ABSTRACT

CHOI, HEESUN. Older Drivers' Attentional Functions and Crash Risks in Various Hazardous Situations: Relationship, Taxonomy, and Compensatory Behaviors. (Under the direction of Dr. Jing Feng).

Older drivers are the fastest growing segment of the driver population. While driving is a primary form of transportation for many older adults, old drivers can be more vulnerable in vehicle crashes than other age groups. Understanding the risk factors that influence older drivers’ safety is essential for developing effective solutions that can help older drivers to maintain driving safety without compromising their mobility. Age-related cognitive changes have been identified as one of the leading causes of the increased vehicle crash risks in older drivers. Among many aspects of cognitive deteriorations that older adults may experience, attentional abilities have been found to be strongly predictive of drivers’ crash risks and unsafe driving behaviors. Most research on the associations between attention and driving risks has focused on individual aspects of attentional functions. Only limited research has attempted to build a comprehensive understanding of the potential impacts of attentional declines on driving risks. Precise relations between distinct functions of the attentional system and crash risks in particular driving conditions associated with each attentional function are yet to be identified.

This dissertation aimed to investigate the distinct attentional functions and the associated driving errors and crash types, with a framework of a neurocognitive model of attention, the Attentional Networks model. This model conceptualizes human attentional system consisting of three distinct brain networks including the alerting, orienting, and executive networks. The current research aimed 1) to identify whether each attentional function is associated with older drivers’ driving safety in particular traffic situations, 2) to
develop and validate a taxonomy of attentional functions and the associated crash risks, and
3) to investigate various factors that potentially accommodate older drivers’ attention-related
crash risks, including self-awareness of functioning and compensatory driving behaviors.

In study 1, an online experiment was conducted to examine whether and to what
extent the three attentional functions (i.e., alerting, orienting, and executive attention) are
involved in driving safety of older adults, by associating each functional efficiency with self-
reported driving errors and history of traffic violations and crashes. The results confirmed
that an inferior level of overall attentional functioning is associated with increased driving
errors and crash risks, and among the three attentional networks, the executive attentional
efficiency was most consistently linked to poor driving performance and increased crash
risks. The results also suggested that specific types of driving errors and crash characteristics
were associated with each of the three attentional functions. For instance, an inferior
executive attention was linked to an increased likelihood of errors occurring while making an
unprotected left turn, merging, multi-tasking, or inhibiting distractions during driving. From
the identified associations, a taxonomy table was drawn to classify efficiency of each
attentional function and increased risks during particular types of traffic situations associated
with each function. The second study conducted an experiment using a driving simulator to
examine the associations between the attentional functions and crash risks in the associated
hazardous events among older drivers as the developed taxonomy table indicates. The
findings from the second experiment provide further supports for the importance of the
executive attention compared to the alerting or orienting attentional functions. The executive
attentional efficiency was associated with increased crash risks in particular sets of hazardous
driving events that are primarily involved in the presence of conflicts among multiple
competing tasks or information that requires a quick resolution to avoid a driving hazard. While no clear connections between the alerting or orienting attention and driving safety emerged in the present study, the general speed of attentional processing was found to have critical impacts on crash risks in various hazardous situations. The present study also provides insight about older drivers’ self-awareness in attentional and driving functioning as well as age-related changes in driving behaviors as compensatory strategies. The main findings include: 1) an individual driver’s perceived attentional efficiency does not accurately reflect one’s actual efficiency level, 2) self-awareness of declines is important in compensatory driving behaviors, but only when it is directly related to driving competency, and 3) older drivers tend to adopt compensatory behaviors as countermeasures of the impacts from age-related declines, but the benefits of those behaviors on driving safety may be limited.
Older Drivers' Attentional Functions and Crash Risks in Various Hazardous Situations: Relationship, Taxonomy, and Compensatory Behaviors

by
HeeSun Choi

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APPROVED BY:

Dr. Jing Feng
Committee Chair

Dr. Anne Collins McLaughlin
Vice-Chair

Dr. Thomas M. Hess

Dr. Chang S. Nam
BIOGRAPHY

HeeSun Choi was born and raised in Seoul, South Korea. She completed her undergraduate studies at Yonsei University. While attending Yonsei University, she studied at University of Washington for a year on a student exchange program. She earned a dual Bachelor’s degree in psychology and business administration and graduated in 2007 with university honors. Afterward, she worked at SK Telecom, a mobile broadband company in Korea. After working in industry for a few years, she decided to pursue a Ph.D. in psychology. In August 2010, she entered graduate school at North Carolina State University and finished a master’s thesis in Human Factors and Applied Cognition in the Psychology department in 2013 as a step on the path to Ph.D. While attending graduate school, she worked on a number of studies on human attention and cognitive aging in the context of driving safety and task performance. After graduation, she will start a postdoctoral fellowship at the National Institute for Occupational Safety and Health (NIOSH) in Morgantown, West Virginia.
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# TABLE OF CONTENTS

LIST OF TABLES..................................................................................................................... vi
LIST OF FIGURES .................................................................................................................. vii
Overview of Research ............................................................................................................. 1
  Motivation for research ........................................................................................................ 1
  Chapter by chapter summary .......................................................................................... 1
Introduction ............................................................................................................................ 3
  Road Safety and Mobility Issues with Increasing Older Drivers ..................................... 3
  Impacts of Cognitive Aging on Driving Safety ................................................................ 5
  Age-related attentional declines and elevated crash risks .......................................... 9
Theoretical Framework: Attention Networks Model .............................................................. 12
Functional Efficiency of Attention Networks and Crash Risks ...................................... 15
Self-Awareness of Functioning, Declines, and Compensatory Behaviors ...................... 22
Research Questions and Hypotheses .................................................................................. 27
Study 1 ................................................................................................................................. 29
  Methods .......................................................................................................................... 30
  Results .......................................................................................................................... 40
  Discussion ...................................................................................................................... 58
Development of Taxonomy .................................................................................................. 63
Study 2 ................................................................................................................................. 65
  Methods .......................................................................................................................... 67
  Results .......................................................................................................................... 79
  Discussion ...................................................................................................................... 93
General Discussion ............................................................................................................... 98
  Summary of Findings ..................................................................................................... 98
  Contribution .................................................................................................................. 100
  Limitation .................................................................................................................... 101
  Direction for Future Research ....................................................................................... 104
Conclusion ............................................................................................................................. 105
References ............................................................................................................................ 137
Appendix ............................................................................................................................... 149
  Appendix A. Study 1 – Online survey ........................................................................... 150
  Appendix B. Study 2 – Screening interview ................................................................ 164
  Appendix C. Study 2 – Entry survey ............................................................................ 166
  Appendix D. Study 2 – Interview material .................................................................. 170
  Appendix E. Study 2 – Macular degeneration test ...................................................... 176
  Appendix F. Study 2 – Experimenter scripts .............................................................. 178
LIST OF TABLES

Table 1. Study 1 and 2 - Participant demographics and self-reported driving measures.107
Table 2. Study 1 and 2 - ANT performance.................................................................107
Table 3. Study 1 - Correlations between ANT and prior violations and crashes..........108
Table 4. Study 1 - Correlations between ANT and the self-reported questionnaires .....108
Table 5. Study 1 - Comparisons of ANT performance by the crash types ..............110
Table 6. Study 1 - Comparisons of ANT performance by the performance errors ....111
Table 7. Study 1 - Associations between ANT performance and crash characteristic ....112
Table 8. Study 1 - A summary of the observed association between ANT indices and driving errors and crashes ..................................................................................115
Table 9. Study 1 – Comparisons of ANT performance and prior driving violations and crashes by age groups ............................................................................................................116
Table 10. Study 2 - The list of simulated driving events..............................................117
Table 11. Study 2 - Correlations between ANT and prior violations and crashes......121
Table 12. Study 2 – A summary of the associations between ANT and the crash risks..122
Table 13. Study 2 - Correlations between the perceived and measured attention ........122
Table 14. Study 2 - Correlations among self-awareness of functioning......................123
Table 15. Study 2 – Results of hierarchical regression analysis on compensatory behaviors ...............................................................................................................................124
LIST OF FIGURES

Figure 1. NHTSA taxonomy of older driver behaviors and crash risks .......................125
Figure 2. Illustrations of the ANT procedures .............................................................126
Figure 3. Comparisons of the executive attentional efficiency among the Type A and E crash groups .................................................................127
Figure 4. Taxonomy table of the three attentional functions and the associated traffic situations .........................................................................................128
Figure 5. Illustrations of the 14 hazardous events presented in a simulated driving ......131
Figure 6. A list of images used for the road-side billboard ads in a simulated driving ...134
Figure 7. Snellen chart (visual acuity test) .................................................................135
Figure 8. An illustration of the visual contrast sensitivity test .................................135
Figure 9. Comparisons of prior crash frequency by attentional functioning and compensatory behaviors groups .........................................................136
Overview of Research

Motivation for Research

Population aging is a global trend that has considerable economic and societal impacts. Among diverse challenges that we may encounter as the population continues to age, maintaining road safety has become one of the central issues for our society. In addition to age-related declines in physical functions, cognitive changes with age contribute significantly to older drivers’ elevated crash rates. Over the past few decades, the attentional function has been a major area of interest within the field of driving safety research, and much evidence has suggested that age-related deficits in attentional function may critically impact older drivers’ crash risks. However, a systematic understanding of how different aspects of attentional function contribute to crash risks in various traffic situations is still lacking. The present research examines if a particular type of attentional function has distinctive impacts on older drivers’ crash risks using a neurocognitive model of attention. In addition, this research investigates the factors that influence older drivers’ driving safety, including perceived attentional efficiency, self-awareness of age-related functional declines, and compensatory driving behaviors.

Chapter by Chapter Summary

The overall structure of this thesis takes the form of six chapters.

1) Introduction. It begins by providing a background of the topic and establishing the importance of the present study. This chapter states how increasing older population has made our society face a challenge of keeping the balance between safety and mobility of
older drivers. It then goes on to present the findings of the prior research on cognitive aging and its impacts on driving safety, focusing on age-related declines in attentional abilities. This chapter also gives a brief overview of the theoretical framework and reviews the relevant literature. At the end of the chapter, it defines the research questions and hypotheses.

2) Study 1. This chapter summarizes the first study that examined self-reported driving errors and crash characteristics in relation to the three attentional functions. It includes descriptions of the methodologies, results of cognitive tests and self-reported driving outcomes, and discussion of findings from the first experiment.

3) Development of taxonomy. The third chapter describes the process of development of a taxonomy table as the outcome of the first study. The taxonomy aims to classify increased crash risks in various traffic conditions and associated attentional function.

4) Study 2. The following chapter describes the second study that examined the proposed taxonomy table using a driving simulator. The second study also investigated the potential factors that have a beneficial influence on older drivers’ attention-related crash risks, including self-awareness of functioning and compensatory driving behaviors. This chapter summarizes the methodologies, findings from results of cognitive tests, simulated driving performance, and interviews, and the discussion.

5) General discussion. The following chapter integrates the findings from the two studies and summarizes and the implications and contributions of main findings. It also addresses key issues and limitations and discusses the future direction.

6) Conclusion. The essay ends with a final summary of findings and implications of the present research.
Introduction

Road Safety and Mobility Issues with Increasing Older Drivers

Older driver population is the fastest-growing segment of the driver population in many countries that experience with societal aging (Sivak & Schoettle, 2011). According to a report published by U.S. Department of Transportation (Federal Highway Administration [FHWA], 2006; 2015), in 2014, there were 38 million licensed drivers aged 65 and older, which represented approximately 18% of all drivers, and this number was 31% increase from 2005. By 2030, the number of older drivers is expected to rise to 57 million (I.S. Government Accountability Office, 2007), and it was estimated the older driver population will represent about 25% of all licensed drivers in the United States (Lyman, Ferguson, Braver, & Williams, 2002). These increases in the number and proportion of older drivers in our driving population pose a major challenge to our society regarding the maintenance of road safety and mobility of older drivers. Evidence has shown that old drivers are more vulnerable to fatal crashes than other age groups (Braver & Trempel, 2004; Cicchino, 2015). With changes in travel patterns, health, and roadway design as well as improvements in vehicle technologies, the fatal rate of older drivers continued to decline. However, they are still in higher risks of involvement in fatal crashes per miles travel compared to middle-aged driver groups (Cicchino, 2015). According to the traffic safety data, drivers aged 65+ made up 17 percent of all traffic fatalities (NHTSA, 2012), and the fatal crash rates increase more noticeably with more advanced age (e.g., 80 or older) among older drivers (Cicchino, 2015). Maintaining the ability to drive is critical for older adults for their well-being. Driving is a
primary form of transportation for many older adults, thus keeping the driver’s license is essential to maintain their mobility and independence (Carp, 1988). Thus, our society is encountering a challenge of potentially conflicting needs of safety and mobility of the older population.

There can be different approaches to resolving this challenge. One of common approach is the use of screening criteria or assessment tool to identify older drivers at high risks. A number of screening measures of various types have been proposed, including questionnaires and scales (e.g., the Manchester Driver Behavior Questionnaire [DBQ; Reason et al., 1990; Reimer et al., 2005], the Attention-related Failures during Driving Questionnaire [AFDQ; Choi, Grün, & Feng, 2015]), paper-and-pencil or computerized cognitive assessment (e.g., the Drive Aware Task [DAT; Feng et al., 2015], the DriveABLE [Dobbs, 2013]), and multi-disciplinary assessment batteries (e.g., the Assessment of Driving-related Skills [ADReS; McCarthy & Mann, 2006]). In addition, various general visual or cognitive tests have also been used as assessment tools that predict driving risks, including a visual attentional test that was addressed earlier, the UFoV (Ball et al., 1988), and the Mini-Mental State Exam (MMSE; Crizzle, Classen, Bedard, Lanford, & Winter, 2012) (See Vrkljan, McGrath, & Letts, 2011 for a review of the widely used fitness-to-drive assessment tools). Although these assessment tools have shown that they can predict older drivers’ driving abilities and crash risks, the main disadvantage of this resolution is that it is primarily used to screen out older drivers at high risks, without considering the potential alternatives to improve the mobility among these older drivers. More preventive approach such as providing cognitive or driving training program to at-risk older drivers can keep older drivers’ mobility
without compromising road safety (Gamache et al., 2010). Developing effective cognitive training programs has been one of the major area of interest within the field of aging (e.g., Ball et al., 2002; Willis et al., 2006). Empirical evidence has suggested that cognitive training could improve driving performance (Ball et al., 2010; Cassavaugh & Kramer, 2009; Roenker et al., 2003). For example, Ball et al. (2010) showed that a cognitive training for reasoning and speed of processing, which consist of up to 10 sessions, significantly reduced crash involvement among older drivers. In addition to cognitive training methods, promoting self-regulatory driving practices and compensatory strategies can also be an effective approach to managing driving safety and mobility among older drivers. Studies have showed that older drivers regulate driving according to their visual or cognitive impairments (Molnar & Eby, 2008; Motak, Gabude, Bougeant, & Huet, 2014), and self-regulatory driving behaviors such as avoidance of specific difficult driving situations were found to be positively related to on-road driving (Baldock, Mathias, McLean, & Berndt, 2006). Given that success of these approaches would critically depend on the knowledge of older driver population, understanding the risk factors that determine older drivers’ elevated crash may be a key to developing effective solutions to improve driving safety without a loss of mobility among older drivers.

**Impacts of Cognitive Aging on Driving Safety**

Age-related declines in physical abilities and survivability from traffic crashes are a major determinant of crash risks and fatality rate among older drivers (Cicchino & McCartt, 2014; Hakamies-Blomqvist, Siren, & Davidse, 2004). In addition, existing research recognizes cognitive aging as one of the leading causes of elevated risks of vehicle crashes.
among older drivers (e.g., Anstey et al., 2005). Normative age-related declines have been shown on many aspects of cognitive abilities that are critical for safe driving, such as processing speed (Deary, Johnson & Starr, 2010), sensory and perceptual processing (Shinar & Schieber, 1991), attention (Ball et al., 1993, Caird et al., 2005; Clay et al., 2005, Cuenen et al., 2012, Owsley et al., 1991; Trick, Enns, Mills, & Vavrik, 2004), executive control (Luszcz, 2011).

In particular, age-related slowing in processing speed can lead to driving impairments and increased crash risks among older drivers (Ball, Edwards, & Ross, 2007) as the general slowing in processing speed could lead to lower efficiency in a various aspects of cognitive functions (Kramer & Madden, 2008; Salthouse, 1996). It has been shown that a slowed processing speed have negative impacts on many stages of cognitive processing, from encoding sensory information to executing responses, all of which are vital for safe driving. Age-related deteriorations in visual sensory processing have also been observed in many aspects of perceptual processing, such as visual acuity, contrast sensitivity, symmetry perception, and depth perception (Faubert, 2002). These perceptual declines with increasing age have been found to be a significant contributing factor to increased vehicle crash risks among older drivers (Shinar & Schieber, 1991). For instance, one study reviewed various aspects of visual requirements and found that deteriorations such as in visual acuity are associated with an increase in accident involvement among older drivers (Shinar & Schieber, 1991). Static acuity was found to be have critical impacts on night-time accident involvement, possibly due to deficits in the legibility of signs or hazards (Shinar & Schieber, 1991). Another study also found that dynamic visual acuity, which involves in resolving
details of a moving target, was closely linked to risks in crash involvements (Shinar, 1977). Several studies have also reported the importance of distinct aspects of perceptual abilities on driving performance (Aksan et al., 2012; Owsley et al., 1991; Shinar & Schieber, 1991). For instance, prior findings suggest motion perception being associated with detection of a sudden hazard occurrence and judgment of speed and distance (Shinar & Schieber, 1991) and contrast sensitivity, the ability to detect target in the presence of low-contrast background, being associated with increased number of vehicle crashes (Owsley et al., 2001). Research also recognizes auditory impairments being linked to vehicle crash involvements among older drivers. (Green, McGwin, & Owsley, 2013)

While many studies have investigated each individual cognitive function or limited sets of relevant cognitive functions, there have been relatively few efforts to develop a more inclusive understanding of relations between many aspects of functional deficits and increased crash risks. Owsley et al. (1991) attempted to construct a model predicting the number of vehicle crashes based on one’s various visual and cognitive condition including ophthalmological health, visual functioning, visual attention capacity, and mental status. The results demonstrated that the visual attention and mental status were the significant predictors of vehicle accidents. Together these variables accounted for about 20% of the variance of general accidents and 29% of the variance of the intersection accidents. Interestingly, the results showed that the vision health and visual sensory functions (e.g., visual acuity, contrast sensitivity, and color discrimination) contributed to visual attention, but were not directly predictive of crash frequency (Owsley et al., 1991). These results suggested that the attentional function, but not the visual sensory functioning, has direct impacts on older
drivers’ vehicle crash risks. More recently, the National Highway Traffic Safety Administration conducted a comprehensive investigation of contributing factors of increased crash risks among older drivers (Staplin, Lococo, Martell, & Stutts, 2012). This investigation analyzed the crash data and reviewed the literature to identify age-related functional deficits that underlie increased likelihood of crash involvement among older drivers. These functional deficits include those appearing in visual sensory functions, attention, working memory, decision-making, spatial abilities, knowledge, and motor functions (e.g., head/neck/trunk range, arm and leg strength and speed). Based on the literature review and an additional expert panel review, a taxonomy table was developed to classify relationships between older drivers’ risky driving behaviors and driving errors and a number of crash-contributing functional deficits (Staplin et al., 2012, p35). The taxonomy also indicates behavioral countermeasures that can accommodate the age-related deficits and ultimately reduce older drivers’ risky driving behaviors and driving errors associated with those deficits. Although the taxonomy has not been further validated with empirical evidence, it suggested the possibility to construct a taxonomy detailing the connections between visual, attentional, cognitive, and motor deficits and particular types of increased driving errors, which can be used as a useful resource for researchers and practitioners. This taxonomy from the NHTSA report (Staplin et al., 2012) is illustrated in Figure 1. For instance, the taxonomy classifies that functional deficits in visual sensory and perception, including visual acuity, contrast sensitivity, visuospatial fields, dark adaptation, and glare recovery, are mainly associated with the likelihood of failing to visually detect potential conflicts, hazards, or traffic control information, while attentional deficits, such as poor selective attention, divided attention, and
executive function, are more likely to be associated with gap judgment errors (i.e., inability to accurately estimate closing speed and distance), inability to predict the development of future conflicts from current traffic and contextual information, slowed vehicle control response, inadequate visual search and attentional failures (e.g., “looked but didn’t see”), slowed decision making, and inappropriate response selection (Staplin et al., 2012). Overall, the taxonomy indicates that attention-related deficits are more prominent in many of critical performance errors of older drivers, compared to sensory or motor deficits. The studies reviewed above highlight the notion that, although various age-related functional deficits contribute to elevated crash risks of older drivers, a major risk fact is attentional deterioration.

**Age-related attentional declines and elevated crash risks**

As addressed in the earlier section, evidence has suggest that attentional function is a strong predictor of drivers’ crash risks and driving errors (Ball et al., 1993, Caird et al., 2005; Clay et al., 2005, Cuenen et al., 2012, Owsley et al., 1991; Trick et al., 2004). Normative declines with age have been observed in a wide range of attentional processes. For example, previous studies have demonstrated age-related deficits in an ability to sustain attention for an extended period of time (i.e., vigilance or sustained attention; Berardi, Parasuraman & Haxby, 2001; McAvinue et al., 2012), capacity limits of attention (Basak & Verhaeghen, 2003), an ability to process certain stimuli selectively in the presence of multiple information (i.e, selective attention; Madden & Langley, 2003; Quigley et al., 2010), spatial coverage of visual attention (Ball et al., 1988), an ability to disengage attention (Cosman et al., 2012),
and an ability to divide and allocate attention to multiple concurrent processing i.e., divided attention; Fraser & Bherer, 2013; Tun & Wingfield, 1995).

In the past few decades, a major focus of prior research that investigated how attentional deficits impact older drivers’ driving performance has been placed on the particular aspect of attentional function that involves in attentional processing across the visual field. This spatial coverage of attention, or visuospatial attention, is associated with an ability to detect a target across an extended visual field. The Useful Field of View (UFoV; Sanders, 1970; Ball et al., 1988), or sometimes referred as the Attentional Visual Field (AVF; Feng & Spence, 2014), or the Functional Field of View (FFoV; Gaspar, Neider, & Kramer, 2013), is defined as the visual field over which one can process visual information. The UFoV test (Ball et al., 1988; Owsley et al., 1991) that measures one’s ability to detect a target presented at a varying eccentricity within the peripheral area, with or without a presence of distractors, is widely used to assess individual differences in the spatial coverage of attention. Much evidence has found that UFoV significantly declines with aging (e.g., Ball et al., 1988; Cosman et al., 2012; Scialfa, Thomas, & Joffe, 1994). Some studies suggested that a constriction in attentional breadth or scope of the area over which one can detect information in a single glance may be an underlying cause of UFoV impairments among older adult (Ball et al., 1993; Kosslyn, Brown, & Dror, 1999), whereas other evidence has suggest that UFoV performance declines with aging primarily due to failures in filtering out distractors that compete with the target (Feng, Craik, Levine, Moreno, Naglie, & Choi, in press) or disengagement deficits (Cosman et al., 2012) rather than the impaired size of a visual field. While there has been theoretical research on mechanisms and causes of age-
related declines in UFoV, a large volume of published studies also investigated the practical implications of age-related deficits in UFoV, particularly in the context of driving. Findings from these studies agreed that individual’s UFoV performance is a significant predictor of older adults’ driving performance (Backs et al., 2011; Ball et al., 1993; Classen et al., 2013; Clay et al., 2005; Cuenen et al., 2012; Daigneault, Joly, & Frigon, 2002; Friedman, McGwin, Ball, Owsley, 2013; Owsley et al., 1991; Owsley et al., 1998; Weaver, Bedard, McAuliffe, & Parkkari, 2009). For instance, Owsley et al. (1998) showed that older drivers who had 40% or more impairment in UFoV were 2.2 times more likely to be involved in a vehicle crash in the next three years. Clay et al. (2005) examined the effect size of the association between the UFoV index and driving performance that was observed in prior eight studies using a meta-analysis method. The results showed that the relationships between inferior UFoV performance and negative driving outcomes were robust across different driving measures, which include official accident records, on-road driving, and simulated driving (Clay et al., 2005). With the extensive evidence that recognizes the importance of UFoV as a reliable predictor of driving performance, UFoV has been one of the widely used assessment tools for older drivers’ potential risks of vehicle crashes.

The convergence of evidence strongly supports the critical role of age-related attentional declines on increased crash risks of older drivers. While most research investigated this association using a single attentional measure (e.g., UFoV) and a single driving measure (e.g., the number of crashes), different aspects of attentional abilities may have distinctive associations with crash risks in particular types of driving conditions or traffic situation. For example, failures in maintaining a high level of attention due to fatigue
or alcohol use during driving may impair drivers’ detection of road hazards, while the inability to divide attention may lead to failures in multi-tasks during driving. However, investigation on potentially unique associations between different aspects of attentional functions and various driving situations is lacking. Most research has focused on only one or a few of individual aspects of attentional functions, and limited research has attempted to identify precise impacts of declines in different attentional functions on crash risks among older drivers, with a theoretical framework of human attention. Using a theoretical model of the attentional system including various attentional functions may provide an opportunity for more systematic and comprehensive investigation of the associations between attention and older drivers’ driving safety.

**Theoretical Framework: Attention Networks Model**

Many researchers had explored the impacts of individual aspects of attentional deficits on driving safety, based on the traditional view of attention as a uniform construct. In the recent years, accumulating evidence suggests that attention is rather a complex construct that consists of multiple components. In particular, a neurocognitive model, the attention network model (Posner & Petersen, 1990), describes attention as a multifaceted construct that includes three distinct functions. This model proposed that the attention system in the human brain consists of three disparate neural networks that control the alerting, orienting, and executive attentional functions (Posner & Petersen, 1990; Posner & Rothbart, 2007). Alerting is a function for achieving and maintaining the mental state of high alert and vigilance. There are in general two types of alerting functions: tonic and phasic alerting. Tonic alerting, or vigilance, is defined as an ability to maintain attention over an extended period of time, while
phasic alerting is increased readiness to respond to the following stimuli after seeing or hearing a cue or a warning signal. The orienting function refers to switching attention toward a particular sensory signal to select task-relevant information among many sensory inputs. The executive function supports an ability to resolve conflicts in the presence of competing for internal or external information (Posner & Rothbart, 2007).

