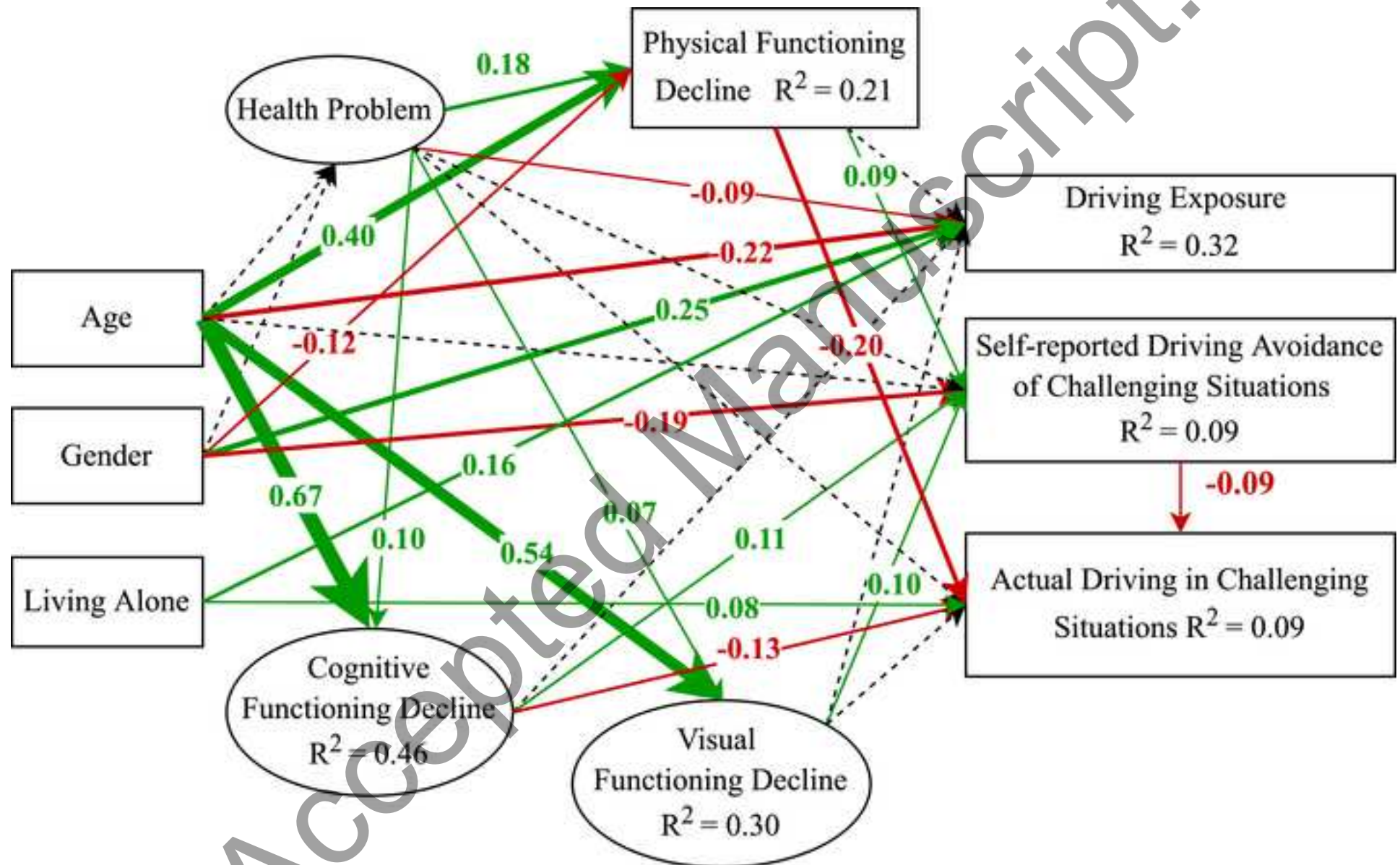


Figure 3: Final trimmed causal model

[Click here to access/download;Figure;Figure 3b Final trimmed causal model.jpeg](#)



**Declaration of interests**

☐The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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