With the concept of three attentional functions defined in anatomical and functional terms, a standard behavioral test, the Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002) has been used to quantify the processing efficiency of each of the three networks. With a combination of the cueing paradigm (Posner, 1980) and the flanker task (Eriksen & Eriksen, 1974), the ANT assesses the efficiency of the alerting, orienting, and executive attentional functions by measuring how responses are influenced by cues and flankers (Fan et al., 2012). A number of studies using the ANT to measure attentional efficiencies suggested that the ANT provides reliable quantitative indices for each of the alerting, orienting, and executive attentional functions.

Using the ANT, a number of studies examined normative age-related changes in the three attentional networks among non-demented healthy older adults (Fernandez-Duque & Black, 2006; Jennings et al., 2007; Mahoney, Verghese, Goldin, Lipton, & Holtzer, 2010; Zhou et al., 2011). For instance, Mahoney et al. (2010) investigated the three attentional functions in a large sample of non-demented older adults, and the results suggested that among the older adults, chronological age was associated with declines in executive attention, which suggests an ability to resolve conflicts declines with increasing age (Mahoney et al., 2010). Age differences in orienting and alerting, however, were not
observed in this study. Similar results were found in Zhou et al. (2011) in which different age groups (younger, middle-aged, and older) were compared with respect to their efficiency of three attentional functions. This study supported that age may have the greatest impacts on the executive attentional function, but not on the alerting or orienting functions (Zhou et al., 2011). However, somewhat contradicting evidence has been reported in Fernandez-Duque & Black (2006) and Jennings et al. (2007). For instance, Jennings et al. (2007) found significant age-related declines in the alerting, but not in the orienting and executive attentional functions after controlling for processing speed. Similarly, in another study by Gamboz, Zamarian, & Cavallero (2010), the orienting and executive attention were not found to be significantly different between younger and older adults, while alerting deficits were found among older adults compared to younger adults. Further inconsistencies were found in Vázquez-Marrufo et al. (2011) in which age-related differences were observed only in the general response speed, but not in any of the three attentional functions.

Further empirical evidence can be found in the studies that did not directly assess all three attentional functions by the ANT but examined age-related differences in different aspects of attentional functions that related to the alerting, orienting and executive attention by using other behavioral as well as neurological measures. In previous studies using various behavioral tasks involving inhibition of incongruent stimuli, such as the flanker task and the Stroop task (Stroop, 1935), the age-related deficits in attention have most consistently observed in the executive type of attentional function (Luszcz, 2011; Vaughan & Giovanello, 2010; Turner & Spreng, 2012; Verhaeghen, 2011). The neurocognitive evidence further supported age-related differences in the pattern of brain activity during executive processing.
(Huizinga, Dolan, & van der Molen, 2006; Turner & Spreng, 2012; Sorond et al., 2008). In addition, evidence has shown that alerting attention is relatively intact with increasing aging (Nebes & Brady, 1993; Carriere, Cheyne, Solman, & Smilek, 2010). For instance, Nebes & Brady (1993) examined the phasic alerting function and found that both healthy and Alzheimer patients were able to utilize the warning signals. Another study that examined the tonic alerting function, using the SART which measures ability to maintain attention to withhold responses to infrequent and unpredictable stimuli, and suggested these abilities are relatively maintained throughout the life span (Carriere et al., 2010).

**Functional Efficiency of Attention Networks and Crash Risks**

Driving is a dynamic task that demands various aspects of attentional functions. Thus, deficits in the three distinct attentional functions may have a critical impact on driving safety. Furthermore, because the three aspects of attention are functionally distinct, the alerting, orienting, and executive may be involved in different traffic situations or driving tasks. For example, the alerting function could be most relevant to monitor the driving environments constantly for potential hazards, while the orienting may be more involved in directing attention to specific traffic signs to pick out the relevant information. The executive attention may be most critical when a driver faces conflicts in the environment. While there is likely a general link between attentional functions and driving performance (Weaver et al., 2009), one of the functions may be more primarily involved in certain driving situations, whereas another particular attentional function is more primarily involved in different sets of traffic situations (Roca, Crundall, Moreno-Ríos, Castro, & Lupiáñez, 2013) or different driving measures (Cuenen et al., 2012). Previous studies that investigated individual attentional
processes related to one of the alerting, orienting, and executive attentional functions provided evidence supporting the differential impacts of the three functions.

First, the alerting function, particularly tonic alerting, may be primarily involved in maintaining high alertness during driving. Driving can be a demanding task and often lasts for a few hours or even longer without a break. Sustaining vigilance during a long or monotonous drive is a key for a driver’s safety. Research has shown that failures in sustained attention are significantly associated with increased driving risks. For instance, being drowsy reduces a driver’s ability to detect and avoid driving hazards (Åkerstedt, Peters, Anund, & Kecklund, 2005). Also, loss of vigilance due to monotonous driving conditions may impair lane positioning and time to cross a lane (Larue, Rakotonirainy, & Pettitt, 2011). Deficits in phasic alerting can also impact driving safety by impairing a driver’s readiness to respond when seeing or hearing a cue or a warning signal for an impending traffic situation or potential hazard. For example, when a driver sees a traffic sign indicating a pedestrian crossing area, the driver must maintain alertness and expect possible pedestrians crossing the street around the vehicle. Failures in phasic alerting function may result in a lack of readiness to respond to anticipate road hazards after an advanced cue or warning.

The orienting function is necessary for drivers to direct attention and to select critical information in the visual field during driving. Studies have suggested that processes related to the orienting function are critically associated with safe driving. Coeckelbergh et al. (2002) examined the individual difference in visual attention using the UFoV test and compared to simulated driving behaviors. Their results showed that ability to identify driving hazards in the visual periphery was associated with driving speed and visual scanning during
driving (Coeckelbergh et al., 2002). Also, previous studies showed that facilitating drivers’ orienting attentional function by providing vibrotactile warning signals during driving could be beneficial for drivers to process time-critical hazardous information as well as to reduce time for braking responses and improve driving safety (Ho, Reed, & Spence, 2006; Ho, Tan, & Spence, 2005). There are different types of orienting attention regarding attention selection mechanisms: exogenous and endogenous processing. Exogenous processing refers to selection directly initiated by the presence of a stimulus, whereas endogenous selection results from top-down processes such as expectancy, motivation, or goal. Given this difference, two types of orienting attentional function may have different impacts on driving performance. For example, exogenous orienting may facilitate older drivers to react faster when salient hazards occur abruptly on the road, while endogenous orienting may be more associated with situations when drivers can anticipate potential hazards based on environmental context (Trick et al., 2004). The endogenous orienting can also produce errors when relevant traffic information or hazard occur unexpectedly (Hills 1980; Rumar 1990; Trick et al., 2004).

The executive attentional function may play an important role in resolving conflicts during driving such as when a driver needs to focus attention on particular information with the presence of other attention-competing information. A number of previous studies suggested that the executive attentional function is critically associated with safe driving (Aksan et al., 2012; Backs et al., 2011; Bunce, Young, Blane, & Khugputh, 2012; Classen et al., 2013; Dobbs, 2013). For instance, Daigneault et al. (2002) showed that older drivers who had been involved in vehicle crashes exhibited inferior executive function measured using a
Stroop test, compared to the peer drivers without crashes. The executive attention may be particularly critical when driving involve multiple tasks or driving through a highly distracting environment. Drivers often need to complete a secondary task such as switching on or off the turning signal, checking side-mirrors, manipulating in-vehicle systems, or even talking with passengers while maneuvering the vehicle. Thus, inability to process one task in the presence of conflicting tasks may lead to poor driving performance. In addition, the executive attentional function is significantly associated with safe driving when driving requires making quick decisions among many alternative options (Cuenen et al., 2012). Drivers need to focus on the most relevant information, to choose the proper response, and to execute the actions while suppressing inappropriate processes. For instance, drivers may encounter multiple concurrent events that demand conflicting responses such as when a sudden appearance of road hazard suggests an abrupt breaking response, while surrounded heavy traffic with a car following behind closely suggests a gentle breaking response or even inhibition of a break response.

Although a number of studies independently investigated how processes related to one of the alerting, orienting, or executive attentional function may be involved in general driving safety as well as driving performance in certain traffic situations, only a limited studies attempted to develop a comprehensive understanding of the impacts of the three attentional functions on driving safety. Given that the three functions serve distinct roles in task performance, a comprehensive examination of the three functions is necessary to understand how deterioration in each of the three attentional functions are related to increased crash risks among older drivers. Furthermore, as discussed earlier, the impacts of
increasing age differ in the three attentional functions. Thus, identifying the precise associations between the three attentional functions and driving safety is important to predict increased attention-related crash risks with increasing age and to develop effective countermeasures.

Distinct impacts of the three attentional functions on driving can be directly compared using the ANT which provides efficiency indices of the three attentional functions within a single task. A few studies investigated the relations between the alerting, orienting, and executive functions and driving performance using the ANT (Backs et al., 2011; Cuenen et al., 2012; López-Ramón, Castro, Roca, Ledesma, & Lupiañez, 2011; Roca et al., 2013; Weaver et al., 2009). López-Ramón et al. (2011) examined the attentional functions of younger and older drivers using a modified version of the ANT (i.e., ANTI), which used an auditory alerting cue and also included invalid orienting cue conditions. The results indicated that older drivers were in general slower in attentional processing speed compared to younger drivers. They also found age-related differences in the patterns in the alerting and orienting attentional efficiencies: older drivers showed a significantly lower endogenous orienting efficiency in the presence of a high-priority warning signs (i.e., auditory warning sign preceded before the spatial orienting cue) (López-Ramón et al., 2011), which may suggest that older drivers are less likely to respond to a relevant information indicating the presence of a potential road hazard. It was also found that older drivers had worse executive attentional efficiencies compared to younger drivers, suggesting that older drivers might be less efficient to resolve conflicts in traffic circumstances given age-related attentional declines (López-Ramón et al., 2011). This study also compared the ANT indices between the
drivers with a high vs. low proneness to attention-related driving errors based on the self-reported tendency of an attention-related error occurring during driving. Results from this study suggest that the high attention-related driving error group showed a lower endogenous orienting efficiency, but a better executive efficiency. This finding implied that although drivers who are more prone to exhibit attention-related driving errors may be less efficient in directing attention to pick out relevant information in traffic situations, they may have lower risks in situations where they deal with conflicts during driving (López-Ramón et al., 2011). The study also provided interesting insights into older drivers’ crash risks related to the three attentional functions. However, no driving outcome measure was included to investigate the potential impacts of older drivers’ individual differences in the three attentional functions on driving performance. Thus, it remains unclear how the observed attentional differences between the age or driving error groups impact driving performance. Weaver et al. (2009) compared the alerting, orienting, and executive efficiency with driving performance both in a simulator and on-road. Their results suggest that overall ANT speed was the most reliable indicator of driving performance, while the three attentional efficiencies did not have consistently associations with general driving performance measures.

The two studies (López-Ramón et al., 2011; Weaver et al., 2009) discussed earlier attempted to connect attentional functions with driving performance and risks in general. However, they did not examine if associations between the three individual attentional and driving performance in more specific driving tasks or traffic situations might exist. While driving performance and crash risks highly depends on specific conditions of driving, very little is known about the roles of the alerting, orienting, and executive attention in a variety of
specific traffic situations. Roca et al. (2013) attempted to assess the impacts of the three attentional functions when drivers encounter different types of hazardous driving situations. The study examined the nine common hazardous events that were categorized in one of the three types: behavioral prediction hazards (i.e., a precursor for a hazard source is visible. Thus the hazard can be avoided if drivers anticipate the actions of the precursor), environmental prediction hazards (i.e., to avoid a hazard, drivers need to anticipate potential hazards from precursors in the environment in which the hazard source is not concealed), and dividing and focusing attention hazards (i.e., multiple sources of potential hazard exist in the environment. Thus drivers need to monitor them and select one to avoid the actual hazard) (Roca et al., 2013). The ANT indices were compared with driving performance in a driving simulator in which the nine hazardous situations were presented. The orienting efficiency was found to be most strongly associated with the hazardous situations among the three attentional efficiencies. The findings also suggest that the orienting attentional functions may have differential impacts on driving risks depending on the types of hazardous situations. For instance, individuals with a higher orienting function were more likely to complete driving safely in a hazardous traffic situation where a single precursor anticipated the hazard source (i.e., behavioral prediction or environmental prediction hazards), whereas they exhibited delayed braking in more complex situations where multiple potential hazard precursors existed (i.e., dividing and focusing attention hazards) (Roca et al., 2013).

Previous evidence has recognized that the three attentional functions (i.e., alerting, orienting, and executive attention) may play an essential, but each with a distinct role in various driving situations. Crash analyses on older drivers often showed that older drivers are
more likely to be involved in certain types of driving errors such as making inadequate surveillance errors and misjudging the length of a gap between vehicles or another vehicle's speed (e.g., Cicchino & McCartt, 2015) and crashes such as multiple-vehicle crashes at intersections (Mayfew, Simpson, & Ferguson, 2006). Distinctive characteristics of older drivers’ driving performance errors and crash types may be due to unique patterns of cognitive and attention impairments with aging. Thus, precise understanding of how the distinct attentional functions are involved in specific driving situations is important to predict when and in what condition older drivers would have increased risks when having deteriorations in the particular attention networks. Despite the importance of understanding the specific connections between the three attentional functions and driving performance when measured in more specific traffic situations or during particular driving tasks, apart from Roca et al. (2013), in general, there is a lack of research in these possible associations.

Self-Awareness of Functioning, Declines, and Compensatory Behaviors

As addressed in the previous chapters, age-related declines have been observed extensively in various cognitive measures of older adults, and evidence has suggested that cognitive test performance measured in controlled setting was positively associated with the everyday cognitive performance. Age-related declines have been found in both psychometric cognitive measures and everyday performances (Allaire & Marsiske, 1999). However, in many tasks, the amount of age-related declines in everyday functioning does not directly correspond to the amount of decline in psychometric measures (Cornelius & Caspi, 1987). Disagreement between the psychometric measures and everyday performance may be explained by roles of mediating factors such as compensatory behaviors, experience,
practice, and motivation that can accommodate the impacts of the cognitive declines on the performance on daily tasks (Germain & Hess, 2007). This fact provides important insight into the relationship between the cognitive declines and driving safety. Some older drivers may effectively cope with attentional declines with increasing age and reduce their negative impacts on driving safety by employing useful coping mechanisms. Thus, it is important to understand factors influencing older drivers’ driving safety, such as compensatory driving strategies adopted by older drivers with increasing age.

There are many forms of compensatory strategies that older drivers may utilize when they aware of their functional declines with aging. A number of studies showed that many older drivers self-limit their driving (e.g., reduce driving exposures, avoid certain traffic area or challenging driving conditions such as night or raining, etc.), and there are significant individual difference in self-regulatory driving behaviors (Devlin & McGillivray, 2014; Motak et al., 2014; Molnar et al., 2014; Owsley, McGwin, Phillips, McNeal, & Stalvey, 2004). For instance, using a survey, Braitman & McCartt (2008) showed that older drivers who reported that they were experiencing cognitive and physical impairments were more likely to make fewer trips, traveling shorter distances, or avoiding night driving, driving on interstates or driving in ice or snow. Devlin & McGillivray (2014) also found that older adults who have increase driving risks due to attentional and cognitive declines tend to take strategic behaviors such as avoiding certain driving situations or restricting driving exposures. Similarly, Stutts (1998) suggested that older drivers when experienced declines in cognitive and visual functions were more likely to show self-regulatory driving behaviors such as driving lower miles and avoiding high-risk driving situations. Studies also showed
that older drivers tend to self-regulate certain driving exposures that were most likely to be associated with the functional declines that they exhibited. For example, Kaleem, Munoz, Munro, Gower, and West (2012) compared visual attention and sensory characteristics of older drivers between who continue to drive at night and who restrict night driving, the findings indicated that older drivers who had had more severe cognitive and visual declines, particularly such as contrast sensitivity, were more likely to restrict their night driving than older adults who scored better in those measures.

Existing evidence suggests that when drivers experience functional deteriorations, they tend to use various types of self-regulations in driving as a compensatory mechanism to reduce potential risks due to such declines. However, studies have also suggested that there are large individual differences and contributing factors that determine self-regulatory driving practices (Molnar et al., 2014). For example, gender and age were found to be significant factors influencing compensatory driving behaviors. Stutts (1998) found significant gender differences in adoption of compensatory strategies with cognitive declines; male showed greater self-regulatory driving behaviors than females. Male drivers who had the severe cognitive declines reduced the driving miles drastically compared to the male drivers with the least declines, while decline level-related differences among female drivers were relatively small. Kaleem et al. (2012) also demonstrated possible gender and age differences in the behaviors of night driving restriction: younger-old drivers and male drivers were more likely to continue to drive at night compared to older-old and female drivers. Molnar et al. (2014) examined the sets of possible predicting factors, including age, overall health rating, self-perceived rating on physical mobility functioning and safe driving abilities,
self-rated driving confidence, comfort, and safety, and objectively derived visual sensory, perceptual, cognitive, and mobility functioning, to identify if they determined the self-regulatory driving among older drivers. Interestingly, the self-perceived driving abilities, self-perceived mobility functioning as well as feelings of comfort and safety, were significantly associated with self-regulatory driving behaviors, but a level of cognitive functioning assessed using objective measure did not predict the self-regulatory driving among older drivers (Molnar et al., 2014). Similar results were demonstrated in Devlin & McGillivray (2014): compensatory self-regulatory driving among older drivers was observed to be more related to individuals’ self-confidence than to their actual functional declines). This evidence may explain why some older drivers who have functional impairments even at severe levels or particular demographics group of drivers do not regulate their driving or adopt strategic compensatory driving behaviors at an appropriate level.

As the adoption of compensatory driving strategies among older adults may heavily rely on self-perception of one’s own abilities, accurate knowledge of one’s own cognitive functioning as well as the risks associated with such cognitive deficits is essential for an older driver to adopt the appropriate self-regulatory driving behaviors to compensate age-related declines in attention and other cognitive functions. However, older drivers may be less likely to judge their cognitive functioning accurately due to influences of such cognitive deficits. For instance, older drivers, particularly those who exhibit severe cognitive declines, might not be able to notice when they had attentional failures in their everyday activities, or not remember after experiencing these failures. The evidence showing that self-rated everyday memory and cognitive efficiency were not strongly predictive of actual
performances in the memory tasks among older adults (Rabbitt & Abson, 1991) would support this possibility. Furthermore, older drivers may over-estimate their own driving competency primarily due to their cumulative driving experience. Consistent with the expectations based on this evidence, studies have shown a weak relationship between the assessed hazard perception and self-rated confidence, suggesting that the self-perceived functioning might not be an accurate reflection of a proxy measure of actual driving ability (Sullivan, Smith, Horswill, & Lurie-Beck, 2010). Therefore, a key for promoting safe driving among older drivers is providing an opportunity for older drivers to learn about the more accurate understanding of their functioning and possible driving risks that are linked to each functional deficit. If older drivers develop accurate knowledge of potential risks due to cognitive deficits with increasing age, they are more likely to adopt appropriate compensatory self-regulation. For instance, research has shown that an educational program for safe driving practices among older drivers at high risk due to visual impairments promoted to decrease driving exposure and to increase self-regulation of challenging driving situations (Owsley et al., 2004). Despite the strong possibility that self-perceived functioning and compensatory driving behaviors influence the impacts of attentional deteriorations on driving safety among older drivers, the relations among attentional functions, self-perceived functioning, adoption of compensatory driving strategies, and driving performance remains unclear.
Research Questions and Hypotheses

The current research aimed to examine the associations between crash risks in particular traffic situations and different aspects of an attentional function using a theoretical framework of the Attentional Networks model. Two studies were conducted to identify distinct impacts of the alerting, orienting, and executive attentional deficits on increased likelihood of particular types of driving errors and crash risks, with a particular focus on older driver population. Study 1 included drivers of all ages, while the recruitment focused on mid to old population, to explore the associations between the attentional functions and driving safety. Then, Study 2 examined the observed associations using a simulated driving only among the older driver population. The following is the list of specific hypotheses that were set for the present research.

**Hypothesis 1:** Drivers’ attentional functioning is significantly associated with driving performance and crash risks.

The present research aimed to examine how an individual driver’s overall attentional functioning is associated with frequency of prior traffic violations, crash/near-crash events, driving errors using self-reports and simulated driving.

**Hypothesis 2:** The alerting, orienting, and executive attentional efficiencies are associated with different types of driving errors and crash risks.

The present research aimed to identify the precise relations between the three distinct attentional functions and driving performance in particular driving conditions or traffic situations. Using self-report measures, Study 1 explored whether and to what extent each of
the three attentional efficiencies influence older drivers’ performance in various driving situations. Based on the identified associations, a taxonomy was developed to classify particular hazardous events that are potentially associated with deficits in the three functions.

**Hypothesis 3:** Drivers’ alerting, orienting, and executive attentional efficiency is associated with driving performance during the different types of hazardous driving events in simulated driving as the taxonomy classification illustrates. (i.e., a lower executive attentional efficiency is associated with increased crash risks in the executive-critical hazardous events.)

The proposed taxonomy of older drivers’ attentional functions and crash risks classifies particular sets of hazardous events as relations to the alerting, orienting, or executive functions. Study 2 examined the validity of these associations using simulated driving.

**Hypothesis 4:** Older drivers’ self-perceived functional efficiency and self-awareness of age-related functional declines predict adoption of compensatory driving behaviors.

The present research aimed to examine the role of self-perceived functional efficiency and self-awareness of age-related declines in self-regulatory or strategic driving behaviors among older drivers.

**Hypothesis 5:** Older drivers’ compensatory driving behaviors reduce risks in attention-related crashes.

A final aim of the research was to examine the relations between compensatory driving behaviors and crash risks among older drivers. It was expected that older drivers who actively use compensatory driving strategies might have reduced crash risks compared to those who do not make efforts to accommodate age-related declines.
Study 1

The first study explored if there are differential relations between deficits in each of three distinct components of attention (i.e., alerting, orienting, and executive attention) and increased crash risks in certain driving situations. It was hypothesized that each attentional function could be distinctively linked to crash risks in different traffic conditions or during certain driving maneuvers. For example, deficits in one particular function of attention may be associated with elevated crash risks in a particular type of driving maneuver such as making a left turn or driving performance error such as a failure to detect relevant traffic information. This study compared efficiency in alerting, orienting and executive attention with various driving errors and prior crash events among drivers of all ages. While the present research aimed to focus on the older driver population, the first study included all population to conduct investigations of the associations between the attentional functions and driving performance as an exploratory phase. Individual drivers’ three disparate functions were measured using the standardized ANT, and driving errors and prior crash events were collected through self-reports in an online experiment. This online recruitment method allowed collecting crash data from a much larger size of driver samples than in a typical on-site laboratory experiment. Preliminary results from this study were reported in Choi & Feng (2016).
Methods

Participants

The experiment was conducted online. Participants were recruited via Amazon Mechanical Turk, an online marketplace for tasks and works (for a description on conducting behavior research using this tool, see Mason & Suri, 2012). A total of 276 complete responses were collected. Nine responses were excluded in the analysis due to 1) mismatched self-reported age and birth year in two separate parts of our experiment (n=6), 2) being false on all trials (0% accuracy) in ANT (n=3). The analysed sample of 267 participants (Age ranged from 23 to 87; $M = 59.40, SD = 10.79$) consisted of 129 males (Age: $M = 60.10, SD = 10.31$) and 138 females (Age: $M = 58.75, SD = 11.22$). Most efforts were made to recruit participants from elderly populations. However, participants in other age groups were not excluded; thus, both young to mid-aged drivers (64 or younger; $n = 149$) as well as older drivers (65 or older; $n = 118$) were included. Participants were required to have a valid driver’s license to be eligible to participate in the study. Most participants reported that they drive frequently (the mean driving days per week = 5.34, $SD = 1.73$; the mean trips per day = 2.34, $SD = 1.42$). The recruitment that was posted on the Mechanical Turk website encouraged drivers who had at least one crash or near-crash events in the recent past to sign up. Among 267 participants, 229 reported one or more crash events occurred within the past three years or one or more near-crash events occurred within the past six months. Given the differences in frequency of event occurrence as well as vividness of events for the event, different time frames for the crash and near-crash events were set. Summary of demographics, driving habits, and prior violations are illustrated in Table1. Participants
received monetary compensations of between $2 and $3. The compensation amount varied across the recruitment batches.

**Stimuli & Measures**

**Attention Networks Test (ANT).** The standard Attention Networks Test (ANT), originally developed by Fan et al. (2002) (for details and original codes, see https://www.sacklerinstitute.org/cornell/assays_and_tools/), was used to assess functional efficiencies of three attentional networks. The version used in the current experiment was the CRSD-ANT, a 10-minute version that was developed by Luke Docksteader (http://docksteaderluke.com) and Kris Scott (http://krssctt.com) at the Center of Research on Safe Driving in the Lakehead University (detailed description and the codes are available at http://crsd.lakeheadu.ca/crsd-ant/). Compared to the original ANT which takes approximately 20 minutes to complete, the CRSD-ANT was developed to be shorter for clinical or applied research settings where a number of tests are often administered together. The 10-minute version of the ANT was found to be valid and well agree with the original version (Weaver, Bédard, & McAuliffe, 2013). The CRSD-ANT program was developed to run on a local computer. For the present online study environment, the codes were adopted and modified for remote testing and data collection. The online ANT ran in a web browser.

A sequence of displays presented in a trial of the ANT task is illustrated in Figure 00. Each trial began with a fixation cross (“+”) and a different type of a cue was followed and presented for 100 ms, except the no-cue condition. An asterisk (“*”) was used as a cue. There were three different cue types: center cue, double cue, and spatial cue. The center cue (i.e., one asterisk at the center of the display) and the double cue (i.e., two asterisks: one located
above and another located below the fixation cross) informed the immediate occurrence of the target without information on the location of the following target. Lastly, the spatial cues (i.e., one asterisk located either above or below the fixation cross) indicated the location of the following target and they were always valid (i.e., the following target always appeared at the cued location). A target appeared after 400 ms on the offset of the cue. The stimulus display consisted of five objects in a row located either above or below the fixation cross. The center item was the target (an arrow pointing to either left or right direction, \( \rightarrow \) or \( \leftarrow \)) that participants were told to respond, accompanied by two flankers on each side. The flankers were either arrows pointing to the same direction as the target (congruent condition, e.g., \( \leftarrow \leftarrow \leftarrow \leftarrow \leftarrow \)) or the opposite direction (incongruent condition, e.g., \( \leftarrow \leftarrow \rightarrow \leftarrow \leftarrow \)).

The stimulus display stayed on the screen until a response was made or 1500 ms from the onset of the target, whichever came first. Participants responded the direction of the target arrow by pressing corresponding right or left direction key on a keyboard. Both reaction time and correctness of each response were recorded. For all RT based performance measures, only correct responses were used, and any response that made faster than 100 ms was excluded because it was considered an anticipatory response.

The efficiency of three attentional functions was measured based on the performance of the four cue conditions (center, double, spatial, and no cue) and the two target congruency conditions (congruent and incongruent). Each efficiency index of alerting, orienting, and executive functions was computed by a subtraction between performances of two associated pairs. The specific calculation method is listed as follows:

\[
\text{Alerting efficiency} = \text{Performance(no-cue)} - \text{Performance(double-cue)}
\]
Orienting efficiency = \text{Performance(\text{center-cue})} – \text{Performance(\text{spatial-cue})}

Executive efficiency = \text{Performance(\text{incongruent})} – \text{Performance(\text{congruent})}

The performance measure for each condition was either reaction time or error rate (i.e., \% incorrect). The original ANT used reaction time differences in cue and target congruency conditions to compute alerting, orienting, and executive indices (Fan et al., 2002). While the reaction time based indices had been more commonly used in previous research, a few prior studies had also used error-rate differences to compute the efficiency of three attentional networks (Ishigami & Klein, 2009; 2011). Prior research that compared two computing methods suggested that both methods provide a usable and robust index for three attentional network efficiencies (Ishigami & Klein, 2009; 2011). The attentional efficiencies computed by the two methods were found to show little difference. For instance, the error-rate based indices were observed to operate more interactively, and more practice effects were observed in RT based indices in general (Ishigami & Klein, 2011). In addition, some age-related differences were suggested because older adults focused more on accuracy whereas young adults focused on speed in ANT, the effects of cues were greater within their type of focused measure (Ishigami & Klein, 2011). The present study computed the efficiency indices with both performance measures. However, the preliminary data analysis indicated that overall error rate was found to be high (error rate $M = 6.28$, $SD = 13.08$) and a large variation was observed among participants (error rate ranged from .00 to 81.45). Given that low ANT error rate has been found in prior studies conducting ANT in laboratory (e.g., CRSD-ANT overall error rate $M = 1.9$, $SD = 2.0$ in Weaver et al., 2013), the high error rate observed in the present study might be the results of the nature of the online data collection. Because the
online experiment was not conducted in a controlled environment and no experimenter was present to monitor during the testing, participants may have completed the task in a relatively relaxed manner in spite of the written instruction of responding both as accurately and fast as possible. Given that the reaction time was summarized from correct trials only and the shorter version of ANT was used in the present experiment, the use of reaction time resulted in significant data loss, which left only a limited number of trials available for computation of efficiency indices. Furthermore, the considerable variability in error rate would make the error-rate based indices be a useful alternative indicator of individual’s attentional performance. Thus, the present study primarily used the error-rate based alerting, orienting, and executive indices when comparing to driving performance.

It should be noted that alerting and orienting efficiency indices represent the benefits (i.e., reduced error rates or reaction time) of the provided alerting double cue or the orienting spatial cues. Therefore, a higher score on altering or orienting index indicates better attentional alerting or orienting functioning, which would reflect an ability to use the cues more efficiently. In contrast, the executive efficiency index indicates the cost (i.e., increased error rates or reaction time) due to incongruent flankers compared to congruent flankers. Therefore, a higher executive score indicates worse executive attentional functioning, which would suggest that ability to resolve conflicts among incongruent perceptual information is less efficient.

**Surveys.** A survey was conducted online via Qualtrics, an online survey tool. The survey consisted of three sections.
Demographics. The first section of the survey asked about demographic information including birth year, gender, education, and health conditions. It also included items for driving experience and habit (e.g., the year that an individual first obtained a driver’s license, numbers of traffic warnings and tickets received in the past five years, and how often and how much an individual drives in a normal week.).

Driver questionnaires and scale. The second section of the survey included a set of established self-reported measures of driving failures and self-efficacy. Three self-reported questionnaires were included: 1) Manchester Driver Behavior Questionnaire (DBQ; 24-item version, Reimer et al., 2005), 2) Attention-related Failures during Driving Questionnaire (AFDQ; 19-item version; Choi, Grühn, & Feng, 2015), and 3) Adelaide Driving Self-Efficacy Scale (ADSES; George, Clark & Crotty, 2007). The DBQ is a widely used questionnaire to measure a driver’s unsafe behaviors with three sub-categories of driving behaviors: errors, lapses, and violations. The errors refer to failures in planning appropriate actions to achieve intended outcome, which potentially lead to dangerous consequences. The lapses include unintentional behaviors occurring particularly due to attention and memory failures, while the violations refer to more deliberate actions that deviate from safe and necessary practices during driving (Reason et al., 1990; Reimer et al., 2005) The AFDQ is a recently proposed questionnaire that aims to measure driving failures that are particularly related to a driver’s attentional deteriorations. The ADSES is a scale that measures how confident a driver is in various driving situations such as driving at night, overtaking, merging, and turning left across oncoming traffic. Standard scoring methods were used for each scale.
**Survey for the prior crash and near-crash events.** The third section of the survey collected details of participants’ prior crash and near-crash events. The survey first collected how many times each participant was involved in crashes in the past three years and near-crashes in the past six months. If a participant reported at least one crash or one near-crash event, they were asked to provide details of their crash / near-crash events.

Before completing a detailed crash report, participants were first asked to indicate if their crash / near-crash event was associated with one of the accident types and performance errors that were provided in a list. A previous report investigating older drivers’ crash risks based on analyses of national databases such as Fatality Analysis Reporting System (FARS) and General Estimates System (GES) identified the five crash types where older drivers were most strongly overrepresented and nine performance errors that underlie those crash types (Staplin et al., 2012). These five crash types were crashes that occurred during: 1) a left turn at an intersection with stop-sign control, 2) a left turn at an intersection with signal control, 3) a right turn in a channelized right-turn lane, merging with traffic approaching from the left, 4) merging at a yield sign onto a limited access highway, and 5) a lane change on a multilane roadway. These particular crash types were adopted because they may be of higher relevance to age-related declines that would have increased older drivers’ likelihood of the crash involvement. Compared to other types of crashes in which older drivers are underrepresented or represented comparably to other driver groups at higher risks such as younger drivers, these crashes would be less likely to be explained by general driving skills, reckless or negligent driving, or other external causes of road crashes. Thus, it was expected that elevated likelihood of involvement in these types of crashes might be more accounted for by
age-related functional declines, which were the primary interest of the present study. Before looking at specific traffic conditions and crash characteristic, this list of crash types was first examined if a driver’s attentional functioning is associated with each type of crash.

The nine performance errors included in the survey were: 1) Failure to visually detect potential conflicts, hazards, or traffic control information, 2) Gap judgment error (i.e., inability to accurately estimate closing speed and distance), 3) Inability to predict the development of future conflicts from current traffic and contextual information, 4) Slowed vehicle control response, 5) Inadequate visual search/improper lookout, or Attentional failure (includes "looked but didn't see"), 6) Slowed decision-making; traffic situation has changed by the time a maneuver is initiated, resulting in potential conflict, 7) Lack of understanding of rules of the road, 8) Lack of understanding of safe driving practices (e.g., aiming mirrors, positioning within intersection to increase sight distance) (does not include willful or aggressive driving), and 9) Inappropriate response (e.g., pedal errors).

In addition, the survey included a list of questions on traffic conditions and driving maneuvers that each of prior crash/near-crash was associated with, to measure if any particular crash situation is linked to attentional functions. The official traffic crash reports from North Carolina and California states were incorporated to develop a list of crash characteristics. The lists included various roadway/environmental conditions (e.g., locality-rural, mixed, or urban; site type- farm, residential, commercial, industrial, etc.; weather-clear, cloud, rain, etc.; lighting- day, dusk, dark, etc.; roadway surface- dry, wet, slip, etc.), traffic situations (e.g., traffic control type- stop, yield, flash, school zone, etc.; estimated speed; collision objects- pedestrian, other motor vehicles, bicycle, etc.), and driving.
maneuvers (e.g., movement preceding the crash—going straight ahead, making left turn, making a U-turn, merging, changing lanes, etc.). In addition, participants were asked to indicate contributing factors to each crash event among 32 types of driver circumstances (e.g., disregarded traffic signs, exceeded speed limit, right turn on red, driver distracted, alcohol/drug use, etc.), 11 road circumstances (e.g., debris, work zone, traffic control device inoperative, etc.), and a mechanical problem. The same list of crash questions was repeated for the number of times prior crashes and near-crashes that each participant reported.

Participants were asked to provide details for each event (Appendix A for a copy of the complete survey).

**Procedure**

Participants were instructed to use a regular PC with a keyboard that has arrow keys. Upon sign-up on the Amazon Mechanical Turk, they were provided a link for the online ANT task, where they were first asked to sign an informed consent form electronically. Participants indicated their current monitor diagonal, and they were asked to use full-screen for best task results. After a brief instruction for the ANT test was presented, participants completed a practice session of 31 trials. Participants were instructed to maintain attention throughout the entire task and avoid any interruption. They were asked to pay attention to the central arrow of each trial and indicate which way it is pointing by pressing the corresponding arrow key on the keyboard. They were told that it would be important to respond as quickly as they can, but without making too many errors because this test measures both their reaction time and accuracy. To facilitate quick responding, it was instructed to keep left and right index fingers over the left and right arrow keys respectively.
Feedback on their performance (i.e., overall accuracy and mean reaction time) was provided for the practice. The testing session consisted of four blocks of 31 trials presented in each block. Thus a total of 124 trials were presented. The entire testing session would take approximately 10 to 15 minutes to complete. The two target locations (up or down), four cue conditions (no cue, center cue, double cue, or spatial cue), two target types (congruent or incongruent), and target arrow directions (left or right) were balanced across the trials. However, due to a technical error of the ANT program, one particular combination, that was the down X spatial X incongruent X left, was missing in each of four blocks: therefore, each block included one each trial of 31 conditions (i.e., 2 locations X 4 cues X 2 targets X 2 directions – 1 condition). Participants were allowed to take a short break between the first and the second blocks. When participants completed the ANT, they received a link to the survey part of the experiment. The entire survey took about 30 minutes to complete. Upon the completion of the survey, participants were provided a unique code that they needed to submit to Mechanical Turk to receive compensation.

Results

The first set of analyses examined the general relations between overall attentional functioning (i.e., accuracy and reaction time) and frequency of prior driving violations and crash, using correlations. Next, analyses were conducted to identify how various driving errors and crashes occurring were linked to individuals’ attentional efficiencies of the alerting, orienting, and executive functions measured using the ANT. Individual drivers’ efficiency indices of the alerting, orienting, and executive attentional functions were
compared with self-reported questionnaire responses and characteristics of prior crash events using correlations (for analyses of questionnaire responses) and mean comparisons (i.e., Kruskal-Wallis and t-test; for analyses of crash reports).

**Correlations among Attentional Functions and Frequency of General Driving Violations and Crashes**

Before looking at the precise relations between the three different attentional functions and particular driving errors and crash types, associations among attentional performance (i.e., overall accuracy and RT as well as the three attentional indices) and general driving performance (i.e., self-reported frequency of prior traffic violations and crashes) were examined. Overall ANT performance and the three efficiency index scores are presented in Table 2, and the correlations among the ANT measures and driving measures are summarized in Table 3.

First, correlations among the three attentional indices were examined. Among three attention network indices, the orienting and the executive indices were significantly correlated ($r = .18, p < .01$). The independence of three attentional networks has been suggested with both anatomical and functional terms, and studies found the three efficiencies were orthogonal (Fan et al., 2002). Consistent with the current results showing a lack of independence among the three functions, other studies also showed that three attentional indices were correlated (see Wang et al., 2014 for review of interactions observed in prior research). Specifically, the current data suggested that the executive and orienting attentional networks may operate interactively: participants with superior orienting efficiency were found to show higher executive index score, thus lower executive efficiency.
The correlations among the ANT measures and unsafe driving indicators (i.e., frequency of traffic warnings, traffic tickets, near-crashes, and crashes in the past years) showed that lower overall ANT accuracy was significantly associated with more traffic tickets \( (r = -.20, p < .01) \) and crashes \( (r = -.15, p < .05) \). The higher executive index (i.e., lower executive efficiency) was associated with more warnings \( (r = .15, p < .05) \) and crashes \( (r = .15, p < .05) \), while the higher alerting index was correlated with less near-crashes \( (r = -.17, p < .01) \). These results would indicate that drivers with higher overall accuracy, better executive function, and better alerting function, tend to drive safely, which would have resulted in fewer traffic tickets, near-crashes, and crashes.

The ANT data showed a positive correlation between overall accuracy and RT \( (r = .25, p < .01) \), which suggests a noticeable level of speed-accuracy trade-off. Furthermore, overall RT was observed to be negatively correlated to frequency of warnings \( (r = -.16, p < .05) \) and traffic tickets \( (r = -.15, p < .05) \), which would indicate drivers with a slowed speed of processing had more traffic warnings and tickets. These results are rather contradictory with previous findings showing the negative impacts of slowed processing speed on driving performance (e.g., Ball et al., 1988; Ball et al., 1993; Aksan et al., 2012). Thus, it can be assumed that RT was a less reliable measure in the current experiment setting. This result further supports the decision of using the error-rate based efficiency indices instead of the RT based indices. In the following investigations on effects of the three attentional functions in various driving errors and crash events, the efficiency indices of the alerting, orienting, and executive function computed using error rates were used.
Correlations among Attentional Functions and Different Types of Driving Failures and Self-Efficacy

Correlation analyses between the ANT measures and the self-reported driving questionnaires (DBQ, AFDQ, and ADSES) were conducted. The results indicate that overall ANT accuracy was negatively correlated with self-reported driving failures (DBQ: $r = -.39, p < .01$; AFDQ: $r = -.40, p < .01$) and positively correlated with self-efficacy on driving (ADSES: $r = .19, p < .01$). As shown in Table 4, the overall DBQ score was positively associated with the orienting ($r = .12, p < .05$) and executive indices ($r = .14, p < .05$), and negatively with the alerting index at marginal level ($r = -.11, p = .06$). Similarly, the overall AFDQ score was found to be positively correlated with the orienting ($r = .13, p < .05$) and executive indices ($r = .14, p < .05$), and negatively correlated with the alerting index ($r = -.12, p < .05$). These results indicate drivers who experienced more frequent failures during driving tend to exhibit a lower efficiency of alerting and executive (note: higher executive index refers to lower efficiency) functions, while their orienting function tends to be higher. The ADSES was found to be correlated only with the executive index ($r = -.15, p < .05$), which indicate drivers with lower efficiency in the executive attention tend to be less confident in driving in general. In the following, the results obtained from the sets of correlational analyses illustrate what particular types of driving failures and self-efficacy were associated with the efficiency in the alerting, orienting, and executive attentional functions. A summary of the significant correlations between the ANT indices and the individual items of the DBQ, AFDQ, and ADSES questionnaires is presented in Table 4.
**Attentional functions and DBQ responses.** Because the violation section measures a driver’s unsafe driving behaviors that would reflect a deliberate intention of the driver to engage in those actions, it would not be associated with a driver’s attentional functioning. Thus, out of the three sub-scales, the error and lapse items, but not the violation items, were included in the analyses. Before looking at the associations between the ANT indices and the individual driving failure cases, the sub-section scores of DBQ were compared with the alerting, orienting, and executive functions. The results indicated that the alerting efficiency was negatively correlated only with the error section (i.e., the better alerting function associated with fewer driving errors; $r = -.12, p < .05$), and the orienting efficiency was not correlated with either the error or lapse sections. The most prominent association was found with the executive function: the efficiency index of executive function was positively correlated (i.e., the lower level of the executive attention, the more driving errors) with error ($r = .16, p < .05$) and the lapse ($r = .17, p < .05$) sub-section scores, which indicating drivers with lower executive efficiency experienced more driving errors and lapses.

Turning now to more specific links between the ANT indices and individual error and lapse items, the results indicated that certain types of driving error and lapse events were associated with each of the alerting, orienting, and executive functions. The Pearson product-moment correlation coefficients of the following results are presented in Table 4. First of all, the executive index was found to be the most critical function that was positively correlated with a total of eight DBQ items including four errors and four lapses. The driving errors are the type that may occur primarily due to failures in assigning attention to relevant driving information or selecting appropriate responses. These errors include: 1) “fail to ‘stop’ or
‘yield’ at a sign, almost hitting a car that has the right of way”, 2) “when preparing to turn from a side road onto the main road, you pay too much attention to the traffic on the main road so that you nearly hit the car in front of you”, 3) “underestimate the speed of an oncoming vehicle when passing”, and 4) “brake too quickly on a slippery road, or turn your steering wheel in the wrong direction while skidding”. The four lapse items mostly reflect an inability to effectively divide and select attention among external and internal processing, which includes: 1) “misread signs and miss your exit”, 2) “forget that your lights are on high beam until another driver flashes his headlights at you”, 3) “you intend to drive to destination A, but you ‘wake up’ to find yourself on the road to destination B, perhaps because B is your more usual destination”, and 4) “realize that you cannot clearly remember the road you were just driving on”.

Next, the alerting score was found to be negatively correlated with two errors that primarily involve failures to notice moving hazardous objects: 1) “fail to notice pedestrians crossing when turning onto a side street” and 2) “when making a turn, you almost hit a cyclist or pedestrian who has come up on your right side”, as well as two lapses that are most likely to associate with distracted and forgetful such as 1) “misread signs and miss your exit” and 2) “forget that your lights are on high beam until another driver flashes his headlights at you”.

Finally, the orienting function was positively correlated with one particular driving error of “fail to notice pedestrians crossing when turning onto a side street” as well as two lapse items that are mostly related to driving while mind-wandering including 1) “you intend to drive to destination A, but you ‘wake up’ to find yourself on the road to destination B,
perhaps because B is your more usual destination” and 2) “realize that you cannot clearly remember the road you were just driving on”. These positive correlations were somewhat unanticipated and suggested that higher efficiency in the orienting function was associated with more frequent driving failures.

**Attentional functions and AFDQ responses.** The Attentional Failures during Driving Questionnaire (AFDQ) was specifically designed to measure the frequency of driving failures that occur because of a driver’s attentional deficits, rather than intentional errors or other cognitive failures. Because AFDQ includes several items illustrating driving failures that are similar to those included in DBQ, those overlapped items were excluded in the following analyses. The analyses showed a pattern of associations between attentional functions and driving failures that were consistent with the previous section. Each of alerting, orienting, and executive functions was found to be associated with different sets of the AFDQ items.

First, higher efficiency in the executive function was related to lower frequency of four failure events that are mostly related to multi-tasking or divided attention: 1) “when you are talking on a phone, you fail to promptly notice that there is a vehicle or pedestrian in your way”, 2) “when checking the rear-view or side mirrors, you fail to promptly notice that the car in front of you brakes”, 3) “during a right turn, you fail to notice a cyclist or pedestrian who is entering the crosswalk from the right side, and you almost hit the person”, and 4) “roadside advertisements capture your attention while driving that you fail to promptly notice that the vehicle in front of you is slowing down”.
The alerting function was found to be negatively correlated with two AFDQ items (i.e., the lower alerting efficiency, the more frequent failures during driving) that would reflect failures in visual detection of hazardous objects: 1) “when entering a roundabout or intersection, you fail to notice vehicles that are not straight ahead” and 2) “you are looking for a specific point on the road, and you fail to promptly notice that the car in front of you brakes”.

Lastly, similar to previous findings with DBQ, a better orienting function was correlated with more frequent occurrence of the following four attentional failures during driving: 1) “when entering a roundabout or intersection, you fail to notice vehicles that are not straight ahead”, 2) “you continue to follow the traffic, without noticing that the light at an intersection has turned red”, 3) “before switching lanes, you are so focused on the traffic in the lane that you wish to join and you fail to notice promptly that the vehicle in front of you brakes”, and 4) “during a right turn, you fail to notice a cyclist or pedestrian who is entering the crosswalk from the right side, and you almost hit the person”.

**Attentional functions and ADSES responses.** ADSES measures a driver’s self-efficacy in various driving situations. Each item of ADSES was also examined in association with the alerting, orienting, and executive attentional functions.

First, the executive function was found to be negatively correlated with self-efficacy levels (i.e., the lower executive attentional efficiency, the less confident in driving) in particular driving situations including driving in the local area, driving in heavy traffic, overtaking on a two-lane road, attempting to merge with traffic, planning travel to a new destination, and driving in high-speed areas. The correlations between self-efficacy scores in
these items and the executive index were in the negative direction, which indicates the drivers who had lower efficiency in executive attentional function tend to be less confident in these particular driving situations.

The results showed that none of the ADSES items was significantly associated with the alerting function, which suggests an individual driver’s efficiency level of the alerting function is not critically associated with the driver’s self-efficacy in driving.

Lastly, self-efficacy in several driving situations including driving in the local area, driving with people in the car, responding to road signs/traffic signals, and attempting to merge with traffic, was found to be negatively correlated with the orienting function. This negative correlation would indicate that the drivers who have a higher level of orienting function tend to rate their driving competency lower in those driving situations.

**Associations between Attentional Functions and Involvement in Different Types of Crashes**

In the present section, a set of analyses were conducted to examine how alerting, orienting, and executive attentional functions are linked to the particular type of crashes. Participants reported the type of crashes, driving errors, traffic conditions, and driving maneuvers that were associated with each of their prior crash events. Given the low frequency of crash reports, for each specific characteristic, crash involved group (i.e., drivers who reported at least one crash being involved in the target characteristic) was compared to reference group (i.e., drivers who reported no crash being involved in the target characteristic) in the alerting, orienting, and executive indices.
Attentional functions and the five crash types. Before investigating specific characteristics of drivers’ crash events, the five particular crash types that were observed to be most dangerous for older drivers were examined first. In these analyses, the target crash present group was compared to the three reference groups: a) drivers had at least one crash of any type but not of the type of interest (general crash group), b) drivers had near-crash events but no crash (near-crash only group), and c) drivers reported none crash nor near-crash (no risk group). Group comparisons in efficiency indices of alerting, orienting, and executive attentional functions were conducted for each of the five crash types. The preliminary analysis of variance and distribution of the data found that the equal variance assumption for ANOVA was violated. Given the small sample size being available in the crash-involved groups who reported a specific type of crashes, a nonparametric test, the Kruskal-Wallis test, was performed to determine significant differences among the groups. When the Kruskal-Wallis test showed significant differences among the groups, then pairwise comparisons were performed by employing the multiple Mann-Whitney tests; each crash type of interest (A, B, C, D, or E) group was compared to the other three reference groups (i.e., general crash, near-crash only, and no crash risk groups). As suggested in Field (2009), to offset a possibly inflated Type I error, the critical level of significance was set to \( \alpha = .05/3 = .0167 \). The ANT indices of crash groups and reference groups are summarized in Table 5.

Crash type A: a left turn at a stop-sign intersection. 15 participants reported that they had at least one crash of this type occurring within the past three years. A Kruskal-Wallis test revealed that there was a significant group difference in executive index, \( H(3) = 9.36, p < .05 \), while alerting \( (H(3) = 5.95, p = .11) \) and orienting \( (H(3) = 2.96, p = .40) \) functions did
not differ among the groups. Mann-Whitney tests for pairwise group comparisons indicated that the executive index was significantly higher (which suggests worse executive function) in the type A crash group (n = 15, M = 12.76, SD = 17.65) than in the general crash group (n = 163, M = 4.03, SD = 11.76) and the near-crash only group (n = 51, M = 3.64, SD = 7.61), but not higher than in the no risk group (n = 38, M = 5.13, SD = 9.72) (Figure 3).

**Crash type B: a left turn at a signal intersection.** A total of 11 participants reported that they had at least one crash of this type. A Kruskal-Wallis test found no group difference in alerting (H(3) = 5.47, p = .14), orienting (H(3) = 2.19, p = .53), and executive indices (H(3) = .81, p = .85).

**Crash type C: a right turn to merge with traffic.** 10 participants reported this crash type and no significant difference was found in the alerting (H(3) = 7.47, p = .06), orienting (H(3) = 6.52, p = .09), and executive (H(3) = 1.24, p = .74) indices across the groups. Although it was not statistically significant, it is worth noting that there was a trend of the type C crash group having a better alerting function.

**Crash type D: a merge at a yield sign onto a highway.** 12 participants reported this crash type. There was no group difference in alerting (H(3) = 5.40, p = .15) and orienting (H(3) = 1.89, p = .60). There was an observed trend of the type D crash group (n = 12, M = 6.90, SD = 5.95) exhibiting lower executive attentional efficiency compared to the general crash group (n = 166, M = 4.60, SD = 12.88) and the near-crash group (n = 51, M = 3.64, SD = 7.61), H(3) = 7.34, p = .06.

**Crash type E: a lane change on a multilane roadway.** 19 participants reported this type of crash, and there was a group difference found in executive attention with a significant
level of .05, H(3) = 7.82, \( p = .05 \). As shown in Figure 3, the type E crash group exhibited worse executive attention (\( n = 19, M = 12.64, SD = 22.01 \)) than the general crash group (\( n = 159, M = 3.82, SD = 10.51 \)) and the near-crash group (\( n = 51, M = 3.64, SD = 7.61 \)).

**Attentional functions and driving performance errors.** Participants also indicated if a particular driving performance error among the nine types was involved in each of prior crash events. For each performance error type, an independent sample t-test was conducted to compare alerting, orienting, and executive indices between the crash involved group and the crash absent group. Among the analyses, only a few tests were found to be significant. First, the analysis for the performance error type of “failure to visually detect potential conflicts, hazards, or traffic control information” showed that there was a significant difference between the crash absent group (\( M = -.16, SD = 4.77 \)) and the crash involved group (\( M = 1.80, SD = 5.19 \)) in alerting function, \( t(265) = -2.19, p < .05 \). Also, the significant difference was found in the orienting index between the crash absent group (\( M = .70, SD = 4.63 \)) and the crash involved group (\( M = 3.52, SD = 5.10 \)), \( t(265) = -3.23 \), \( p < .01 \). Both the results on alerting and orienting indices indicated that drivers who had a crash due to failures to visually detect potential hazards or other relevant information tend to have superior alerting and orienting functions, compared to drivers who did not have a crash that involved this type of error. In addition, the test for another performance error type of “slowed decision-making; traffic situation has changed by the time a maneuver is initiated, resulting in potential conflict”, indicated that the crash involved group (\( M = 2.88, SD = 4.13 \)) showed a higher alerting function than the crash absent group (\( M = -.06, SD = 4.86 \)), \( t(265) = -2.15, p < .05 \). A summary of the group comparisons is presented in Table 7.
Attentional functions and traffic conditions / driving maneuvers. To further explore if involvement in crashes with specific characteristics could be related to the alerting, orienting, and executive functions, self-reported crash details were examined. Specific crash characteristics were collected from participants’ crash reports (Appendix A. part III-C). Among the collected data, the analyzed crash characteristics included the following traffic conditions and driving maneuvers: 1) locality type, 2) site type, 3) traffic control type, 4) vehicle preceding movement, and 5) crash-contributing driver circumstance. Similar to the previous analyses, if participants indicated that any of their previous crash events was associated with the traffic characteristic of interest, they were classified as the crash involved group and compared to the crash absent group, who was not involved in a crash that was associated with the characteristic of interest, using t-tests. The multiple t-tests were administrated to analyze each crash characteristic, which may inflate Type I error in overall results. However, given that the crash occurrence being associated with each characteristic was limited, this approach was available and useful for the present research which was conducted as exploratory in nature. The following sections describe the results with significance α level of .05 or any results approaching the significance level (i.e., on or below the .08). A complete list of the significant and approaching significant associations is shown in Table 7.

Locality types. A separate t-test was conducted for each of three locality types of “Rural (<30% developed)”, “Mixed (30% to 70% developed)”, and “Urban (>70% developed)”. The results showed a trend that drivers who had crashes in the mixed locality environment tend to exhibit a higher level of orienting function ($M = 2.18$, $SD= 6.14$),
t(90.49) = -1.92, p = .06, and a lower level of executive function (M = 7.83, SD = 18.55),
t(75.03) = -1.91, p = .06, compared to drivers who did not experience a crash in the mixed
locality environment (Orienting M = .66, SD = 4.14; Executive M = 3.47, SD = 7.09). The
results also showed a trend for the urban locality type that the crash involved group tend to
have a lower level of orienting function (M = 7.83, SD = 18.55), t(75.03) = -1.91, p = .06,
compared to drivers who did not experience a crash in the mixed locality environment (Orienting M = .66, SD = 4.14; Executive M = 3.47, SD = 7.09). The
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results also showed a trend for the urban locality type that the crash involved group tend to
have a lower level of orienting function (M = 7.83, SD = 18.55), t(75.03) = -1.91, p = .06,
compared to drivers who did not experience a crash in the mixed locality environment (Orienting M = .66, SD = 4.14; Executive M = 3.47, SD = 7.09). The
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compared to drivers who did not experience a crash in the mixed locality environment (Orienting M = .66, SD = 4.14; Executive M = 3.47, SD = 7.09). The
results also showed a trend for the urban locality type that the crash involved group tend to
have a lower level of orienting function (M = 7.83, SD = 18.55), t(75.03) = -1.91, p = .06,
group (Alerting $M = .21$, $SD = 4.69$; Orienting $M = .73$, $SD = 4.25$), alerting $t(265) = 2.25$, $p < .05$ and orienting $t(8.13) = -3.29$, $p < .05$.

**Preceding movements.** Participants also reported the movement of the vehicle preceding the crash and t-tests were conducted for each of the following lists of vehicle movements: stopped, going straight ahead, ran off road, making right turn, making left turn, making U-turn, backing, slowing / stopping, passing other vehicle, changing lanes, parking maneuver, entering traffic, other unsafe turning, crossing into opposing lane, merging, and traveling wrong way. There were a few trends observed at an approaching significance level with both positive (i.e., a lower level of attentional functioning being associated with crash involvement) and negative (a higher level of attentional functioning being associated with crash involvement) relationships. Alerting index was negatively linked to stopped movement (crash group $M = 1.20$, $SD = 4.63$ vs. no crash group $M = -.16$, $SD = 4.88$), $t(265) = -1.74$, $p = .08$), while positively linked to changing lanes (crash involved group $M = -2.61$, $SD = 4.77$ vs. crash absent group $M = .21$, $SD = 4.84$), $t(265) = 1.97$, $p = .05$). The orienting index was negatively linked to ran off road (crash involved group $M = 3.49$, $SD = 5.96$ vs. crash absent group $M = .95$, $SD = 4.70$), $t(265) = -1.74$, $p = .08$), while positively linked to backing (crash involved group $M = -.66$, $SD = 3.72$ vs. crash absent group $M = 1.21$, $SD = 4.83$), $t(265) = 1.80$, $p = .07$). Lastly, the trends were also observed in executive index being positively linked to making U-turn (crash involved group $M = 19.22$, $SD = 15.25$ vs. crash absent group $M = 4.49$, $SD = 11.28$), $t(265) = -1.84$, $p = .07$; only two samples were available in the crash involved group) and other unsafe turning (crash involved group $M = 19.74$, $SD = 2.73$ vs. crash absent group $M = 4.48$, $SD = 11.32$), $t(265) = -1.90$, $p = .06$; only two samples were
available in the crash involved group), which indicating drivers who had crashes while making U-turn or other unsafe turning tend to exhibit lower efficiency in the executive attention.

Contributing driver circumstances. In the crash report, participants self-reported if they were involved in any of particular driver failures or mistakes that led to crash. A provided list of 34 crash-contributing driver circumstances included various types of deliberate deviations from safe driving practices, negligent or aggressive driving, and other intended or unintended errors (See Appendix A. part III for the complete list). Because only a few responses were collected for each contributing factor, nine aggregated factors were created: 1) Disregarded yield, stop, or other traffic signs, 2) Exceeded or failure to reduce speed, 3) Improper turn, 4) Lane-related error, 5) Improper passing, 6) Improper maneuvers during yield, backing, or parking, 7) Attentional failure, 8) Careless, negligent, or aggressive behaviors, and 9) Other external or internal conditions (e.g., visibility obstructed, alcohol use, etc.). T-tests were conducted to compare the crash involved group and the crash absent group in their alerting, orienting, and executive efficiency scores for each of the nine factors. One unexpected finding was that drivers who had had a crash due to attentional failures, which include inattention, being distracted (e.g., talking, eating, etc.), and being absorbed in mind wandering, ($M = 2.20, SD= 4.71$) tend to show a higher level of alerting function than the crash absent group ($M = -.26, SD= 4.81$), $t(265) = -2.89, p < .001$. In addition, drivers who reported a speed-related driver behavior (i.e., exceeded authorized speed limit, exceeded safe speed for conditions, or failure to reduce speed) that led to crashes ($M = 3.49, SD= 7.04$) tend to exhibit a higher level of orienting function, compared to drivers who did not report a crash
related to this circumstance \((M = .69, SD = 4.25), t(36.59) = -2.26, p < .05\). There were also trends observed for two particular crash-contributing driver circumstances being associated with the alerting function. Driver who had crashes related to disregarded yield, stop, or other traffic signs \((M = 2.08, SD = 4.01)\) tend to show a higher level of alerting function than the crash absent group \((M = -0.06, SD = 4.89), t(265) = -1.82, p = .07\). In addition, driver who had crashes related to improper passing \((M = 6.70, SD = 8.35)\) tend to show a higher level of alerting function than the crash absent group \((M = -0.10, SD = 4.63), t(6.10) = -2.14, p = .08\).

**Summary of Attentional Functions and Associated Types of Driving Errors and Crash Characteristics.**

The analyses in the prior two sections indicated that the alerting, orienting, and executive attentional functions were associated with frequency of different types of driving errors and the involvement of particular types of crashes. Table 8 summarizes the observed associations.

The self-reported questionnaire responses and crash report analyses showed the importance of the executive function on a driver’s safety. Drivers who exhibited lower executive efficiency were more likely to make errors when driving situations demand to process multiple targets or tasks, thus show lower confidence in those situations. Crash data also confirmed that these drivers with lower executive efficiency were more likely to involve crashes when making changes in lanes or of traffic direction. In general, the observed associations from the questionnaire responses and crash reports were in agreement with each other, with a few exceptions. Both data indicated that the executive function was associated with increased risks when attention must be assigned to multiple locations, potential hazards,
traffics, or tasks. A few observed discrepancies were further discussed in the following discussion section.

Increased crash risks being associated with the alerting and orienting were found to be less prominent and also bi-directional. Both positive and negative impacts of the alerting and orienting functions were observed, which depended on certain traffic conditions or driving situations. Given a number of independent t-tests were conducted to examine different types of crash characteristics separately without controlling others, these results need to be interpreted with caution and considered not confirmatory evidence.

**Age Effects on Associations between Attentional Functions and Driving Performance**

The results presented in the previous sections were from the analyses with the samples of all ages, although the present research was particularly interested in the older driver population. Additional analyses were conducted to investigate if there were any significant effects of age in the observed associations between the attentional functions and driving performance.

First, analyses were conducted to examine the effects of age on the ANT performance. A correlation analysis showed that age was not correlated with any of the ANT measures, including overall accuracy and RT and the three attentional indices (Pearson correlation coefficient ranged between -.03 and .01, \( p > .05 \)). Additionally, two age groups (64 and younger vs. 65 and older) were compared to confirm the lack of associations, and the group differences were only found in the overall ANT accuracy. The older drivers (age 65+; \( M = .92, SD = .16 \)) were less accurate than the mid-young drivers (age 64-; \( M = .95, SD = .10 \)) during the ANT task (Table 9). Age differences in prior traffic violations and crashes were
also examined, but none was found to be significantly different between the two age groups (Table 9). These findings suggested that effects of age were limited in the present study. A lack of age-related differences in the ANT and driving performance may be due to the selected driver samples in the current study. Although participants of all ages were included, an average age of the entire participants was around 60, which included the majority of late-mid to old drivers. Furthermore, the participants consisted of higher-risk drivers due to the recruitment of drivers with crash experience in the recent past. Thus the age-related difference might not be critical.

Given the limited age-related differences, it was expected that the age would have minimal impacts on the observed associations between the attentional functions and crash risks measures. Partial correlational analyses were conducted on a few selected associations that were found to be significant in the prior results. For instance, the correlation between the overall ANT accuracy and the number of crashes ($r = -.15, p < .05$) and between the executive index and the number of crashes ($r = .14, p < .05$) were unchanged when controlling for age. In addition, age differences were examined for the crash type analyses. In the previous section, it was found that the drivers who had the two certain types of crashes (crash type A: a left turn at a stop-sign intersection and type E: a lane change on a multilane roadway) exhibited significantly lower executive attentional efficiency, compared to the general crash, near-crash only, and no crash risk groups. The Kruskal-Wallis test was performed to determine if there was a significant difference in ages among the groups (mean age of each group is presented in Table 5). In each analysis, the groups of target crash types were a little older than the reference groups, but the results indicated that the group
differences were not significant (Crash type A: H(3) = 5.90, $p = .12$; type E: H(3) = 4.62, $p = .20$). Taken together, the observed associations between the attentional functions and driving performance remained significant when controlling for age.

**Discussion**

The main aim of the first study was to explore the unique relations between a driver’s attentional functions and driving performance under various driving situations. The findings confirmed that a driver’s overall attentional functioning plays a critical role in the occurrence of driving errors or crash. The more interesting finding was that the three attentional functions were distinctively associated with certain types of driving errors and crashes. Despite its exploratory nature, this study offers some insight into which particular traffic situations might be associated with each of distinct attentional functions.

The most prominent and consistent finding was that a driver’s low executive attentional efficiency is most critically linked to more driving errors and increased crash risks. The low executive efficiency was not only found to be associated with high crash risks in general but also related to the elevated risks in certain driving situations. The questionnaire and crash report analyses collectively suggested that the high risk situations mainly related to when a driver needs to divide attention among multiple visual locations (e.g., visually process or respond to more than two traffic flows and/or potential hazards at the same time) or multiple concurrent tasks (e.g., driving with external and/or internal secondary tasks or distraction). For instance, the results indicated that drivers who have a lower level of executive attention had increased crash risks particularly when making a left turn at a stop-
sign intersection, but not at a traffic signal-controlled intersection. Given that making an unprotected left turn requires divided attention between approaching traffic and the road to enter to, this difference could be explained by the role of executive function in driving. Similarly, low executive efficiency was associated with increased crash risks during merging and changing lanes, which also require a driver to process more than two traffic flows.

The results from the self-reported driving errors measured using the questionnaires suggested that lower alerting attentional functioning may escalate driving errors in the situations that demand a driver’s quick detection of important traffic information or potential hazards, particularly when they occurred in the visual periphery (e.g., a cyclist or a pedestrian coming up on a right side). Such association suggests that a poor ability to maintain the readiness to respond to impending events may increase fatal driving errors when a sudden hazard appears. However, less consistent and somewhat contradictory associations between the alerting and safe driving were found in the self-reported driving errors and the crash events. For instance, whereas the questionnaire analyses indicated that failures to perceive potential hazards or traffic information in the visual periphery were associated with lower alerting efficiency, the crash report analyses indicated the opposite connections in the comparable situations in which failures to detect or respond hazards or traffic information occurred (i.e., the higher alerting efficiency, the increased crash risks). In addition, the results showed that driving while being distracted or inattentive was associated with lower alerting efficiency in the questionnaire analyses, but with higher alerting efficiency in crash reports. The reason for this is not clear, but it may have something to do with the difference between the self-noticed driving errors without crash occurrence and the crash events that could not be
avoided by a driver. Alternatively, more precise differences of the traffic situation, such as the spatial location of traffic information source (e.g., periphery vs. central visual field) or causes of distraction (e.g., boredom vs. task-overloaded) may result in different consequences. Contrary to general expectations, the positive associations observed between high alerting efficiency and increased crash risks may be in line with previous studies indicating people with a higher tendency of absent-mindedness tend to show higher alerting index scores because they are more likely to react strongly to salient warning cues (Ishigami & Klein, 2009). The phasic alerting function that was measured in ANT is related to a driver’s ability to increase readiness for an impending traffic situation or potential hazard when there is a warning sign. However, it can also be related to attention being predominantly captured by the most salient but irrelevant environmental stimuli. Thus, a driver may fail to detect or respond to the most relevant but less salient hazards or traffic changes.

The observed impacts of the orienting function on driving errors and crash risks were found to be weak and somewhat unexpected. First, the orienting function was not associated with any general driving performance measures (i.e., the frequency of warning, tickets, crash, and near-crash). Some associations between the orienting function and specific driving errors or crash types were observed. However, these connections were rather inconsistent with what previous research has found. While the prior research showed that higher orienting efficiency was associated with better hazard detection and responses (Roca et al., 2013), the present results indicated that the higher orienting efficiency was mostly positively related to the increased driving errors and crashes. One possible explanation for the unclear pattern of
associations can be related to how orienting function was measured in the present study. Similar to the alerting efficiency, the orienting function was measured as the function of paying attention to a spatial location that is indicated by an immediate cue. It has been suggested that such measures may reflect more of a reflexive process to sensory inputs rather than an individual’s ability to intentionally select a spatial location and direct attention to it (Ishigami & Klein, 2009). While the latter is an important ability involved in driving performance, the orienting index in the present study may not fully reflect the top-down orienting function that might be more relevant for safe driving. Furthermore, previous studies suggested that the impacts of orienting efficiency may differ depending on the complexity of traffic situations. Higher orienting efficiency was found to be associated with lower crash risks in the traffic situations where a driver could anticipate and avoid the potential hazards that were visible or predictable from environmental cues, whereas it was associated with higher crash risks in more complex situations where a driver has to monitor multiple potential hazard sources before selecting one as the actual hazard (Roca et al., 2013). However, it is also possible that a lack of independence between the orienting and the executive functions found in the current samples may have resulted in positive associations between orienting function and driving errors or crash risks.

Although bi-directional and somewhat inconsistent associations were observed, the results showed that it is likely that some distinct connections exist between the alerting, orienting, and executive functions and elevated crash risks. However, caution must be applied, particularly for the findings from the crash reports, as the crash data and analyses were limited. Because vehicle crash rate is very low in general, our sample size for crash
involved groups was also very small. Small sample sizes in the crash report analyses made the observed effects small, while statistically significant or approaching to a significant level. In addition, the individual statistical analysis was conducted for each type of driving errors and crash characteristics, which would result in significant Type I error problems. While some useful insight was earned with this approach in the exploratory phase, more sophisticated and conservative statistical analyses should be conducted to support the current findings.

Another limitation of the present study is that all driving performance measures including crash reports were self-reported. Given that human memory is reconstructive (Schwarz & Sudman, 2012), distortions may exist in the recall of drivers’ past driving errors and crash events, and also they might not be able to examine accurately the reason that directly led to crashes. Individuals who have deficits in attentional functions may be even less likely to have an accurate perception of their driving ability and recollection of their crash events.

Furthermore, the present study did not consider any variables that potentially moderate the relations between attentional functions and driving risks. For instance, driving experience may significantly impact the likelihood of involving particular types of crash. Because the present study mostly recruited participants who had at least one crash or near-crash events in recent past, the sample might be a biased group of drivers who are at higher risks, thus not representative of a general driver population.

One final aspect to be noted for Study 1 is that the results indicated minimal to none age-related differences. As addressed in the introduction, previous studies showed age-
related declines in the ANT performance, while there were some inconsistencies in on which aspects of the attentional functions being the most vulnerable to aging (e.g., Fernandez-Duque & Black, 2006; Jennings et al., 2007; Mahoney et al., 2010; Zhou et al., 2011). A lack of age differences in the current results may be primarily due to the fact that the participants were in a homogenous group that exhibited a higher crash risk than a general driver population and that most participants were in the mid to old ages as well. The finding may suggest that the age itself does not play a critical role among the drivers with a higher risk or low cognitive functioning. It also suggests that the associations between the attentional functioning and driving safety are consistent regardless of chronological age.

The findings from the first study provide some support for the conceptual premise, with some limitations, that the impacts of the alerting, orienting, and executive functions on the elevated crash risks are distinct. The next section described the process of developing a taxonomy of the attentional functions and traffic situations that illustrates the associations suggested by the self-reported measures in the present study.

**Development of Taxonomy**

Study 1 examined if the efficiency of each attentional network that carries out distinct functions (i.e., alerting, orienting, and executive attention) is differentially linked to crash risks in particular driving tasks or traffic situations. By comparing drivers’ self-reported driving errors and prior crash events with their functional efficiency in alerting, orienting, and executive attentional networks, Study 1 identified some distinct connections between the
three aspects of attention and particular types of driving errors and crashes. It can, therefore, be assumed that when older drivers experience declines in a particular aspect of attentional functions with increasing age, they may encounter differential impacts on crash risks, depending on environmental conditions, traffic situations, or driving tasks. Given these distinct relations, if an individual older driver has a more accurate understanding about one’s own attentional efficiency and the potential risks that are linked to a particular type of attentional decline, the driver may benefit from the knowledge by adopting appropriate coping strategies such as avoiding certain traffic situations. Thus, some form of an association structure can be of great help to individual drivers with attentional deficits for a self-intervention plan. In addition, this association structure can be used as a conceptual framework among researchers, occupational therapists, and practitioners.

The present research attempted to build a taxonomy of the attentional functions and traffic situations to illustrate how different aspects of attentional functions are potentially linked to increased crash risks in specific traffic situations. Because it was intended to provide knowledge about specific driving situations that can commonly occur in everyday driving, a list of hazardous scenarios were drawn by retrieving the associations from scattered information observed in the questionnaire items and prior crash reports in Study 1. The hazardous scenarios were specified by traffic location (intersection and non-intersection), driving maneuver (making a left turn, making a right turn, entering traffic, going straight, making a U-turn, changing lanes, merging, and backing), traffic control (stop, signal, yield, roundabout, and no-control), and hazard sources (e.g., oncoming traffic, pedestrian, etc.). Because the results of Study 1 suggested both positive and negative
relationships between functional efficiency and increased crash risks, the taxonomy indicates the possible directions of each association.

The taxonomy table of the attentional functions and the retrieved hazardous driving situations is illustrated in Figure 4. This was not an exhaustive list. Instead, it was aimed to cover common hazardous situations that older drivers may encounter during their everyday driving. A total of 17 potentially hazardous situations were included in the taxonomy. Each hazardous scenario was indicated by its association as well as directions of each association with one or more of the alerting, orienting, or executive attentional functions.

**Study 2**

The second study had two main objectives. First, it aimed to examine and validate the proposed taxonomy of three distinct attentional functions and crash risks in various traffic situations among older drivers using simulated driving. Although the general relations between attentional functions and crash risks were statistically significant in Study 1, the observed effects were small. This finding could be due to the low crash rate in daily driving as measured by self-reported crash history in Study 1. Moreover, details about crashes, unsafe driving behaviors, and driving errors were collected via self-reports. Older participants might experience memory declines thus it could be difficult to recall the exact details of prior crash events or driving errors. In addition, individuals who have deficits in attentional functions may be even less likely to have an accurate perception of their driving performance and recollection of their crash/near-crash events due to severe cognitive
declines. Thus, an alternative measure that is less susceptible to the influences of memory or attentional deficits may be needed to examine the associations between attentional functions and crash risks. Study 2 aimed to examine the taxonomy that was built based on self-reports measures in Study 1 in a more controlled driving environment. While Study 1 also included mid-aged drivers to enable a large sample size, for the primary interests of the current research on older drivers, Study 2 included older drivers only. Driving simulation was used to simulate the hazardous driving situations to investigate relations between older drivers’ deteriorations in the three distinct attentional functions and increased crash risks in various driving situations. It was hypothesized that functional efficiency scores of alerting, orienting, and executive attention predict older drivers’ performance in simulated driving, and they were distinctively associated with certain hazardous situations that have different traffic conditions, maneuvers, and road environments.

The second objective of Study 2 was to investigate the influence of self-awareness of attentional declines and the use of compensatory driving behaviors among older drivers. Previous studies have suggested that older drivers often used compensatory strategies to cope with declines in driving ability (Devlin & McGillivray), and when older drivers were aware of functional impairments, they were more likely to adopt behavioral changes to compensate for them (Braitman & McCartt, 2008; Staplin et al., 2012). Therefore, it was expected that the level of self-awareness of one’s attentional and cognitive declines would have a critical impact on changes in their driving behaviors, which would lead to reducing crash risks due to age-related declines.
Methods

Participants

A total of 82 older adults (age range of 65-92 years; except the two participants who were 87 and 92 years old, the age of the rest of the participants were between 65 and 85; \( M = 73.16, SD = 5.20 \)) were recruited for this Study (50 males and 32 females). The sample size was determined a priori based on previous research that examined the associations between attentional scores and simulated driving performance measures with a comparable experimental design (Roca et al., 2013) and estimated using a power of .80, a significance level of .05, and an expected correlation coefficient \( \rho \) of .35. Initially, it was planned to test 20% more than the estimated sample size given the possibility of 20% dropouts due to simulator sickness. However, it had turned out a higher dropout rate than estimation and the recruitments continued until a total of 82 participants were completed. Out of 82 participants, 60 (age \( M = 73.32, SD = 4.97 \); 41 males and 19 females) participants were able to complete simulated driving task.

Participants were recruited from local communities as well as from a retirement residence. Eligibility to participate in the experiment that was listed in the recruitment advertisement include holding a valid government-issued driver’s license, driving on a regular basis, and a normal or corrected-to-normal vision, with no history of severe visual, hearing, or memory problems or any other major health issues. A brief screening interview was conducted prior to recruiting (Appendix B). During the screening interview, participants reported their general conditions of health, vision, hearing, and memory. Anyone who reported experiencing serious motion sickness while watching 3D or IMAX movies or
getting easily tired while watching TV or computer screens was not recruited due to a possible simulator sickness. Participants reported that they drove almost every day and the average miles driven during the past year was approximately 10,000 miles. Demographics and driving information are illustrated in Table 1.

Stimuli & Measures

Entry survey. A short survey included questions for participants’ driving-related information: date of being licensed, frequency and intensity of driving, self-rates / perception of others of driving safeness, numbers of past driving violations and crashes, medical problems, medications, and vision problems. A copy of the entry survey is enclosed in Appendix C.

Attention Network Test (ANT). The Attention Network Test (ANT; Fan et al., 2002) was used to assess participant’s functional efficiency in three attentional networks (i.e., alerting, orienting, and executive). The ANT used in Study 2 was programmed and administered using E-Prime (Version 2.0, Psychology Software Tools, Pittsburgh, PA) on an off-line local PC instead of an online browser.). The test was displayed on 800 x 600 resolution monitor where the stimuli were presented within a visual angle of 10°. The size and the angle of stimuli were designed to be presented in the focal visual field. However, participants’ position was not restrained. Thus both viewing distance and viewing angle were not restrained.

The ANT employed in Study 2 was similar to the one used in Study 1 except a few minor changes, including the numbers of trials, the inclusion of a neutral target condition, and the use of a mouse instead of a keyboard for a response. The test started with a short
practice followed by two testing blocks. During practice, feedback on accuracy and reaction
time was provided for each trial. The procedure of each trial is same as the ANT used in
Study 1. In addition to the two types of flankers (congruent and incongruent) used in Study 1,
three types were used in the present ANT: 1) arrows pointing the same direction as the target
(congruent condition; e.g., “←←←←”), 2) arrows pointing the opposite direction
(incongruent condition; e.g., “←→←→”), or 3) horizontal bars that did not contain any
directional information (neutral condition; e.g., “− − ←”). Responses were made by
pressing a corresponding mouse button (i.e., a left button for “←” and a right button for
“→”).

Reaction time and correctness of each response were recorded, and only correct
responses were used for RT based performance indices. Any responses made faster than 100
ms were excluded. A method to compute three efficiency indices for the alerting, orienting, and executive attentional functions was same as in Study 1. Given that the present
experiment was a traditional laboratory study and the accuracy was found to be comparable
to previous studies (error rate in the present study: $M = 2.35$, $SD = .33$; e.g., error rate in Fan
et al., [2002]: $M = 1.91$, $SD = .36$), the RT based indices were primarily used in the analyses.

**Simulated driving task.** The driving situations described in the taxonomy were
implemented in a simulated driving task. STISIM Drive® 3 (Systems Technology,
Incorporated) was used to develop the simulated driving environment. A PC-based desktop
version of the simulator with one screen was used to display the simulated driving
environment. Driving scenes were displayed on a high-resolution 42 inch TV monitor at a
viewing distance of approximately 100 - 130 cm (i.e., the display was located at 85 cm from
a steering wheel) for the first 15 participants and a 27 inch PC monitor at a distance of 80 - 110 cm (i.e., at 65 cm from a steering wheel) for the rest of the participants. The monitor change was made midway in the experiment to deal with a high dropout rate due to simulator sickness occurring among the participants who had the simulator environment displayed on the large monitor. Although the screen size had been changed, the visual angle was maintained relatively consistent. Driving maneuver was controlled by a Logitech Driving Force™ GT which included a steering wheel and two pedals of gas and brake.

A practice session of a length of 2-3 minutes was implemented to train participants with simulator environment and basic maneuvers with simulator controls. An experimenter assisted participants during the practice drive for them if necessary. The practice drive included a 9,000 ft. route consisting of multiple sections of a straight roadway, a curve road, and four intersections that were one-lane or two-lanes for the traffic in each direction. The practice drive environment was designed to be similar to the testing drive environment, but none of the static or dynamic traffic stimulus (e.g., buildings, approaching/crossing traffics, pedestrians, etc.) was presented during the practice. Two practice intersections for each direction (i.e., making a left or a right turn) were provided, and the turns were made at a traffic light controlled intersection or a stop sign-controlled intersection. Throughout the practice drive, auditory instructions were given to guide the route as well as to train participants to get familiar with the display and the controls. Participants were first asked to check rear-view and side mirrors, then to speed up, slow down and stop, and make a couple of turns to the right and left.
The testing session consisted of two drives. Each drive was a route of about 35000 ft. in a virtual environment, and it took approximately 10 to 15 minutes to complete if driven at an appropriate speed as guided by the street speed signs. The environments were designed to be seen as a residential, industrial, or commercial area with varying levels of developments. There were sections of high-way driving. The instructed driving speed ranged between 35 to 65 mph depending on the traffic environment, and speed limit signs were displayed at every location where the speed limit changed throughout the drives. The driving scenario included various traffic locations (intersection and non-intersection), traffic controls (signal, stop, yield, etc.), driving maneuvers (driving straight, turning left, turning right, entering traffic, changing lanes, and merging), and hazard sources (vehicles, motorcycles, cyclist, pedestrian, etc.). Route instructions were provided to guide the traveling directions. The drive contained a large number of dynamic (e.g., vehicles, pedestrians) and static objects (e.g., buildings, trees) to reflect a common daily driving environment. The driving speed instructed by speed limit signs was between 35 to 55 mph.

Each of the two drives consisted of 14 hazardous situations and four benign intersections (Figure 5). The 14 hazardous driving situations were designed based on the taxonomy of attentional functions and crash risks in various traffic situations. Among the 17 situations that the developed taxonomy illustrates, three scenarios that involve entering a roundabout, making a U-turn, and backing-up were excluded due to the limitation of the simulator program. Also, the two events that involve making a right turn at a channelized right-turn lane with a yield sign were changed to general unprotected right turn situations in the present simulated driving because a channelized lane was not available in the simulator.
used for the current experiment. Each of the 14 hazardous situations occurred once during each drive. Thus, two crash chances for each type of the 14 hazardous situations were available during the simulated driving session. The hazardous events occurred in a pre-determined order which balanced between the intersection and non-intersection hazardous situations as well as across turning directions. The four benign intersections were inserted in the scenarios to prevent participants from anticipating the occurrence of the hazardous situation at every intersection. Orders and descriptions of the driving scenarios in the drive 1 and 2 are summarized in Table 9.

For the events designed for drivers to engage in a multi-tasking, a brief sentence verification task was employed. When a driver entered the section of the events, there were four sentences (e.g., “Ottawa is a capital of Canada”) were played, and the participants were asked to verbally answer if the sentence was correct or incorrect. Each sentence lasted between two to four seconds, and the onset of each sentence was 400 ft. apart. A hazardous event (i.e., a sudden stop by a leading vehicle) occurred during the play of the last sentence. One type of events involves eye-catching road-side stimuli that were placed to induce a driver’s distraction. During the distance of 1,400 ft., a total of seven billboards containing disturbing or attracting images were displayed on the side of the road. While a driver drove through the area, a hazardous event (i.e., a vehicle in the center median lane pullouts in front of the driver and stops suddenly when a pedestrian walks out from the side) occurred. The images used to develop the billboard were presented in Figure 6.

Participants were instructed to drive in a natural manner as they would normally drive on the real road. Participants were allowed to change a lane, to pass slow traffic, or to do
whatever they would like as they would do in an actual roadway. They were told to maintain the appropriate speed as directed by speed limit signs displayed throughout the drives.

Participants’ driving performance was recorded throughout the entire drive. Driving performance data included total travel time, the number of crashes, time to collisions, the number of stop sign missed, the number of off-roads, the number of centerline crossings, and other traffic mistakes (e.g., illegal turns, speed exceedances, and traffic light passed).

**Structured interview.** A structured interview on attentional / cognitive functions and driving behaviors was administered, which consisted of two parts: 1) the first section was for older drivers’ self-awareness of attentional functioning and self-rated functional efficiencies of various cognitive functioning in the context of driving, and 2) the second section was for the changes made in driving behaviors or strategies in the recent past to assess older drivers’ compensatory driving.

The first section started with the three attentional functions as defined in the Attention Networks model (Posner & Petersen, 1990). For each of the alerting, orienting, and executive attentional functions, participants were asked to give a rating on each of the following three items about ones’ own functioning; 1) perceived functional efficiency, 2) awareness of functional declines with aging in everyday life, and 3) awareness of functional declines in the context of driving. The experimenter first provided a definition as well as a couple of examples of everyday tasks that would reflect each of the attentional functions. For example, the alerting function would be demanded while reading a book or boiling water, or when going to a pool with grandkids, continuously scanning the water for prolong periods of time looking out for them. The alerting function would also involve increased readiness such as
when hearing emergency sirens, one should be alerted and prepared to respond to the impending situation. After participants had been told about the function, they were asked to rate their own functional efficiency compared to their peers in a 5-point Likert scale with 1 being worse than most peers and 5 being better than most peers. Next question asked if a participant has noticed that daily activities requiring the particular function are becoming more difficult or challenging in their daily living over the past 5 or 10 years. The 5-point Likert scale, with 1- being strongly disagree or definitely no changes and 5- being strongly agree or definitely noticed changes, was used for rating. After the second question, additional descriptions of how each function is involved in driving was provided to help participants to understand the role of each attentional function within the context of driving. For example, participants were told that alerting function would be demanded during a long drive (i.e., tonic alerting) or to increase readiness for a deer crossing after seeing a sign indicating a deer crossing area (i.e., phasic alerting). Then, participants were asked if the function had become more difficult or challenging during driving. After the three questions for each of alerting, orienting, and executive attentional functions, the interview continued with a list of various cognitive functioning in the context of driving and participants were asked if each function had become more challenging with increasing age. The list of driving tasks was adopted from previous research conducted using an unstructured interview of older drivers (Staplin et al., 2012). Some of the driving tasks and traffic situations were retrieved from the present taxonomy. The list included: 1) to read or check road signs or traffic signals, 2) to know when you have the right-of-way to proceed at an intersection (through or turn), 3) to judge gaps in traffic, 4) to detect other vehicles or pedestrians in the periphery, 5) to keep up with
the flow of traffic on high speed roads), 6) to judge what other drivers are going to do in traffic to anticipate potential hazards, 7) to pay attention to everything at the same time, 8) to merge at a yield sign, 9) to enter or exit a roundabout, 10) to change lanes on a multilane roadway, 11) to make a unprotected left turn at an intersection (e.g., stop-sign, flash signal, etc.), 12) to make a right turn in a busy area where lots of other road users such as pedestrians and cyclists are around, 13) to pay attention to signal light changes, 14) to ignore distracting roadside scenes, 15) to multi-task during driving (e.g., eating or talking.), 16) to check a rear-view or side mirrors, 17) to make a U-turn, and 18) to back up. All responses were recorded on a 5-point scale, qualitative answers and comments were also collected to have a complete understanding of one’s self-perception of own cognitive functioning. Lastly, there was one last open-ended question asking if there are any other particular traffic situations or driving asks that they find it become more difficult or challenging.

The second section assessed older drivers’ changes in driving behaviors and adoption of compensatory strategies. The first question was open-ended asking participants to describe if they have changed their driving habits and behaviors in the past 5 to 10 years, followed by a list of possible compensatory driving strategies that participants indicated whether they had adopted any. The list of the compensatory driving strategies was adopted from Staplin et al. (2012) as well as from a list from the NHTSA guidelines (retrieved from: http://www.nhtsa.gov/people/injury/olddrive/Driving_Safely_Aging_Web/page4.html). The NHTSA guidelines listed a list of recommended behaviors that older drivers can take specifically when they have the symptoms of decreased attention and reaction time. The compensatory driving behaviors included in the interview are: 1) drive fewer miles, 2) make
fewer trips per week, 3) drive slower than a speed limit, 4) drive with a passenger (i.e., avoid driving alone), 5) use adaptive equipment (e.g., seat cushion, special mirrors, etc.), 6) use assistive in-vehicle technologies (e.g., collision avoidance technology), 7) leave more room between one’s own car and a car at the front to increase following distance, 8) take more time to scan the environments at intersections, 9) scan farther down the road continuously to anticipate future problems and plan actions in advance, and 10) plan the route before leaving. Participants were also asked if they have avoided or become more cautious in various traffic situations including 1) night driving, 2) unfamiliar areas, 3) when driving far from home, 4) high-speed roads, 5) freeways or expressways, 6) high traffic roads, 7) rush hours, 8) when changing lanes or merging, 9) bad weather (e.g., rain, snow, fog, etc.), and 10) unprotected left turns. Responses were collected as yes or no, but participants were told to elaborate and further explain if they wanted. The script used to conduct the interview is enclosed in Appendix D.

Vision Tests. Three screening vision tests on visual acuity, macular functioning, and contrast sensitivity were conducted to make sure that participants had normal visual sensory capabilities. Visual acuity was examined using a widely used measure of the Snellen chart (McGraw, Winn, & Whitaker. 1995) at a viewing distance of 40 cm. The Amsler’s chart, which was used to check macular degeneration, was downloaded from https://www.macular.org/sites/default/files/amslerchart.pdf (Appendix E). The standard test procedure specified in the chart was followed. To examine contrast sensitivity, an online test (https://www.vcstest.com/test/) was employed (Shoemaker & Hudnell, 2001). The test displays a series of stimuli, which are the images of parallel bars on a white background.
Participants responded which direction the black bars in each image was tilted (e.g., 'Left,' 'Up,' or 'Right'). As progress, the images generally get harder to see because they get lighter and the parallel bars get closer together.

**Procedure**

After being briefed and providing consent to participate, participants first filled out the entry survey. Then, the three vision tests were completed. During the visual acuity test, participants read the Snellen chart at a viewing distance of 40 cm with their head fixed on a headrest. Visual acuity of the left and the right eye was examined separately by covering the other eye using an eye occluder. Participants read out the letters that an experimenter pointed to. An experimenter asked participants to read smaller letters until they were no longer able to read the letters. The procedure was repeated with another eye. Participants’ macular functioning was tested using the Amsler’s chart, separately for each eye. Participants were asked to fix their gaze at the center black dot within a grid while trying to check if any lines are distorted, curvy, or missing. During the contrast sensitivity test, 45 images (i.e., 5 sets of 9 images) were presented for each eye with the other eye covered, and participants indicated the direction of the tilts of each image verbally, and an experimenter made clicks to the corresponding response image below the test image to proceed to next image (a sample trial is illustrated in Figure 8). If a participant was not able to make out the direction of tilt of the bars in an image, he/she answered “blank.”

After the vision tests, the simulated driving session was conducted. First, an experimenter provided instructions on how to use the steering wheel, pedals, signal lights, and other fundamental controls. The experimenter also demonstrated how to start and stop
the vehicle as well as how to make a turn. Participants were required to complete a practice drive, during which the experimenter observed a participant’s driving behaviors and intervened if the participant seemed confused or needed assistance. The practice drive was repeated if necessary. Before starting the first testing drive, participants were told that there would be various hazardous events and a crash could occur due to the nature of the challenging driving scenario. Participants completed two simulated driving sessions with a break between the two sessions. Participants were allowed to take a longer break if they experienced some feeling of disorientation during the first drive but were willing to continue.

Next, participants completed the ANT task measuring their attentional functions. The experimenter verbally explained about the different cue types and target types. Participants were asked to hold the mouse with two hands and rest each thumb on the left or right button to make a response. Participants first completed the practice which consisted of 12 trials that presented stimuli at a slower speed, then another 12 trials that were at the same rate on the testing trials. After a short practice, two testing blocks, each of which took approximately 5 - 7 minutes, were administered, and participants were allowed take a short break between the two testing blocks. Each testing block consisted of 96 trials. The two target locations (up or down), four cue conditions (no cue, center cue, double cue, or spatial cue), three target types (congruent, incongruent, or neutral), and target arrow directions (left or right) were balanced across the trials. Participants were instructed to respond as quickly and accurately as possible.

Lastly, the structured interview was conducted by the experimenter. A voice recording device was turned on during the entire interview. For the questions that were on a
numeric scale, participants were told about the scales and asked to provide the corresponding numeric values. In addition, they were also allowed to give their answers in sentences, and an experimenter chose the numeric value that matched the most closely to the text-based answer. Some participants completed the ANT and an interview after the first drive and before the second drive to ease the feeling of slight simulator sickness that they experienced during the first drive.

Multiple experimenters contributed to the effort of this experiment, and everyone followed a script for the experiment procedure that was developed to maintain consistency across experimenters. The script is enclosed in Appendix F. The entire experimental session lasted approximately 1.5 to 2 hours for each participant. Participants were compensated at a rate of $15 per hour. Each participant received a compensation ranging from $20 to $40, depending on how quickly he/she completed the testing. After participation, participants signed the receipt for the compensation and were debriefed.

Results

Data analyses were conducted to address the following three questions. First, what are the general relations between attentional functioning and older drivers’ prior traffic violations, crashes, and simulated driving performance? Second, how valid is the taxonomy classifying increased risks in particular sets of traffic situations linked to alerting, orienting, and executive attentional functions? Third, how do individuals’ self-perceived attentional functioning and age-related declines relate to the use of compensatory driving behaviors? In the following sections, I describe the results according to the order of these questions.
Older Drivers’ Attentional Functioning and General Driving Safety

Older drivers’ overall attentional functioning and efficiency of different aspects of attentional functions (i.e., alerting, orienting, and executive) were first examined and compared to prior traffic violations and simulated driving performance by correlational analyses.

**ANT performance.** First, older drivers’ ANT performance was examined. It was found that compared to Study 1, the mean reaction time (RT) was shorter ($M = 655.82, SD = 86.67$) and the overall accuracy was higher ($M = .98, SD = .04$). No speed-accuracy trade-off was observed in the present samples (correlation between accuracy and RT $r = .02, p = .87$). Three functional efficiency indices for alerting, orienting, and executive attention were computed based both on reaction time (RT) and error rate. Table 2 shows the means and standard deviations of the ANT performance indices. As indicated in the methods, the RT based indices were primarily used in the analyses. Alerting ($M = 29.93, SD = 33.63$), orienting ($M = 10.92, SD = 15.65$), and executive ($M = 122.79, SD = 54.84$) indices were more likely to operate independently. Only the correlation between the orienting and executive functions was found to be marginally significant in the present sample ($r = -.22, p = .051$).

**Self-reported safe driving, prior driving violations, and general driving performance.** Participants self-rated themselves as generally safe drivers, with a mean self-rated driving safety of 8.45 (SD = 1.22) on a 10-point Likert scale with 0 being very unsafe and 10 being very safe. Among the 82 participants, 17 participants reported that their friends or family had expressed concerns about their driving safety. Participants indicated that they
had received average of .13 ($SD = .38$) warnings, .20 ($SD = .53$) traffic tickets, and .35 ($SD = .62$) crashes in the past 5 years. Out of the 82 older drivers, 22 participants could not complete the simulated driving task due to simulator sickness. As a result, the simulated driving performance was analyzed with a sample of the 60 participants who completed both simulated driving sessions. During the two simulated driving tasks, participants were involved in an average of 5.20 accidents ($SD = 3.00$; accidents include off-road accidents, collisions, and pedestrian hits), 6.69 violations ($SD = 4.38$; violations include speed exceedances, speeding tickets, traffic light tickets, and stop sign tickets), and 34.27 time of lane crossings ($SD = 6.97$; lane crossings include centerline crossings and road edge excursions). The high number of lane crossings were mainly due to non-critical failures to keep lanes while making turns. The correlational analysis was also administered to examine if age is associated with simulated driving performance among older drivers. The data showed that age was positively correlated with frequency of accidents ($r = .28, p < .05$), but not with violations ($r = -.07, p = .60$) or lane crossings ($r = .04, p = .78$) occurring during the simulated driving.

**Associations between attentional functioning and overall driving safety**

**measures.** ANT performance was compared with self-reported driving safety measures as well as simulated driving performance. None of the self-reported driving safety or traffic violations (i.e., the frequency of warnings, tickets, near-crashes, and crashes in the past five years) was significantly correlated with ANT performance (See Table 11 for a full list of the correlations). Among the three simulated driving performance measures (i.e., accidents, violations, and lane crossings), the frequency of accidents was significantly correlated with
both overall ANT accuracy ($r = -.30, p < .05$) and RT ($r = .27, p < .05$), indicating that older drivers who were more accurate and faster on the attentional task were less likely to be involved in crashes during simulated driving. Frequency of traffic violations during simulated driving was correlated with overall ANT accuracy ($r = -.41, p < .05$), but not with RT ($r = -.13, p = .31$). Consistent with the findings in Study 1, among the three attentional functions, the executive function was found be most critically associated with crash risks: the lower executive efficiency was significantly correlated with more accidents in simulated driving ($r = .29, p < .05$), whereas no association was found between the number of accidents and the alerting ($r = .21, p = .12$) or orienting ($r = -.01, p = .96$) index. The executive function was also marginally correlated with the lane crossings ($r = .25, p = .05$). No other correlations were found significant.

**Alerting, Orienting, and Executive Attentional Functioning and Hazardous Driving Events**

To investigate the validity of the taxonomy (developed based on findings from Study 1) of three attentional functions and participants’ driving performance at various hazardous driving events, associations between each of alerting, orienting, and executive attention and crash occurrences during specific hazardous driving events were examined. A total of 14 hazardous events were presented during the driving simulation. During the experiments, however, it was observed that two particular hazard events could not be sufficiently displayed in one-screen setting of the simulator. Significant numbers of participants reported that they clearly anticipated a crash, but they were not able to avoid it due to a blocked view of the hazards in a screen. These events were: 1) a driver makes a left turn at a stop sign
intersection where there are heavy crossing traffics and 2) a driver makes a left turn at a stop sign intersection and multiple pedestrians start crossing the road. Therefore, the two events were excluded from data analyses. The remaining 12 events were grouped into the categories of the alerting-, orienting-, and executive-critical hazardous events based on the taxonomy. As the taxonomy indicates, many of the events were included in more than one category (see Table 10). The following sections describe the observed significant associations between the hazardous event categories and the attentional functions. The summary of the observed significant associations was presented in Table 12.

**Executive attention and hazardous driving events.** Findings in Study 1 suggested that the executive attention is the most important aspect of the three attentional functions that could have an impact on older drivers’ crash risks. The 11 specific hazardous events were indicated to link to the executive function. After excluding two events that could not be appropriately represented in the simulator, a set of the executive-critical hazardous category included the remaining nine events. Each event was repeated twice in the simulated driving; thus, participants had a total of 18 chances of crash occurrences during the executive-critical hazardous events. Correlation analysis showed that frequency of crashes occurring during the events of the executive-critical hazardous category was significantly associated with executive attention \((r = .28, p < .05)\), suggesting that older drivers with lower executive efficiency showed a higher rate of crash involvements in the executive-critical hazardous events. An additional linear regression analysis was administered to confirm the associations. The results showed that the executive attention is a significant predictor of the number of crashes in this particular category of hazardous traffic situations and driving tasks, \(F(1,58)\)
=4.74, p < .05, R^2 = .08. Older drivers’ executive attention was accounted for 8% of the variance in crash risks within the executive-critical events. This result confirms the taxonomy relations between older drivers’ executive attention and elevated crash risks in the executive-critical hazardous events. Crash frequency during the executive-critical hazardous events was not correlated with alerting (r = .17, p = .19) or orienting (r = -.16, p = .24) function. Mean completion time of the executive-critical hazardous events was also compared with the executive score, which showed no association (r = .01, p = .94). This result suggests that older drivers who had lower executive efficiency were not more cautious during the hazardous events by taking longer time.

In addition to the association between the executive attentional efficiency and crash frequency during the executive-critical events, individual hazardous events were further analyzed to investigate if crash risks in any particular hazardous situations among the list of executive-critical events were more critically associated with the executive function. One particular event was found to be significantly associated with the executive functioning: a vehicle merges towards the driver’s lane unexpectedly and abruptly (r = .32, p < .05). One additional association was at a marginally significant level: a driver makes a right turn at an intersection where pedestrians cross the road from the left (r = .24, p = .06). These results suggest that certain driving situations are more likely to involve the executive attentional function during driving than other situations. However, due to the variable nature of crash in one driving event, these results on individual hazardous events were preliminary and inconclusive.
Alerting attention and hazardous driving events. The taxonomy proposed that the alerting function may be associated both positively and negatively with older drivers’ increased crash risks depending on hazardous events. Among the four events being indicated to be associated with the alerting function, three events that were in positive relations (i.e., the higher alerting function, the higher crash risks) were grouped as the positive alerting-critical hazardous events, and the remaining one event was classified as the negative alerting-critical hazardous event. The analysis showed there was no significant correlation between the alerting efficiency and the crash frequency in the negative alerting-critical events ($r = .06$, $p = .66$). Interestingly, a positive correlation was found between the crash frequency in the negative alerting-critical events and the overall ANT RT ($r = .49$, $p < .01$), indicating that the hazardous events that were initially categorized to alerting-critical in the taxonomy were more likely to be associated with the general speed of attentional processing. For the negative alerting-critical event (i.e., a lower alerting efficiency is associated with increased crash risks), which was a challenging lane-change situation, the correlation analysis was administered to examine this association. However, the result indicated that the crash frequency in this event was not correlated with the alerting score ($r = .04$, $p = .75$).

Interestingly, the completion time of the event (i.e., time to drive 2000 ft where the lane change occurred) was found to be negatively correlated with the alerting score ($r = -.26$, $p < .05$). Together these results may suggest that although older drivers who have a lower alerting efficiency did not get involved in more crashes during lane changes, they had to or chose to drive slowly in order to complete lane changes.
Additional correlation analysis was conducted to examine if any particular hazardous events other than the classified alerting-critical events were associated with the alerting function. The result showed that the higher alerting efficiency was significantly correlated with increased numbers of when drivers were involved in multi-tasking ($r = .32, p < .05$). This may suggest that older drivers with a higher level of alerting function are less likely to maintain safe driving when they multi-task.

Another interesting finding was that the overall completion time of simulated driving was found to be negatively correlated with the alerting score ($r = -.26, p < .05$). This result, together with no significant association between the crash occurrence and the alerting indices, may suggest that older drivers with deficits in alerting attention did not get involved in more crashes, but they were driving more slowly to complete the driving safely.

**Orienting attention and hazardous driving events.** The number of crashes occurring in the five events was aggregated for the orienting-critical hazardous events. There was no significant association observed between the orienting efficiency and the number of crashes during the orienting-critical events ($r = -.07, p = .59$). Similar to the relation between the overall ANT RT and the frequency of crashes during alerting-critical events, a positive correlation was found between the overall ANT RT and the frequency of the crash during orienting-critical events ($r = .42, p < .01$). These results suggest that the crash risks in the hazardous events that were initially classified to link to the orienting function in the taxonomy may be rather associated with the overall speed of attentional processing.
Self-Awareness of Functioning and Compensatory Driving Behaviors

Self-perceived attentional efficiency and awareness of age-related declines.

Correlational analyses were conducted to examine if older drivers’ self-perceived functional efficiency in the alerting, orienting, and executive attention as compared to peers reflect their attentional efficiency accurately. The summary of correlations between the measured efficiency using ANT and self-rated efficiency in the alerting, orienting, and executive attention is described in Table 13. None of the measured functional efficiency was correlated with self-rated efficiency (alerting: $r = .04, p = .72$; orienting: $r = -.14, p = .20$; executive: $r = .03, p = .83$). These results suggest that older drivers might not have an accurate perception of their own attentional functioning.

In addition, older drivers’ self-awareness of age-related functional declines was examined. Participants reported whether they had noticed increased difficulty in 1) the alerting, orienting, or executive attention-related performance in everyday life (i.e., Self-awareness of attentional declines in everyday life), 2) the alerting, orienting, or executive attention-related performance during driving (i.e., Self-awareness of attentional declines during driving), and 3) various driving situations and driving tasks (e.g., to check traffic signs, to enter or exit a roundabout, making a U-turn, etc.) (i.e., Self-awareness of declines in driving competency). A summary of self-awareness scores is illustrated in Table 14. The results showed that older drivers were moderately aware of attention-related declines both in the context of everyday activities and driving: self-awareness of declines ranged between 2.02 and 2.61 on a scale of 1 to 5 where 1 represents definitely no changes and 5 definitely noticed changes (Table 14). The self-awareness of declines in driving competency was found
be relatively lower (M = 1.83, SD = .62). The positive correlations were observed among the self-awareness of attentional declines in everyday life and during driving, and the awareness of declines in driving competency (Table 14), which indicate that older drivers who were aware of declines in attention-related performance were more likely to be aware of declines in driving performance.

**Compensatory driving behaviors.** Out of the provided list of 20 potential driving habits and strategies that may be used as compensatory behaviors for older drivers’ safety, participants reported that on average they had adopted 10.46 types of compensatory behaviors (SD = 4.05). A hierarchical regression analysis was conducted to examine the extent to which predictors among attentional functioning, self-awareness of attentional declines, and self-awareness of declines in driving competency accounted for individual differences in older drivers’ adoption of compensatory behaviors. The predictors included the variables of age and the ANT performance measures (i.e., overall RT and accuracy, and the alerting, orienting and executive attentional efficiency indices). In addition, self-awareness of age-related declines in alerting, orienting, and executive functions in daily life as well as during driving was included in the second block. As summarized in Table 15, the first and the second block of predictors accounted for 7% and 16% of the variance in compensatory driving behaviors, respectively, but the models did not reach significant level (model 1: F(6, 81) = .99, p = .44; model 2: F(8, 81) = 1.67, p = .12). Among the predictors, the awareness of attentional declines during driving, but not the awareness of attentional declines in everyday life, was positively and significantly related to compensatory behaviors, $\beta = .30$, $t = 2.09$, $p < .05$, indicating that older drivers’ level of awareness in attentional declines in the context of
driving is a significant predictor of adoptions of compensatory behaviors during driving. Finally, the third block was added in the hierarchical regression analysis for the primary purpose of determining if the effect of self-awareness of attentional declines during driving with aging (a) on compensatory behaviors (b) was mediated by self-awareness of age-related declines in driving competency (c). The correlation analysis showed that all three variables were significantly correlated to one another (a-b: \( r = .28, p < .05 \); a-c: \( r = .52, p < .01 \); b-c: \( r = .38, p < .01 \)), indicating that a mediational approach was appropriate to be conducted. The third model in which the self-awareness of age-related declines in driving competency was entered into the equation was found to be significant (\( F(9, 81) = 2.36, p < .05 \)) and the amount of variance explained significantly increased to 23% (\( \Delta R^2 = .07, p < .05 \)). The self-awareness of age-related declines in driving competency was a significant predictor of compensatory driving behaviors (\( \beta = .34, t = 2.61, p < .05 \)). With the addition of the self-awareness of age-related declines in driving competency in the third step, the self-awareness of attentional declines during driving was no longer a statistically significant predictor (\( \beta = .15, t = 1.04, p = .30 \)), suggesting that the self-awareness of declines in driving competency mediated the effect of self-awareness of attentional declines during driving on compensatory behaviors. Results from a follow-up Sobel test (Sobel, 1982) indicated that the mediation effect is statistically significant (\( t = 3.05, p < .01 \)).

**Additional insights from open-ended questions and interviews.** To understand older drivers’ attitudes and thoughts that were not captured in the numeric scales, participants’ responses collected in the open-ended questions and throughout an interview were examined qualitatively. When respondents were asked to give information on
experiencing particular declines in driving skills, the majority commented that night driving became very challenging thus they started avoiding driving at night. Other responses to this question included parallel parking, making a curve on a narrow road with a guard rail, and perceiving depth while driving. Some participants expressed the belief that the difficulties they had experienced while driving, particularly during driving at night, backing up, or reading signs, were mainly due to physical or sensory problems such as vision declines or neck rotation. Participants also commented about environmental changes: traffic design had become more complicated, there had been more distractions such as cell phone use, and we have more erratic drivers on the road compared to the past, and that these changes resulted in that driving, in general, had become more challenging for them. Taken together, these responses suggest that older drivers tend to be aware of contributing external factors or any functional declines that can be more directly perceived, whereas they were less likely to be aware of attentional or cognitive declines and their potential impacts on driving competency. In addition, a few participants made meaningful comments that suggested self-reports may not be a good measure for functional declines if those functional demands can be avoided in most time when drivers decide to do it. For example, one participant said that he had always avoided multi-tasking while driving thus he had not had much chance to be aware of any declines in doing it.

In response to the question for any changes in driving behaviors they started making with aging, a range of interesting responses were elicited. Other than the provided lists of compensatory driving behaviors, a few respondents reported that they no longer make long drives and have more breaks or switch drivers if they had to make a long trip. Among the
provided list, participants most strongly commented on two particular compensatory behaviors of avoiding harsh environmental conditions: driving at night or during bad weather. Responses suggest that older drivers were trying to completely avoid those driving situations. An interesting issue was alluded when a number of respondents commented that they did not adopt particular compensatory behaviors or make specific driving behavioral changes, but they had started driving more cautiously in general. Together these responses provide insights into older drivers’ compensatory strategies. Older drivers might not have much knowledge about specific compensatory driving behaviors and how their driving safety would benefit from them. Thus, they tried to be careful in general without taking specific strategies or avoided certain environmental conditions that are relatively easier to be limited.

Interviews also identified gaps between intention and adoption of compensatory driving behaviors among older drivers. A number of participants commented that they think they should have made the suggested behavioral changes while driving with increasing aging, but had not changed in daily driving. Furthermore, responses suggested that accessibility is another hurdle for an older driver to utilize compensatory methods. Many respondents commented that they would like to have advanced safety technologies such as collision avoidance system, but the features were not available in their vehicles.

One of the issues detected from interviews is that some of the older drivers’ behavioral changes such as driving fewer miles and make fewer trips were because of changes in life style. One respondent who was recruited from a local retirement community commented that she ended up reducing most of her driving because she moved to the community and no longer needed to make many trips. Interviews raised another issue
regarding the interview on compensatory driving changes. A few participants said that because they had always been very careful while driving, they did not feel to need extra careful behaviors with increasing age. They reported that they had maintained a level of safety as they had had and did not change much. Given the interviewers asked whether they changed their driving habits and behaviors recently or adopt new compensatory strategies, the drivers who have been the most careful during driving might have scored the lowest in for the interview questions on compensatory driving behaviors. This suggests that further investigation for older drivers’ practice of compensatory driving is necessary to gain a complete understanding of the effects of compensatory behaviors on driving safety.

**Effects of Attentional Functioning and Compensatory Behaviors on Crash Risks**

To examine a potential role of the use of compensatory driving behaviors in the relationship between attentional functioning and older drivers’ crash risks, a 2 × 3 ANOVA with attentional functioning (2 groups: superior vs. inferior groups based on overall ANT RT) and compensatory behaviors (3 groups: high vs. mid vs. low compensatory driving groups) was conducted for the self-reported number of crashes occurred in the past 5 years (Figure 9). The older drivers were grouped in the high, mid, and low compensatory driving groups based on their number of compensatory behaviors reported out of 20 listed items: low (0-25 percentile)- 0 to8 items adopted; mid (25-75 percentile)- 9 to13 items adopted; high(75-100 percentile)- 14 to 20 items adopted. Consistent with the previous findings in the correlation analysis, the superior and inferior attentional groups were not significantly different in prior crash frequency as measured by self-reports, $F(1,76) = .20, p = .66$. There was a main effect of compensatory driving, $F(2,76) = 3.85, p < .05$. Because the equal
variance assumption has been violated (Levene’s test $F(5,76) = 8.26, p < .01$), the main effect of compensatory driving was re-examined with the Welch test which confirmed the significant mean differences across the compensatory driving groups, $F(2,47.394) = 5.47, p < .01$. The Games-Howell post hoc test revealed that the mid compensatory group ($M = .51$, $SE = .09$) had more crashed in the past 5 years compared to the low compensatory group ($M = .06$, $SE = .14$), but no difference was found when compared to the high compensatory group ($M = .27$, $SE = .13$). The interaction of attentional functioning and the compensatory driving was not found to be significant. It was somewhat unexpected to find that older drivers who adopted only minimal compensatory behaviors reported less crash involvements in the past five years than those who adopted more compensatory behaviors. These results may suggest that the relations between compensatory driving behaviors and driving safety are more complex than our general expectations. A few alternative explanations for this relations were addressed in the following discussion.

**Discussion**

Study 2 examined the taxonomy that was developed based on the findings from Study 1, which classifies the possible connections between different aspects of attentional function (i.e., alerting, orienting, and executive attention) and increased crash risks in particular driving situations. The second aim of this study was to assess the importance of potential moderating factors such as self-awareness of declines and compensatory behaviors of older drivers.
Overall, the results further supported that the attentional function is critically associated with older drivers’ crash risks. The most obvious finding to emerge from the analyses is that among the three aspects of attentional functions, the efficiency of individual’s executive function was the most reliable predictor of older drivers’ driving safety. Individuals’ executive efficiency score was associated with overall crash frequency and lane crossings in a simulated driving task. The more important finding was that the executive function was significantly predictive of crash risks in the set of hazardous events that were classified as the executive-critical events in the taxonomy. Contrary to expectations of the taxonomy, this study did not find significant associations between the alerting or orienting function and the sets of hazardous events that were proposed to be linked to each function in the taxonomy. These results suggest that a weak link may exist between the alerting or orienting function and the suggested hazardous traffic situations. Thus, the validity of the current version of taxonomy needs to be considered preliminary and not conclusive. Together these results suggest that it is likely that somewhat differential connections may exist between particular attentional functions and increased risks in certain driving conditions, particularly the association between the executive attention and the taxonomy-classified driving situations. However, the precise links between the three attentional functions and risks in various traffic situations need to be further investigated.

One interesting finding was that participants’ crash risks at the alerting-critical and orienting-critical events were significantly linked to the overall ANT RT. In contrast, no association was found between the overall ANT RT and the executive-critical events. The effects of speed of processing on increased crash risks were found to remain significant when
controlling for executive attentional efficiency. This is an interesting observation as it suggests that the speed of attentional processing could be another major factor, in addition to the executive attentional function, that determines older drivers’ crash risks. The present study was initially designed to investigate the potential roles of attentional functions in older driver’s crash risks using a three-factor model based on a framework of the Attentional Networks model. The present findings, however, may provide evidence for an alternative two-factor model which identifies the speed of attentional process and the executive attentional function predicting older drivers’ increased crash risks with aging.

As addressed in the introduction of this paper, prior research sometimes observed a discrepancy or low correlation between older adult’s cognitive performance in a controlled measure and in everyday task performance (e.g., Marsiske & Willis, 1995; Owsley, Sloane, McGwin, & Ball, 2002). This study investigated drivers’ self-awareness and compensatory behaviors because they may play any moderating roles in the effects of attentional declines on crash risks. The results were consistent with previous studies showing that older adults’ self-perception of their own cognitive functioning is not always accurate (e.g., Oliver, Robins, Richard, 1994; Horswill, Anstey, Hatherly, Wood, & Pachana, 2011). Although the older drivers’ perception of their own attentional functions did not accurately reflect the actual level of efficiency, many reported that they have experienced and are aware of declines in their attentional and cognitive functions as well as driving competency with increasing age. However, older drivers’ self-awareness of declines in three attentional functions was not found to be a significant predictor of their behavioral changes for compensatory driving. The meaningful factor leading to the adoption of compensatory
behaviors among older drivers is self-awareness of declines in driving competency, rather than self-awareness in attentional declines either in daily life or in the context of driving. These results suggest that awareness of functional declines in specific driving tasks is a key to determine older drivers’ compensatory behaviors. Self-awareness in functional declines in an abstract cognitive construct is less likely to lead to individual’s behavioral changes.

Some of the interesting questions emerging from the results relate to a role of compensatory behaviors in driving safety. Contrary to general expectations, this study did not find a clear positive association between compensatory driving behaviors and driving safety among older drivers. These results may suggest the general adoption of compensatory behaviors may not be always beneficial to safe driving. Adopting more compensatory practices universally during driving does not seem to reduce the elevated crash risks resulting from age-related declines significantly. It is possible that the relations between compensatory driving behaviors and driving safety may be rather complex, and possibly differ depending on the type of specific compensatory driving. It may be the case that many older drivers do not have accurate knowledge of compensatory driving behaviors, which might have resulted in using the compensatory behaviors in an ineffective way. In addition, the results may suggest that older drivers tend to start adopting compensatory behaviors after they encounter serious situations such as a crash. Those direct experience might provide insight about their risks, which may result in changes in driving behaviors. These results, therefore, further support that accurate understanding of functional declines and the specific impacts linking to those declines is important for older drivers to select and adopt appropriate compensatory behaviors.
Another possible explanation for the observed increased crash rates in the group of older drivers who adopted a mid-level of compensatory behaviors compared to those who adopted only minimum compensatory practices could be related to a role of experience of crashes in promoting changes in a driver’s behaviors. Given that the individual’s prior crash frequency and behavioral changes were measured in a simple self-reported form without information collected about whether the crash events or the behavioral changes came first, the older drivers may have reduced driving and became more cautious after they had an accident. The interview responses suggesting the gaps between intention and adoption of compensatory driving provide further support for this hypothesis that older drivers may not develop compensatory behavioral changes until they experience crashes or other critical situations.

Finally, the present study shows inconsistency between on-road and simulated driving crashes as a relation to one’s attentional functioning. This suggests that older drivers may still use some compensatory strategies during their everyday driving possibly without much self-awareness, which would have reduced the impacts of attentional deficits on their on-road crash occurrences, but not on the simulated driving. If this was the case, the questionnaire or the open-ended interview might not be able to capture those types of compensatory behaviors. This finding may further support the importance of compensatory driving as a moderating factor to reduce crash risks among older drivers. Thus, further work is required to identify effective compensatory driving behaviors and to examine their precise roles on driving safety.
General Discussion

Summary of Findings

Prior studies have noted the importance of attentional ability on driving safety. In reviewing the literature, however, only limited research was found on the investigation of how certain aspects of attentional functions would impact on driving performance in different types of traffic situations. Using the Attentional Networks model, the present research attempted to identify the precise connections between efficiency in the three distinct functions of the alerting, orienting and executive attentional networks and crash risks in various traffic situations among older drivers.

Two studies were conducted to explore various traffic situations, different types of crashes, and driving errors in relation to the efficiencies of the alerting, orienting, and executive attentional functions. Findings from the two studies provide strong support to the notion that the potential impacts of three aspects of attentional functions on safe driving are not equivalent. The present research has observed that the three attentional functions are distinctively involved in driving, and some unique associations between each of the function and crash risks in different driving situations may exist. Evidence from self-reports of prior driving errors and crash events (Study 1) and simulated driving (Study 2) suggested that older drivers’ crash risks in many driving situations are primarily linked to their efficiency of executive attention, particularly during those situations when a driver encounters conflicts among multiple competing tasks that requires a quick resolution to avoid a driving hazard. For example, the taxonomy illustrates a situation of a vehicle merging into the driver’s lane
unexpectedly as being associated with the efficiency of executive attention. While the executive efficiency was a significant predictor of crash risks, the connections between driving safety and either of alerting or orienting were not clear in the present study. It is possible that particular driving situations, which might not be detected in the current study, are linked to the alerting or orienting deficits. For example, the alerting function may be strongly associated with hazardous situations that involve a long drive which demands vigilance for an extended period of time. With regard to the orienting function, its importance may be the most prominent during the driving situations that require anticipation or prediction of potential hazards (Roca et al., 2013). Because the hazardous driving events included in the experiment of Study 2 mostly involved the unexpected and abrupt appearance of a hazardous object, it might not be able to detect the associations between the efficiency of the orienting function of attention and crash risks in these driving situations. The present study advanced our understanding about the differential associations between distinct attentional functions and older drivers’ crash risks. From the observed associations, a taxonomy was developed. This taxonomy, while still preliminary, classifies different types of driving errors and crash risks in association with the alerting, orienting, or executive attentional efficiency.

Another aim of this study was to examine the roles of self-awareness and compensatory driving behaviors. The results of this investigation revealed that a driver’s self-awareness of attentional efficiency was neither accurate nor predictive of compensatory driving behaviors. It was somewhat expected results, considering that one’s own level of attentional functioning or changes is difficult for individuals to be aware of, thus plays a
limited role in the adoption of compensatory driving strategies. This study found that self-awareness of declines in everyday driving performance was a significant determinant that led to changes in driving behaviors among older drivers. In general, therefore, it seems that more concrete and direct knowledge regarding the driving competency is necessary for older drivers to adopt compensatory driving behaviors. This finding further highlights the importance of identifying the unique connections between attentional deficits and crash risks. Information on precise impacts of the attentional function, in which an individual driver may suffer deficits, is essential to provide more effective communications for safe driving practices. For instance, if a driver has severe age-related declines in the executive attention, the driver can benefit the most from avoiding or being more cautious in making an unprotected left turn or merging, while this driver might not need to avoid or take extra caution when backing up or at a roundabout, or to reduce driving hours.

**Contributions**

From a practical perspective, the ultimate goal of this line of research on impacts of cognitive aging on driving safety is to reduce older drivers’ critical driving errors and crash risks. Given universally observed age-related declines in various cognitive functions, increased crash risks with aging may be inevitable among many older drivers. Therefore, developing effective countermeasures is vital to maintaining road safety for older drivers as well as drivers and pedestrians of other ages as well. The present study confirms previous findings and contributes additional evidence on that attentional deficit is one of the critical factors that elevate crash risks. More intriguing finding from this study, while still preliminary, suggest that the alerting, orienting, and executive attentional functions have
unique impacts in certain traffic situations. These findings provide an essential ground for developing more effective countermeasures for increased crash risks among older drivers. For instance, the findings provide early steps to establish a basis for personalized cognitive training methods such as an attentional or driving training tool that is tailored according to an older driver’s need to improve driving competency in particular traffic situations. In addition, the knowledge from the present findings may also benefit individual older drivers in terms of the development of compensatory strategies during driving. Each driver may use the knowledge about the unique associations between particular attentional deficits and distinct types of crash risks as a guide to avoid particular driving situations or to adopt relevant compensatory driving strategies.

This research also provides a contribution to improving our understanding of the attentional networks model. The present research attempted to apply the neurocognitive model of human attention to daily driving. The findings further support the model and previous research that conceptualizes attention as a set of disparate control networks (Posner & Petersen, 1990; Raz & Buhle, 2006), which challenged the traditional views of attention as a uniform construct. While the present finding provides additional empirical evidence for functional independence of neural networks controlling distinct aspects of attentional functions, it also suggests that not all three attentional functions have uniform impacts on an everyday task such as driving.

**Limitation**

The most significant limitation lies in the limited availability of the crash data due to the low crash rate in both using self-reports (Study 1) and the simulated driving (Study 2).
Based on the exploratory findings from the first study, the taxonomy was developed to illustrate the sets of certain hazardous traffic situations in which drivers with deficits in the alerting, orienting, or executive attentional functions would be at higher risks. The second study examined the proposed associations in a simulated driving task where hazardous events were designed to trigger crashes. The limited numbers of crash occurrences, however, only allowed examinations of driving hazards in an aggregated form. Because it was not possible to examine individual hazardous events separately, it is left unknown to what extent each situation is associated with attentional efficiency. Therefore, the current taxonomy is not yet conclusive and needs further validation.

Another source of weakness in this research which could have limited the findings and generalizability were the simulated driving methods used in Study 2. Being limited to the capability of the driving simulator, the experiment was not able to include certain traffic situations such as back-up, U-turn, channelized right turn lanes, and roundabout, which may be the types of driving that are most dangerous for drivers with attentional deteriorations. In addition, it is unfortunate that the two hazardous events of making unprotected left-turn were excluded in the analysis in Study 2 because the current driving simulator used a one-screen setting which could not sufficiently present hazards occurring peripheral area while making a left-turn. Thus, the association between this particular type of hazardous events and the executive function could not be further examined in Study 2, while crash risks during this particular type of driving situations were found to be significantly linked to the executive efficiency in Study 1.
Thirdly, the scope of the investigation regarding compensatory driving behaviors was limited by the absence of objective measures and the lack of detailed information. For instance, the participants self-reported if they have changed driving habits and strategies. However, the study did not examine whether they actually use the compensatory driving in a consistent and effective manner in daily driving. Furthermore, the present study evaluated the use of compensatory driving behaviors in a rather general form. However, the list of compensatory behaviors provided to the participants was not exhaustive, and a precise role of each compensatory strategy on driving safety was not examined. The analyses assumed that the compensatory behaviors included in the list are unidirectional, and the impact of each behavior on driving safety is equivalent. As discussed earlier, however, certain compensatory behaviors may not always be beneficial, and the relations between certain compensatory driving behaviors and driving safety may be more complex than our general belief. For instance, if an older driver tries to completely avoid certain traffic environments such as high-speed roads or freeways, it may reduce risks of involvement in speed-related crashes, but may increase total driving length, which possibly leads to increased risks in other types of crashes. Thus, further information on individual compensatory behaviors was necessary to examine their roles in safe driving among older drivers.

Lastly, while the primary focus was on the older driver population, the present research did not directly compare among experienced drivers of various ages. In the present research, participants were mostly mid- to old-aged drivers (Study 1) or older drivers (Study 2), and age-related differences in attentional functions as well as in crash risks were not examined. In addition to cognitive declines, there are other contributing factors that could
potentially be confounding such as driving experience or driving patterns which may impact the likelihood of involving particular types of crash.

**Direction for Future Research**

The taxonomy being proposed in the present research, while providing useful insights for the associations between the distinct attentional functions and crash risks, is still preliminary and needs further validation. Considerably more work will need to be done to establish complete and more conclusive connections between various attentional functions and driving safety in particular driving situations. Large-scale controlled experiments could provide more definitive evidence for the currently classified associations. Also, further efforts need to be made to identify additional hazardous driving situations that are potentially associated with the alerting, orienting, and executive attention. In particular, more research is needed on the precise impacts of alerting and orienting deficits function on driving safety of older drivers.

Given the limitations of the self-reported and simulated driving measures, various methodologies can be carried out to validate the associations in future research. For instance, the Drive Aware Task (Feng et al., 2015; Feng et al., in preparation) is a computer-based task that aims to measure a driver’s hazard detection in the context of driving, which allows controlling various parameters such as complexity of road environment and location of the hazardous source. This type of controlled methods can be useful to examine the precise associations and mechanisms between attentional functions and specific traffic situations. In addition, because a computerized task could provide repeated measures of each single
condition more easily compared to a simulated driving, it may allow further validation of each association as proposed by the taxonomy.

The next step of this line of research, after the taxonomy is further validated, will be to implement the research into the development of countermeasures for attention-related crash risks among older drivers. For instance, the taxonomy can be used to develop personalized training tools or recommendations for individual older drivers to help them to deal successfully with age-related changes and maintain their mobility.

Finally, further studies regarding the nature and extent of compensatory driving behaviors would be worthwhile. The present findings raise several intriguing questions. For example, the relations between compensatory behaviors and driving safety were observed to be complex or even bi-directional. The study also found that there seem to be gaps between intention and adoption of compensatory driving. During the interviews, older drivers also suggested there are other important factors related to decisions of seeking compensatory driving resolutions, including accessibility and life changes. More research on this issue will provide important practical implications for our understanding of how we can promote the effective use of compensatory driving behaviors among older drivers.

**Conclusion**

Attention is critical for safe driving. When older drivers suffer from severe age-related declines in attentional functions, they may face higher crash risks. With a particular interest in the older driver population, the present research investigated the potential impacts that different aspects of attentional functions – alerting, orienting, and executive attention
would have on elevated crash risks in various traffic situations. Using self-reports and simulated driving measures, the two-phased study suggested that distinct associations exist between individual attentional functions and increased risks in different types of hazardous driving situations. The most prominent finding to emerge from this study is that the executive attention is a critical factor that is linked to safety in many driving situations, particularly those the hazardous situations that demand the ability to resolve conflicts among ongoing external or internal processing, or potential hazards occurring at spatially separated locations. Despite that less clear associations were observed between the alerting or orienting functions and crash risks, an interesting finding was that the general speed of attentional processing was associated with various hazardous situations. An implication of the current study is the possibility that unique impacts of each of distinct attentional functions on a driver’s crash risks can be identified, which will serve as a basis for the development of more effective countermeasures for older drivers. This study has also shown older drivers’ inaccurate self-awareness regarding one’s own cognitive functions as well as ineffective use of compensatory driving strategies. This finding further emphasized the importance of providing effective measures and countermeasures to older drivers to promote safe driving practices.
Table 1
Study 1 and 2 - Participant demographics and self-reported driving measures. For study 2, information is separately presented for all vs. simulator completed only samples.

<table>
<thead>
<tr>
<th></th>
<th>Study 1 (n= 267)</th>
<th>Study 2 (n= 82)</th>
<th>Simulator completed (n= 60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age range</td>
<td>23 – 87</td>
<td>65 – 92</td>
<td>65 - 87</td>
</tr>
<tr>
<td>Age (Mean</td>
<td>SD)</td>
<td>59.40 (10.79)</td>
<td>73.16 (5.20)</td>
</tr>
<tr>
<td>Gender: Male</td>
<td>Female</td>
<td>129</td>
<td>138</td>
</tr>
<tr>
<td>Years licensed</td>
<td>40.04 (11.11)</td>
<td>56. 22 (5.58)</td>
<td>56.55 (5.30)</td>
</tr>
<tr>
<td>Driving per week (days)</td>
<td>5.34 (1.73)</td>
<td>6.15 (1.27)</td>
<td>6.22 (1.22)</td>
</tr>
<tr>
<td>Miles driven last year</td>
<td>Approx. 5,000^1</td>
<td>9461.83 (5617.62)</td>
<td>10066.24 (5084.94)</td>
</tr>
<tr>
<td># of Tickets/Citations^2</td>
<td>.58 (1.34)</td>
<td>.13 (.38)</td>
<td>.13 (.34)</td>
</tr>
<tr>
<td># of Warnings^3</td>
<td>.45 (.91)</td>
<td>.20 (.53)</td>
<td>.22 (.56)</td>
</tr>
<tr>
<td># of Crashes^3</td>
<td>.85 (.84)</td>
<td>.34 (.61)</td>
<td>.32 (.60)</td>
</tr>
<tr>
<td># of Near-crashes^4</td>
<td>.59 (.90)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

1 Miles driven last year was reported on categorical scale: M = 2.07, SD = 1.34 on a scale of 0- under 1000, 1- between 1000 and 5000, 2- between 5000 and 10000, 3- between 10000 and 15000, 4- between 15000 and 20000, and 5- over 20,000.

2 Number of occurrences in the past five years

3 Number of occurrence in the past three years in study 1 or five years in study 2

4 Number of occurrences in the past six months; responses only collected in study 1

Table 2
Study 1 and 2 - ANT performance. Mean (SD): Alerting, orienting, and executive attentional network scores were computed using both (b) reaction and (c) error rate.

<table>
<thead>
<tr>
<th></th>
<th>Study 1 (n= 267)</th>
<th>Study 2 (n= 82)</th>
<th>Simulator completed (n= 60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Overall results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT (ms)</td>
<td>673 (100)</td>
<td>655.82 (87.21)</td>
<td>649.24 (86.67)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>.94 (.13)</td>
<td>.98 (.03)</td>
<td>.98 (.04)</td>
</tr>
<tr>
<td>(b) Attentional indices (RT based)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alerting</td>
<td>27.02 (52.65)</td>
<td>29.93 (33.63)</td>
<td>28.90 (33.81)</td>
</tr>
<tr>
<td>Orienting</td>
<td>34.07 (40.78)</td>
<td>10.92 (15.65)</td>
<td>12.04 (14.63)</td>
</tr>
<tr>
<td>Executive</td>
<td>110.59 (48.67)</td>
<td>122.79 (54.84)</td>
<td>124.54 (57.66)</td>
</tr>
<tr>
<td>(c) Attentional indices (Error-rate based)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alerting</td>
<td>.08 (4.86)</td>
<td>-.004 (.03)</td>
<td>-.004 (.03)</td>
</tr>
<tr>
<td>Orienting</td>
<td>1.05 (4.77)</td>
<td>.01 (.02)</td>
<td>.004 (.02)</td>
</tr>
<tr>
<td>Executive</td>
<td>4.60 (11.35)</td>
<td>.03 (.09)</td>
<td>.04 (.10)</td>
</tr>
</tbody>
</table>
Table 3
Study 1 - Correlations between ANT and prior violations and crashes.

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>RT</th>
<th>Alert</th>
<th>Orient</th>
<th>Exec</th>
<th>Warning</th>
<th>Ticket</th>
<th>Near-Crash</th>
<th>Crash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td></td>
<td>-.25*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alerting</td>
<td>.20*</td>
<td>.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orienting</td>
<td>-.17*</td>
<td>-.28*</td>
<td>-.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Executive</td>
<td>-.44*</td>
<td>-.11</td>
<td>-.06</td>
<td>.18*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warning</td>
<td>-.10</td>
<td>-.16*</td>
<td>.04</td>
<td>.04</td>
<td>.15*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ticket</td>
<td>-.20*</td>
<td>-.15*</td>
<td>.02</td>
<td>.02</td>
<td>.12</td>
<td>.57*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near-rash</td>
<td>.03</td>
<td>.01</td>
<td>-.17*</td>
<td>.06</td>
<td>-.01</td>
<td>.17*</td>
<td>.19*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crash</td>
<td>-.15*</td>
<td>-.07</td>
<td>.03</td>
<td>.09</td>
<td>.15*</td>
<td>.59*</td>
<td>.39*</td>
<td>-.07</td>
<td>-</td>
</tr>
</tbody>
</table>

*significant correlation at \( p < .05 \)

Table 4
Study 1 - Correlations between ANT and the self-reported questionnaires. A summary of significant correlations between the three ANT indices and the AFDQ, DBQ, and ASDES is presented. Note that the positive correlation coefficient in the alerting and orienting indices indicates negative association (i.e., lower efficiency index, less frequent driving error or higher efficacy), whereas in the executive index it indicates a positive association (i.e., lower efficiency index, more frequent driving errors or lower efficacy)

<table>
<thead>
<tr>
<th></th>
<th>Alerting</th>
<th>Orienting</th>
<th>Executive</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBQ</td>
<td>-.11*</td>
<td>.12*</td>
<td>.14*</td>
</tr>
<tr>
<td>Errors</td>
<td>-.12*</td>
<td></td>
<td>.16*</td>
</tr>
</tbody>
</table>

Fail to notice pedestrians crossing when turning onto a side street. -.13* .18*

When making a turn, you almost hit a cyclist or pedestrian who has come up on your right side. -.14*

Fail to ‘Stop’ or ‘Yield’ at a sign, almost hitting a car that has the right of way. .13*

When preparing to turn from a side road onto a main road, you pay too much attention to the traffic on the main road so that you nearly hit the car in front of you. .21*

Underestimate the speed of an oncoming vehicle when passing. .20*

Brake too quickly on a slippery road, or turn your steering wheel in the wrong direction while skidding. .12*
<table>
<thead>
<tr>
<th>Lapses</th>
<th>Alerting</th>
<th>Orienting</th>
<th>Executive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Misread signs and miss your exit.</td>
<td>-.14*</td>
<td>.14*</td>
<td>.17*</td>
</tr>
<tr>
<td>Forget that your lights are on high beam until another driver flashes</td>
<td>-.16*</td>
<td>.14*</td>
<td>.15*</td>
</tr>
<tr>
<td>his headlights at you.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>You intend to drive to destination A, but you ‘wake up’ to find you</td>
<td>.16*</td>
<td>.16*</td>
<td></td>
</tr>
<tr>
<td>yourself on the road to destination B, perhaps because B is your</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>more usual destination.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Realize that you cannot clearly remember the road you were just</td>
<td>.17*</td>
<td>.17*</td>
<td></td>
</tr>
<tr>
<td>driving on.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AFDQ</strong></td>
<td>-.12*</td>
<td>.13*</td>
<td>.14*</td>
</tr>
<tr>
<td>When entering a roundabout or intersection, you fail to notice</td>
<td>-.22*</td>
<td>.17*</td>
<td></td>
</tr>
<tr>
<td>vehicles that are not straight ahead.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>You are looking for a specific point at the road, and you fail to</td>
<td>-.14*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>promptly notice that the car in front of you brakes.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>You continue to follow the traffic, without noticing that the light</td>
<td>.15*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>at an intersection has turned red.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>When you are talking on a phone, you fail to promptly notice that</td>
<td>.26*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>there is a vehicle or pedestrian in your way.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>When checking the rear-view or side mirrors, you fail to promptly</td>
<td>.14*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>notice that the car in front of you brakes.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before switching lanes, you are so focused on the traffic in the lane</td>
<td>.16*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>that you wish to join and you fail to notice promptly that the vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in front of you brakes.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During a right turn, you fail to notice a cyclist or pedestrian who</td>
<td>.14*</td>
<td>.16*</td>
<td></td>
</tr>
<tr>
<td>is entering the crosswalk from the right side, and you almost hit the</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>person.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roadside advertisements capture your attention while driving that</td>
<td>.14*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>you fail to promptly notice that the vehicle in front of you is slowi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>down.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ADSES</strong></td>
<td>-.15*</td>
<td>-.14*</td>
<td>-.13*</td>
</tr>
<tr>
<td>Driving in your local area</td>
<td>-.15*</td>
<td>-.14*</td>
<td>-.13*</td>
</tr>
<tr>
<td>Driving in heavy traffic</td>
<td>-.15*</td>
<td>-.14*</td>
<td>-.13*</td>
</tr>
<tr>
<td>Driving with people in the car</td>
<td>-.15*</td>
<td>-.14*</td>
<td>-.13*</td>
</tr>
<tr>
<td>Responding to road signs/traffic signals</td>
<td>-.17*</td>
<td>-.20*</td>
<td>-.12*</td>
</tr>
<tr>
<td>Overtaking on a two-lane road (with possible oncoming traffic)</td>
<td>-.13*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attempting to merge with traffic</td>
<td>-.15*</td>
<td>-.20*</td>
<td>-.12*</td>
</tr>
<tr>
<td>Planning travel to a new destination</td>
<td>-.13*</td>
<td>-.20*</td>
<td>-.12*</td>
</tr>
</tbody>
</table>

*significant correlation at \( p < .05 \)

*significant correlation at \( p = .06 \)
Table 5
Study 1 - Comparisons of ANT performance by the crash types. Mean (SD). Crash type descriptions: A) a left turn at a stop-sign intersection; B) a left turn at a signal intersection; C) a right turn to merge with traffic; D) a merge at a yield sign onto a highway; E) a lane change on a multilane roadway.

<table>
<thead>
<tr>
<th>Crash-involved Groups</th>
<th>Crash Type A</th>
<th>General (no A)</th>
<th>Crash Type B</th>
<th>General (no B)</th>
<th>Crash Type C</th>
<th>General (no C)</th>
<th>Crash Type D</th>
<th>General (no D)</th>
<th>Crash Type E</th>
<th>General (no E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
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<td>163</td>
<td>11</td>
<td>167</td>
<td>10</td>
<td>168</td>
<td>12</td>
<td>166</td>
<td>19</td>
<td>159</td>
</tr>
<tr>
<td>Age</td>
<td>63.47</td>
<td>59.81</td>
<td>63.45</td>
<td>59.90</td>
<td>56.20</td>
<td>60.35</td>
<td>61.67</td>
<td>60.01</td>
<td>62.31</td>
<td>59.86</td>
</tr>
<tr>
<td>Sex M</td>
<td>F</td>
<td>9</td>
<td>6</td>
<td>81</td>
<td>82</td>
<td>6</td>
<td>5</td>
<td>84</td>
<td>83</td>
<td>7</td>
</tr>
<tr>
<td>ANT index</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Acc</td>
<td>82.47</td>
<td>94.90</td>
<td>82.26</td>
<td>94.62</td>
<td>80.16</td>
<td>94.67</td>
<td>84.95</td>
<td>94.50</td>
<td>84.59</td>
<td>94.96</td>
</tr>
<tr>
<td>(b) RT</td>
<td>622.27</td>
<td>678.73</td>
<td>678.45</td>
<td>673.68</td>
<td>561.00</td>
<td>680.70</td>
<td>636.33</td>
<td>676.69</td>
<td>646.26</td>
<td>677.28</td>
</tr>
<tr>
<td></td>
<td>(83.97)</td>
<td>(105.92)</td>
<td>(105.58)</td>
<td>(105.52)</td>
<td>(182.64)</td>
<td>(95.54)</td>
<td>(99.47)</td>
<td>(105.40)</td>
<td>(13.58)</td>
<td>(101.78)</td>
</tr>
<tr>
<td>(c) Alert</td>
<td>.42</td>
<td>.54</td>
<td>-.57</td>
<td>.60</td>
<td>4.38</td>
<td>.30</td>
<td>-.52</td>
<td>.60</td>
<td>-.49</td>
<td>.65</td>
</tr>
<tr>
<td></td>
<td>(7.91)</td>
<td>(4.19)</td>
<td>(8.71)</td>
<td>(4.21)</td>
<td>(7.68)</td>
<td>(4.26)</td>
<td>(7.87)</td>
<td>(4.28)</td>
<td>(4.69)</td>
<td>(4.57)</td>
</tr>
<tr>
<td>(d) Orient</td>
<td>3.42</td>
<td>.91</td>
<td>3.13</td>
<td>.99</td>
<td>5.27</td>
<td>.87</td>
<td>2.87</td>
<td>.99</td>
<td>4.04</td>
<td>.77</td>
</tr>
<tr>
<td></td>
<td>(8.54)</td>
<td>(4.23)</td>
<td>(5.69)</td>
<td>(4.68)</td>
<td>(8.37)</td>
<td>(4.37)</td>
<td>(6.48)</td>
<td>(4.61)</td>
<td>(7.04)</td>
<td>(4.31)</td>
</tr>
<tr>
<td>(e) Exec</td>
<td>12.76</td>
<td>4.02</td>
<td>2.61</td>
<td>4.90</td>
<td>7.09</td>
<td>4.62</td>
<td>6.89</td>
<td>4.61</td>
<td>12.64</td>
<td>3.82</td>
</tr>
<tr>
<td></td>
<td>(17.65)</td>
<td>(11.76)</td>
<td>(7.13)</td>
<td>(12.81)</td>
<td>(13.60)</td>
<td>(12.50)</td>
<td>(5.95)</td>
<td>(12.88)</td>
<td>(22.40)</td>
<td>(10.51)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crash-absent Reference Groups</th>
<th>Near-crash only</th>
<th>No crash risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>51</td>
<td>38</td>
</tr>
<tr>
<td>Age</td>
<td>59.04</td>
<td>56.55</td>
</tr>
<tr>
<td>Sex M</td>
<td>F</td>
<td>20</td>
</tr>
<tr>
<td>ANT index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Acc</td>
<td>98.10 (8.40)</td>
<td>89.92 (18.50)</td>
</tr>
<tr>
<td>(b) RT</td>
<td>670.31 (78.07)</td>
<td>668.61 (100.51)</td>
</tr>
<tr>
<td>(c) Alert</td>
<td>-1.16 (4.33)</td>
<td>-.33 (6.36)</td>
</tr>
<tr>
<td>(d) Orient</td>
<td>.81 (3.87)</td>
<td>1.06 (5.91)</td>
</tr>
<tr>
<td>(e) Exec</td>
<td>3.64 (7.61)</td>
<td>5.13 (9.72)</td>
</tr>
</tbody>
</table>

110
Table 6
Study 1 - Comparisons of ANT performance by the performance errors. Mean (SD).

<table>
<thead>
<tr>
<th>Crash occurred due to a performance error in:</th>
<th>(1) Visual detection</th>
<th>(2) Gap judgment</th>
<th>(3) Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash-involved</td>
<td>Crash-absent</td>
<td>T</td>
<td>Crash-involved</td>
</tr>
<tr>
<td>Alert</td>
<td>1.80(5.19)</td>
<td>-.16(4.77)</td>
<td>-2.19*</td>
</tr>
<tr>
<td>Orient</td>
<td>3.52(5.10)</td>
<td>.70(4.63)</td>
<td>-3.23*</td>
</tr>
<tr>
<td>Exec</td>
<td>7.08(18.07)</td>
<td>4.25(10.06)</td>
<td>-.88</td>
</tr>
<tr>
<td>(4) Response speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crash-involved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alert</td>
<td>-.78(7.58)</td>
<td>.15(4.59)</td>
<td>.54</td>
</tr>
<tr>
<td>Orient</td>
<td>3.91(9.22)</td>
<td>.82(4.16)</td>
<td>-1.49</td>
</tr>
<tr>
<td>Exec</td>
<td>10.23(16.61)</td>
<td>4.14(10.73)</td>
<td>-1.61</td>
</tr>
<tr>
<td>(7) Traffic rules</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crash-involved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alert</td>
<td>-.52(15.77)</td>
<td>.14(4.68)</td>
<td>.63</td>
</tr>
<tr>
<td>Orient</td>
<td>1.94(5.02)</td>
<td>1.04(4.78)</td>
<td>-.32</td>
</tr>
<tr>
<td>Exec</td>
<td>6.08(11.23)</td>
<td>4.58(11.37)</td>
<td>-.23</td>
</tr>
</tbody>
</table>

* significant difference between the crash-involved vs. the crash-absent group at p < .05
Table 7
Study 1 - Associations between ANT performance and crash characteristic. Comparisons between the crash-involved vs. the crash-absent group for each crash characteristic in the ANT indices, Mean (SD). The t-tests were conducted only when 2+ samples were available in the crash-involved group. The significant and approaching significant group differences were indicated in bold. Each contributing driver circumstance combined relevant factors: 1) Disregarded traffic signs - Disregarded yield sign, Disregarded stop sign, Disregarded other traffic signs, Disregarded road markings; 2) Speed-related error - Exceeded authorized speed limit, Exceeded safe speed for conditions, Failure to reduce speed; 3) Improper turn - Improper turn, Right turn on red; 4) Lane-related error - Crossed centerline/going wrong way, Improper lane change, Use of improper lane, Overcorrected/Oversteered; 5) Improper passing - Passed on hill, Passed on curve, Other improper passing; 6) Improper maneuvers during yield, backing, or parking - Failed to yield right of way, Improper backing, Improper parking; 7) Attentional failure - Inattention, Driver distracted (talking, eating, etc.), Absorbed in mind wandering; 8) Careless, negligent, or aggressive behaviors - Improper or no signal, Followed too closely, Operated vehicle in erratic, reckless, careless, negligent or aggressive manner; and 9) Other external or internal conditions - Swerved or avoided due to wind, slippery surface, vehicle, object, or non-motorist, Visibility obstructed, Alcohol/Drug use, Physical impairment due to illness/medical condition, Fatigue, and Fall asleep, fainted, or loss of consciousness.

<table>
<thead>
<tr>
<th>(a) Locality</th>
<th>Alerting</th>
<th>Orienting</th>
<th>Executive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crash</td>
<td>Crash</td>
<td>Crash</td>
</tr>
<tr>
<td></td>
<td>involved</td>
<td>absent</td>
<td>involved</td>
</tr>
<tr>
<td></td>
<td>n(crash)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural</td>
<td>36</td>
<td>.26(6.00)</td>
<td>.05(4.67)</td>
</tr>
<tr>
<td>Mixed</td>
<td>69</td>
<td>-.14(5.32)</td>
<td>.16(4.70)</td>
</tr>
<tr>
<td>Urban</td>
<td>87</td>
<td>.50(4.39)</td>
<td>-.12(5.07)</td>
</tr>
<tr>
<td>(b) Site</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farms, wood, pastures</td>
<td>19</td>
<td>.82(6.82)</td>
<td>.03(4.69)</td>
</tr>
<tr>
<td>Residential</td>
<td>72</td>
<td>.83(5.06)</td>
<td>-.19(4.77)</td>
</tr>
<tr>
<td>Commercial</td>
<td>89</td>
<td>.14(4.26)</td>
<td>.05(5.14)</td>
</tr>
<tr>
<td>Institutional</td>
<td>3</td>
<td>3.12(3.13)</td>
<td>.05(4.87)</td>
</tr>
<tr>
<td>Industrial</td>
<td>7</td>
<td>-3.13(9.02)</td>
<td>.17(4.70)</td>
</tr>
</tbody>
</table>
Table 7 (Continued)

<table>
<thead>
<tr>
<th>Traffic control</th>
<th>Alerting</th>
<th></th>
<th></th>
<th>Orienting</th>
<th></th>
<th></th>
<th>Executive</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n(crash)</td>
<td>Crash</td>
<td>Crash</td>
<td>t</td>
<td>Crash</td>
<td>Crash</td>
<td>t</td>
<td>Crash</td>
<td>Crash</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>absent</td>
<td></td>
<td>involved</td>
<td>absent</td>
<td></td>
<td>involved</td>
<td>absent</td>
</tr>
<tr>
<td>(c) Traffic control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stop</td>
<td>34</td>
<td>1.83(6.26)</td>
<td>-17(4.58)</td>
<td>-1.81*</td>
<td>1.07(6.00)</td>
<td>1.05(4.58)</td>
<td>-.02</td>
<td>5.24(10.97)</td>
<td>4.24(10.97)</td>
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<tr>
<td>Yield</td>
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<td>1.34(4.01)</td>
<td>.01(4.90)</td>
<td>-.10</td>
<td>2.59(6.03)</td>
<td>.97(4.69)</td>
<td>-1.24</td>
<td>9.83(17.48)</td>
<td>4.31(10.89)</td>
</tr>
<tr>
<td>Stop and go</td>
<td>33</td>
<td>.85(3.93)</td>
<td>-.03(4.97)</td>
<td>-1.16</td>
<td>.72(3.64)</td>
<td>1.01(4.91)</td>
<td>.43</td>
<td>6.70(19.18)</td>
<td>4.30(9.79)</td>
</tr>
<tr>
<td>Flashing</td>
<td>9</td>
<td>-3.47(7.88)</td>
<td>.21(4.69)</td>
<td>2.25*</td>
<td>10.32(8.70)</td>
<td>.73(4.25)</td>
<td>-3.29*</td>
<td>14.72(21.95)</td>
<td>4.25(10.71)</td>
</tr>
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<td>-</td>
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<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>Human control</td>
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<td>-8.13(9.72)</td>
<td>.24(4.63)</td>
<td>2.01</td>
<td>7.14(9.49)</td>
<td>.93(4.59)</td>
<td>-1.46</td>
<td>9.27(18.36)</td>
<td>4.51(11.21)</td>
</tr>
<tr>
<td>Warning</td>
<td>4</td>
<td>-3.91(12.07)</td>
<td>.14(4.70)</td>
<td>.67</td>
<td>3.91(4.69)</td>
<td>1.01(4.77)</td>
<td>-1.21</td>
<td>4.98(8.58)</td>
<td>4.59(11.40)</td>
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<tr>
<td>School zone</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Double yellow or no passing</td>
<td>3</td>
<td>.00(3.13)</td>
<td>.0(4.88)</td>
<td>.05</td>
<td>-.15(3.35)</td>
<td>1.06(4.79)</td>
<td>.44</td>
<td>.10(3.23)</td>
<td>4.65(11.40)</td>
</tr>
<tr>
<td>(d) Preceding Movement</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Stopped</td>
<td>47</td>
<td>1.20(4.63)</td>
<td>-16(4.88)</td>
<td>-1.74*</td>
<td>1.36(5.14)</td>
<td>.98(4.70)</td>
<td>-.49</td>
<td>5.41(14.77)</td>
<td>4.43(10.51)</td>
</tr>
<tr>
<td>Going straight ahead</td>
<td>77</td>
<td>-.41(4.16)</td>
<td>.28(5.11)</td>
<td>1.05</td>
<td>1.58(4.74)</td>
<td>.84(4.78)</td>
<td>-1.15</td>
<td>4.89(15.06)</td>
<td>4.48(9.49)</td>
</tr>
<tr>
<td>Ran off road</td>
<td>11</td>
<td>2.27(5.78)</td>
<td>-.01(4.81)</td>
<td>-1.53</td>
<td>3.49(5.96)</td>
<td>.95(4.70)</td>
<td>-1.74</td>
<td>12.98(21.72)</td>
<td>4.24(10.62)</td>
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<tr>
<td>Right turn</td>
<td>15</td>
<td>2.08(6.75)</td>
<td>-.04(4.71)</td>
<td>-1.12</td>
<td>3.63(7.07)</td>
<td>.90(4.57)</td>
<td>-1.48</td>
<td>5.75(11.06)</td>
<td>4.53(11.39)</td>
</tr>
<tr>
<td>Left turn</td>
<td>19</td>
<td>1.48(4.22)</td>
<td>-.03(4.90)</td>
<td>-1.30</td>
<td>1.25(5.31)</td>
<td>1.04(4.74)</td>
<td>-.19</td>
<td>4.63(8.92)</td>
<td>4.60(11.53)</td>
</tr>
<tr>
<td>U-turn</td>
<td>2</td>
<td>3.13(4.42)</td>
<td>.06(4.86)</td>
<td>-.89</td>
<td>3.80(1.58)</td>
<td>1.03(4.78)</td>
<td>-.82</td>
<td>13.22(15.25)</td>
<td>4.49(11.28)</td>
</tr>
<tr>
<td>Backing</td>
<td>23</td>
<td>.00(1.89)</td>
<td>.09(5.05)</td>
<td>.18</td>
<td>-66(3.72)</td>
<td>1.21(4.83)</td>
<td>1.80*</td>
<td>3.60(13.99)</td>
<td>4.69(11.10)</td>
</tr>
<tr>
<td>Slow/stopping</td>
<td>15</td>
<td>.00(7.09)</td>
<td>.09(4.71)</td>
<td>.07</td>
<td>2.11(6.13)</td>
<td>.99(4.69)</td>
<td>-.89</td>
<td>5.20(8.70)</td>
<td>4.56(11.50)</td>
</tr>
<tr>
<td>Passing</td>
<td>5</td>
<td>.00(4.94)</td>
<td>.08(4.87)</td>
<td>.59</td>
<td>9.11(9.06)</td>
<td>.90(4.55)</td>
<td>-2.02</td>
<td>9.02(9.52)</td>
<td>4.51(11.38)</td>
</tr>
</tbody>
</table>
Table 7 (Continued)

<table>
<thead>
<tr>
<th>(d) Preceding Movement</th>
<th>Alerting</th>
<th></th>
<th>Orienting</th>
<th></th>
<th>Executive</th>
</tr>
</thead>
<tbody>
<tr>
<td>n(crash)</td>
<td>Crash involved</td>
<td>Crash absent</td>
<td>t</td>
<td>Crash involved</td>
<td>Crash absent</td>
</tr>
<tr>
<td>Changing lanes</td>
<td>12</td>
<td>-2.61(.21)</td>
<td>.21(4.84)</td>
<td>1.97*</td>
<td>2.91(7.15)</td>
</tr>
<tr>
<td>Parking</td>
<td>5</td>
<td>1.25(2.80)</td>
<td>.06(4.89)</td>
<td>-.54</td>
<td>1.25(1.71)</td>
</tr>
<tr>
<td>Entering traffic</td>
<td>8</td>
<td>2.34(5.73)</td>
<td>.01(4.83)</td>
<td>-1.34</td>
<td>5.14(7.93)</td>
</tr>
<tr>
<td>Other unsafe turning</td>
<td>2</td>
<td>-9.38(17.68)</td>
<td>.15(4.68)</td>
<td>.76</td>
<td>-.90(10.10)</td>
</tr>
<tr>
<td>Crossing into opposing lane</td>
<td>2</td>
<td>3.15(.01)</td>
<td>.06(4.87)</td>
<td>-.89</td>
<td>-4.02(5.69)</td>
</tr>
<tr>
<td>Merging</td>
<td>9</td>
<td>.35(2.90)</td>
<td>.07(4.92)</td>
<td>-.17</td>
<td>2.04(6.60)</td>
</tr>
<tr>
<td>Traveling wrong way</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(e) Contributing driver circumstance</th>
<th>Alerting</th>
<th></th>
<th>Orienting</th>
<th></th>
<th>Executive</th>
</tr>
</thead>
<tbody>
<tr>
<td>n(crash)</td>
<td>Crash involved</td>
<td>Crash absent</td>
<td>t</td>
<td>Crash involved</td>
<td>Crash absent</td>
</tr>
<tr>
<td>Disregarded signs</td>
<td>18</td>
<td>2.08(4.01)</td>
<td>-06(.489)</td>
<td>-1.82*</td>
<td>1.49(6.25)</td>
</tr>
<tr>
<td>Speed-related error</td>
<td>34</td>
<td>.55(6.95)</td>
<td>.01(4.49)</td>
<td>-.44</td>
<td>3.49(7.04)</td>
</tr>
<tr>
<td>Improper turn</td>
<td>8</td>
<td>-.39(3.10)</td>
<td>.10(4.91)</td>
<td>.28</td>
<td>1.34(7.16)</td>
</tr>
<tr>
<td>Lane-related error</td>
<td>13</td>
<td>.72(5.13)</td>
<td>.05(4.85)</td>
<td>-.49</td>
<td>.10(8.47)</td>
</tr>
<tr>
<td>Improper passing</td>
<td>7</td>
<td>6.70(8.35)</td>
<td>-10(4.63)</td>
<td>-2.14*</td>
<td>1.98(3.59)</td>
</tr>
<tr>
<td>Improper maneuver</td>
<td>13</td>
<td>-.24(3.24)</td>
<td>.10(4.93)</td>
<td>.25</td>
<td>1.39(5.14)</td>
</tr>
<tr>
<td>Attentional failure</td>
<td>37</td>
<td>2.20(4.71)</td>
<td>-26(4.81)</td>
<td>-2.89*</td>
<td>1.25(3.22)</td>
</tr>
<tr>
<td>Careless, negligent, or aggressive</td>
<td>11</td>
<td>.57(3.37)</td>
<td>.06(4.92)</td>
<td>-.34</td>
<td>.17(4.14)</td>
</tr>
<tr>
<td>Other external or internal conditions</td>
<td>29</td>
<td>.00(4.09)</td>
<td>.09(4.95)</td>
<td>.10</td>
<td>1.45(4.62)</td>
</tr>
</tbody>
</table>

* significant difference between the crash-involved vs. the crash-absent group at p < .05

a approaching significant .05 ≤ p < .08
Table 8
Study 1 - A summary of the observed association between ANT indices and driving errors and crashes.

<table>
<thead>
<tr>
<th>Questionnaire</th>
<th>Higher efficiency was associated with increased driving errors or crashes related to:</th>
<th>Lower efficiency was associated with increased driving errors or crashes related to:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alerting</strong></td>
<td>• Right turn to merge with traffic or passing</td>
<td>• Failures to visually detect potential hazards, particularly moving objects (e.g., pedestrian or vehicles) while making a turn or entering or exiting traffic</td>
</tr>
<tr>
<td></td>
<td>• Failures to detect potential conflicts, hazards, or traffic control information, or to respond to signs or changes</td>
<td>• Being distracted and forgetful of completing a task</td>
</tr>
<tr>
<td></td>
<td>• Inattention, being distracted, mind-wandering</td>
<td>• Flashing signal</td>
</tr>
<tr>
<td></td>
<td>• Flashing signal</td>
<td>• Lane change</td>
</tr>
<tr>
<td><strong>Orienting</strong></td>
<td>• Mind-wandering</td>
<td>• Highly developed or visually cluttered road environment</td>
</tr>
<tr>
<td></td>
<td>• Failures to perceive potential hazards or relevant traffic information in visual periphery</td>
<td>• Back-up</td>
</tr>
<tr>
<td></td>
<td>• Merging or switching a lane</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Failures to visually detect relevant information</td>
<td>• Failures in assigning attention to important traffic information or selecting the appropriate action</td>
</tr>
<tr>
<td></td>
<td>• Mid-level developed environment or industrial sites</td>
<td>• Stop or yield sign intersection</td>
</tr>
<tr>
<td></td>
<td>• Flashing signal</td>
<td>• Failures to divide attention to multiple tasks or locations, or to direct attention selectively to the most relevant traffic information among many</td>
</tr>
<tr>
<td></td>
<td>• Vehicle being ran off the road</td>
<td>• External or internal distraction</td>
</tr>
<tr>
<td></td>
<td>• Failures to control the appropriate speed</td>
<td>• Complicated and visually cluttered environment</td>
</tr>
<tr>
<td><strong>Executive</strong></td>
<td>• Unprotected left turn</td>
<td>• unprotected left turn</td>
</tr>
<tr>
<td></td>
<td>• Lane change on a multilane roadway</td>
<td>• Unprotected left turn</td>
</tr>
<tr>
<td></td>
<td>• Mid-level developed road environment</td>
<td>• Lane change on a multilane roadway</td>
</tr>
<tr>
<td></td>
<td>• U-turn or other unsafe turns</td>
<td>• Mid-level developed road environment</td>
</tr>
<tr>
<td></td>
<td>• Merging at a yield sign</td>
<td>• U-turn or other unsafe turns</td>
</tr>
</tbody>
</table>
Table 9
Study 1 – Comparisons of ANT performance and prior driving violations and crashes by age groups.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>64 and younger (n=149)</th>
<th>65 and older (n=118)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Overall attentional performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT (ms)</td>
<td>675.87 (93.56)</td>
<td>668.27 (107.03)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>.95 (.10)</td>
<td>.91 (.16)</td>
</tr>
<tr>
<td>(b) ANT indices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alerting</td>
<td>.02 (4.50)</td>
<td>.16 (5.29)</td>
</tr>
<tr>
<td>Orienting</td>
<td>1.12 (4.81)</td>
<td>.97 (4.74)</td>
</tr>
<tr>
<td>Executive</td>
<td>4.54 (11.09)</td>
<td>4.68 (11.72)*</td>
</tr>
<tr>
<td>(c) Prior violations and crashes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warning</td>
<td>.48 (1.00)</td>
<td>.82 (1.66)</td>
</tr>
<tr>
<td>Ticket</td>
<td>.43 (.86)</td>
<td>.48 (.96)</td>
</tr>
<tr>
<td>Near-crash</td>
<td>.77 (.73)</td>
<td>.94 (.96)</td>
</tr>
<tr>
<td>Crash</td>
<td>.65 (.95)</td>
<td>.52 (.95)</td>
</tr>
</tbody>
</table>

*significant group differences at p <.05
Table 10
Study 2 - The list of simulated driving events. Drive 1 and 2 presented the same list of hazardous events in a different pre-selected order. The "+" indicates a positive association between the attentional function and likelihood of crash occurrence (i.e., a higher efficiency, a higher crash risk), and the "−" indicated a negative association (i.e., a lower efficiency, a higher crash risk).

<table>
<thead>
<tr>
<th>Event ID</th>
<th>Traffic Location</th>
<th>Maneuver</th>
<th>Traffic Control</th>
<th>Hazard source</th>
<th>Hazardous event scenario</th>
<th>Alert</th>
<th>Orient</th>
<th>Exec</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Drive 1]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NI5</td>
<td>Non-intersection</td>
<td>Merging</td>
<td>Yield</td>
<td>Merging traffic</td>
<td>The driver merges at a yield sign onto a highway, and a merging traffic accelerates.</td>
<td>+</td>
<td></td>
<td>−</td>
</tr>
<tr>
<td>(benign)</td>
<td>Intersection</td>
<td>Making left turn</td>
<td>Signal</td>
<td></td>
<td>Making a left turn on green light with no hazard</td>
<td>−</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I10</td>
<td>Intersection</td>
<td>Going straight ahead</td>
<td>Signal</td>
<td>A jaywalking pedestrian</td>
<td>The driver follows the traffic at the intersection; a j-walking pedestrian invades the driver's trajectory abruptly.</td>
<td>−</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I1</td>
<td>Intersection</td>
<td>Making left turn</td>
<td>Stop</td>
<td>Oncoming traffic</td>
<td>The driver makes a left turn at a stop sign-controlled intersection where there are multiple crossing vehicles.</td>
<td>−</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NI2</td>
<td>Non-intersection</td>
<td>Going straight ahead</td>
<td>Eye-catching roadside stimuli</td>
<td></td>
<td>The driver is distracted to eye-catching (disturbing) ads, and the leading vehicle makes a sudden stop.¹</td>
<td>−</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I4</td>
<td>Intersection</td>
<td>Making right turn</td>
<td>A cyclist or motorcyclist</td>
<td></td>
<td>While the driver makes a right turn, and a cyclist approaches from behind and attempts to go straight at the intersection.</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(benign)</td>
<td>Intersection</td>
<td>Going straight ahead</td>
<td>Signal</td>
<td></td>
<td>Going straight on green light with no hazard</td>
<td>−</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NI3</td>
<td>Non-intersection</td>
<td>Changing lanes</td>
<td>A sudden deceleration of leading vehicle</td>
<td></td>
<td>When the driver attempts to change lanes on a multilane roadway, the leading vehicle brakes unexpectedly.</td>
<td>−</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>I5</td>
<td>Intersection</td>
<td>Making right turn</td>
<td>Pedestrians approaching from the left to right</td>
<td></td>
<td>When the driver attempts to make a right turn, pedestrians cross the road from the left.</td>
<td>+</td>
<td>+</td>
<td>−</td>
</tr>
</tbody>
</table>

¹ Disturbing includes both eye-catching (disturbing) ads and leading vehicle makes a sudden stop.
<table>
<thead>
<tr>
<th>Event ID</th>
<th>Traffic Location</th>
<th>Maneuver</th>
<th>Traffic Control</th>
<th>Hazard source</th>
<th>Hazardous event scenario</th>
<th>Alert</th>
<th>Orient</th>
<th>Exec</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Drive 1]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NI1</td>
<td>Non-intersection</td>
<td>Going straight ahead</td>
<td>Multi-tasking</td>
<td></td>
<td>While the driver is involved in a secondary auditory task, the leading vehicle makes a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>sudden stop.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I3</td>
<td>Intersection</td>
<td>Making left turn</td>
<td>Signal</td>
<td>Oncoming traffic</td>
<td>The driver attempts to make an unprotected left turn at an intersection with a flash</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>signal (yellow flashing) where multiple approaching vehicles and motorcycles pass the</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>intersection.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I2</td>
<td>Intersection</td>
<td>Making left turn</td>
<td>Stop</td>
<td>Pedestrians on a</td>
<td>The driver attempts to make a left turn at a stop sign-controlled intersection where</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>crosswalk</td>
<td>pedestrians are crossing the road.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(benign)</td>
<td>Making right turn</td>
<td>Stop</td>
<td></td>
<td>Making a right turn at a stop-sign intersection with no hazard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NI4</td>
<td>Non-intersection</td>
<td>Merging</td>
<td>A car makes a rapid merging</td>
<td></td>
<td>A vehicle parked on the side of the road merges towards the driver's lane unexpectedly.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I9</td>
<td>Intersection</td>
<td>Going straight ahead</td>
<td>Signal</td>
<td>Traffic light changing to red</td>
<td>The light is turning red when the driver continues to drive at the intersection by</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>following the leading vehicles; then the cross traffic starts crossing.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I7</td>
<td>Intersection</td>
<td>Making right turn</td>
<td>No</td>
<td>A pedestrian</td>
<td>After the driver turns right to go onto a side street, a pedestrian is attempting to</td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>cross the road.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(benign)</td>
<td>Intersection</td>
<td>Going straight ahead</td>
<td>No</td>
<td></td>
<td>Going straight with no hazard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I6</td>
<td>Intersection</td>
<td>Making right turn</td>
<td>No</td>
<td>An unexpected stop of</td>
<td>The driver attempts to make a right turn onto a busy main road, and the leading vehicle makes a sudden stop after completing the turn.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>the leading vehicle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10 (Continued)
<table>
<thead>
<tr>
<th>Event ID</th>
<th>Traffic Location</th>
<th>Maneuver</th>
<th>Traffic Control</th>
<th>Hazard source</th>
<th>Hazardous event scenario</th>
<th>Alert</th>
<th>Orient</th>
<th>Exec</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Drive 2]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I2</td>
<td>Intersection</td>
<td>Making left turn</td>
<td>Stop</td>
<td>Pedestrians on a crosswalk</td>
<td>The driver attempts to make a left turn at a stop sign-controlled intersection where pedestrians are crossing the road.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(benign)</td>
<td>Intersection</td>
<td>Going straight ahead</td>
<td>Signal</td>
<td></td>
<td>Going straight on green light with no hazard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NI4</td>
<td>Non-intersection</td>
<td>Merging</td>
<td>A car makes a rapid merging</td>
<td></td>
<td>A vehicle parked on the side of the road merges towards the driver's lane unexpectedly.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I1</td>
<td>Intersection</td>
<td>Making left turn</td>
<td>Stop</td>
<td>Oncoming traffic</td>
<td>The driver makes a left turn at a stop sign-controlled intersection where there are multiple crossing vehicles.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I4</td>
<td>Intersection</td>
<td>Making right turn</td>
<td>A cyclist or motorcyclist</td>
<td></td>
<td>While the driver makes a right turn, and a cyclist approaches from behind and attempts to go straight at the intersection.</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>(benign)</td>
<td>Intersection</td>
<td>Making right turn</td>
<td>Stop</td>
<td></td>
<td>Making a right turn at a stop-sign intersection with no hazard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NI2</td>
<td>Non-intersection</td>
<td>Going straight ahead</td>
<td>Eye-catching roadside stimuli</td>
<td></td>
<td>The driver is distracted to eye-catching (disturbing) ads, and the leading vehicle makes a sudden stop.(^1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I6</td>
<td>Intersection</td>
<td>Making right turn</td>
<td>No</td>
<td>An unexpected stop of the leading vehicle</td>
<td>The driver attempts to make a right turn onto a busy main road, and the leading vehicle makes a sudden stop after completing the turn.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NI3</td>
<td>Non-intersection</td>
<td>Changing lanes</td>
<td>A sudden deceleration of leading vehicle</td>
<td></td>
<td>When the driver attempts to change lanes on a multilane roadway, the leading vehicle brakes unexpectedly.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(benign)</td>
<td>Intersection</td>
<td>Making left turn</td>
<td>Signal</td>
<td></td>
<td>Making a left turn on green light with no hazard</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 10 (Continued)

<table>
<thead>
<tr>
<th>Event ID</th>
<th>Traffic Location</th>
<th>Maneuver</th>
<th>Traffic Control</th>
<th>Hazard source</th>
<th>Hazardous event scenario</th>
<th>Alert</th>
<th>Orient</th>
<th>Exec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[Drive 2]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I10</td>
<td>Intersection</td>
<td>Going straight ahead</td>
<td>Signal</td>
<td>A jaywalking pedestrian</td>
<td>The driver follows the traffic at the intersection; a j-walking pedestrian invades the driver's trajectory abruptly.</td>
<td></td>
<td></td>
<td>−</td>
</tr>
<tr>
<td>I5</td>
<td>Intersection</td>
<td>Making right turn</td>
<td>Pedestrians on the crosswalk approaching from the left to right</td>
<td></td>
<td>When the driver attempts to make a right turn, pedestrians cross the road from the left.</td>
<td>+</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>NI5</td>
<td>Non-intersection</td>
<td>Merging</td>
<td>Yield</td>
<td>Merging traffic</td>
<td>The driver merges at a yield sign onto a highway, and a merging traffic accelerates.</td>
<td></td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>I3</td>
<td>Intersection</td>
<td>Making left turn</td>
<td>Signal</td>
<td>Oncoming traffic</td>
<td>The driver attempts to make an unprotected left turn at an intersection with a flash signal (yellow flashing) where multiple approaching vehicles and motorcycles pass the intersection.</td>
<td></td>
<td></td>
<td>−</td>
</tr>
<tr>
<td>I9</td>
<td>Intersection</td>
<td>Going straight ahead</td>
<td>Signal</td>
<td>Traffic light changing to red</td>
<td>The light is turning red when the driver continues to drive at the intersection by following the leading vehicles; then the cross traffic starts crossing.</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>(benign)</td>
<td>Intersection</td>
<td>Going straight ahead</td>
<td>Signal</td>
<td></td>
<td>Going straight on green light with no hazard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NI1</td>
<td>Non-intersection</td>
<td>Going straight ahead</td>
<td>Multi-tasking</td>
<td></td>
<td>While the driver is involved in a secondary auditory task, the leading vehicle makes a sudden stop.</td>
<td></td>
<td></td>
<td>−</td>
</tr>
<tr>
<td>I7</td>
<td>Intersection</td>
<td>Making right turn</td>
<td>No</td>
<td>A pedestrian</td>
<td>After the driver turns right to go onto a side street, a pedestrian is attempting to cross the road.</td>
<td>+</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. The events of I1 and I2 were excluded in the data analyses because those events could not be sufficiently viewed in one-screen setting of the simulator.  
1 Images used in the distracted road-side ads are presented in Figure 6.
Table 11
Study 2 - Correlations between ANT and prior violations and crashes. Correlations with the simulation crash were from n=60, and all others were from n=82.

<table>
<thead>
<tr>
<th></th>
<th>Acc</th>
<th>RT</th>
<th>Alert</th>
<th>Orient</th>
<th>Exec</th>
<th>Warning</th>
<th>Ticket</th>
<th>Prior Crash(^1)</th>
<th>Sim. Crash(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td>.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alerting</td>
<td>-.37*</td>
<td>.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orienting</td>
<td>.12</td>
<td>.13</td>
<td>.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Executive</td>
<td>-.39*</td>
<td>.16</td>
<td>-.02</td>
<td>-.22a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warning</td>
<td>-.05</td>
<td>.02</td>
<td>.03</td>
<td>.01</td>
<td>.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ticket</td>
<td>.03</td>
<td>-.14</td>
<td>-.06</td>
<td>.12</td>
<td>-.20</td>
<td>.30*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prior Crash</td>
<td>.11</td>
<td>-.03</td>
<td>-.07</td>
<td>.03</td>
<td>-.05</td>
<td>.12</td>
<td>.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim. Crash</td>
<td>-.30*</td>
<td>.27*</td>
<td>.21</td>
<td>-.01</td>
<td>.29*</td>
<td>-.04</td>
<td>-.19</td>
<td>-.08</td>
<td></td>
</tr>
</tbody>
</table>

* Correlation is significant at p < .05
a marginally significant at p = .053
\(^1\) Prior crash indicates the self-reported number of crashes occurring in the past 5 years
\(^2\) Sim. crash indicates the number of crashes occurring in simulated driving
Table 12
Study 2 – A summary of the associations between ANT and the crash risks. The associations indicate the crash risks in the set of taxonomy-defined hazardous events. Each cell describes the significant associations observed at $p < .05$

<table>
<thead>
<tr>
<th>Taxonomy events</th>
<th>ANT indices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
</tr>
<tr>
<td>(a-1) Alerting-critical events (positive relationship)</td>
<td><strong>Slower</strong> attentional speed, <strong>elevated</strong> crash risks</td>
</tr>
<tr>
<td>(a-2) Alerting-critical event (negative relationship)</td>
<td></td>
</tr>
<tr>
<td>(b) Orienting-critical events</td>
<td><strong>Slower</strong> attentional speed, <strong>elevated</strong> crash risks</td>
</tr>
<tr>
<td>(c) Executive-critical events</td>
<td></td>
</tr>
</tbody>
</table>

*Only one event type was included.*

Table 13
Study 2 - Correlations between the perceived and measured attention. (n = 82)

<table>
<thead>
<tr>
<th>Perceived attentional efficiency†</th>
<th>Alerting</th>
<th>Orienting</th>
<th>Executive</th>
</tr>
</thead>
<tbody>
<tr>
<td>M (SD)</td>
<td>4.04 (.79)</td>
<td>3.77 (.89)</td>
<td>3.49 (1.11)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measured attentional efficiency</th>
<th>Alerting</th>
<th>Orienting</th>
<th>Executive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alerting</td>
<td>.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orienting</td>
<td>.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Executive</td>
<td>.03</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Perceived attentional efficiency measured by self-reports on a 5-point Likert scale with 1 - being worse than most peers and 5 - being better than most peers
**Table 14**
Study 2 - Correlations among self-awareness of functioning.

<table>
<thead>
<tr>
<th>Mean (SD)</th>
<th>Attentional functions in everyday life</th>
<th>Attentional functions during driving</th>
<th>Driving competency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.26 (2.19)</td>
<td>2.19 (1.10)</td>
<td></td>
</tr>
<tr>
<td>Alerting: 2.61 (1.51)</td>
<td>Alerting: 2.34 (1.46)</td>
<td>1.83 (.62)</td>
<td></td>
</tr>
<tr>
<td>Orienting: 2.02 (1.37)</td>
<td>Orienting: 2.18 (1.42)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Executive: 2.13 (1.36)</td>
<td>Executive: 2.05 (1.32)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Correlation</th>
<th>Attentional functions in everyday life</th>
<th>Attentional functions during driving</th>
<th>Driving competency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attentional functions in everyday life</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Attentional functions during driving</td>
<td>.62*</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Driving competency</td>
<td>.47*</td>
<td>.52*</td>
<td>-</td>
</tr>
</tbody>
</table>

*significant correlation at $p < .001$
Table 15
Study 2 – Results of hierarchical regression analysis on compensatory behaviors.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>B</th>
<th>SE (B)</th>
<th>β</th>
<th>p</th>
<th>ΔR²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.11</td>
<td>.10</td>
<td>.14</td>
<td>.26</td>
<td>.07</td>
</tr>
<tr>
<td>ANT accuracy</td>
<td>20.07</td>
<td>16.66</td>
<td>.16</td>
<td>.23</td>
<td></td>
</tr>
<tr>
<td>ANT RT</td>
<td>.002</td>
<td>.01</td>
<td>.01</td>
<td>.94</td>
<td></td>
</tr>
<tr>
<td>Alerting</td>
<td>.02</td>
<td>.02</td>
<td>.18</td>
<td>.17</td>
<td></td>
</tr>
<tr>
<td>Orienting</td>
<td>-.03</td>
<td>.03</td>
<td>-.10</td>
<td>.41</td>
<td></td>
</tr>
<tr>
<td>Executive</td>
<td>.01</td>
<td>.01</td>
<td>.07</td>
<td>.57</td>
<td></td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.10</td>
<td>.10</td>
<td>.12</td>
<td>.33</td>
<td>.08*</td>
</tr>
<tr>
<td>ANT accuracy</td>
<td>20.22</td>
<td>16.29</td>
<td>.16</td>
<td>.22</td>
<td></td>
</tr>
<tr>
<td>ANT RT</td>
<td>-.002</td>
<td>.01</td>
<td>-.05</td>
<td>.70</td>
<td></td>
</tr>
<tr>
<td>Alerting</td>
<td>.02</td>
<td>.02</td>
<td>.17</td>
<td>.17</td>
<td></td>
</tr>
<tr>
<td>Orienting</td>
<td>-.04</td>
<td>.03</td>
<td>-.16</td>
<td>.16</td>
<td></td>
</tr>
<tr>
<td>Executive</td>
<td>.01</td>
<td>.01</td>
<td>.08</td>
<td>.52</td>
<td></td>
</tr>
<tr>
<td>Awareness of attentional declines in everyday life</td>
<td>.05</td>
<td>.51</td>
<td>.01</td>
<td>.92</td>
<td></td>
</tr>
<tr>
<td>Awareness of attentional declines during driving</td>
<td><strong>1.09</strong></td>
<td><strong>.52</strong></td>
<td><strong>.30</strong></td>
<td><strong>.04</strong>*</td>
<td></td>
</tr>
<tr>
<td><strong>Step 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.12</td>
<td>.09</td>
<td>.15</td>
<td>.20</td>
<td>.07*</td>
</tr>
<tr>
<td>ANT accuracy</td>
<td>14.23</td>
<td>15.84</td>
<td>.12</td>
<td>.37</td>
<td></td>
</tr>
<tr>
<td>ANT RT</td>
<td>-.001</td>
<td>.01</td>
<td>-.01</td>
<td>.92</td>
<td></td>
</tr>
<tr>
<td>Alerting</td>
<td>.02</td>
<td>.01</td>
<td>.13</td>
<td>.27</td>
<td></td>
</tr>
<tr>
<td>Orienting</td>
<td>-.04</td>
<td>.03</td>
<td>-.17</td>
<td>.14</td>
<td></td>
</tr>
<tr>
<td>Executive</td>
<td>.002</td>
<td>.01</td>
<td>.03</td>
<td>.84</td>
<td></td>
</tr>
<tr>
<td>Awareness of attentional declines in everyday life</td>
<td>-.21</td>
<td>.50</td>
<td>-.06</td>
<td>.68</td>
<td></td>
</tr>
<tr>
<td>Awareness of attentional declines during driving</td>
<td><strong>.56</strong></td>
<td><strong>.54</strong></td>
<td><strong>.15</strong></td>
<td><strong>.30</strong></td>
<td></td>
</tr>
<tr>
<td>Awareness of declines in driving competency</td>
<td><strong>2.20</strong></td>
<td><strong>.84</strong></td>
<td><strong>.34</strong></td>
<td><strong>.01</strong>*</td>
<td></td>
</tr>
</tbody>
</table>

* significant at p < .05
Figure 1. NHTSA taxonomy of older driver behaviors and crash risks (Staplin et al., 2012, p35)
Figure 2. Illustrations of the ANT procedures. a) Study 1 and b) Study 2.
Figure 3. Comparisons of the executive attentional efficiency among the Type A and E crash groups. (means with ± 1 SE) among the crash and reference groups for the type A (i.e., crash during a left turn at a stop-sign intersection) and type E (i.e., crash during a lane change on a multilane roadway) crashes.
Figure 4. Taxonomy table of the three attentional functions and the associated traffic situations. A red-filled cell indicates a negative association (i.e., a lower efficiency, increased risks), and a blue-filled cell indicates a positive association (i.e., a higher efficiency, increased risks).
<table>
<thead>
<tr>
<th>Traffic Location</th>
<th>Maneuver</th>
<th>Traffic Control</th>
<th>Potential Hazard Sources</th>
<th>Example Hazardous Driving Situations</th>
<th>Alert</th>
<th>Orient</th>
<th>Exec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop</td>
<td>Making a left turn</td>
<td>An oncoming traffic (vehicles and motorcycles)</td>
<td>A driver makes a left turn at a stop sign-controlled intersection, while there are multiple oncoming vehicles and motorcycles.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>A Pedestrian on a crosswalk</td>
<td>A driver makes a left turn at a stop sign-controlled intersection, when pedestrians are crossing the road.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal</td>
<td>Making a left turn</td>
<td>An oncoming traffic (vehicles and motorcycles)</td>
<td>A driver makes an unprotected left turn at an intersection while a flashing signal, when multiple vehicles and motorcycles are approaching the intersection.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>A cyclist or pedestrian approaching from the right</td>
<td>When a driver makes a turn in a channelized right-turn lane at a yield sign, a cyclist or pedestrian approaches from the behind and passes the driver's trajectory.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield</td>
<td>Making a left turn</td>
<td>A cyclist or pedestrian on the crosswalk approaching from the left</td>
<td>When a driver makes a turn in a channelized right-turn lane with a yield sign, and a cyclist or pedestrian approaches from the left to cross the road.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>A meeting traffic decelerating or stopping unexpectedly</td>
<td>A driver makes a right turn onto a busy main road, and there is an unexpected speed-change in the traffic of the main road.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Entering traffic</td>
<td>A cyclist or pedestrian crossing</td>
<td>A driver turns right to go onto a side street, and a cyclist or pedestrian crosses the road.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Round-about</td>
<td>Going straight ahead</td>
<td>A sudden acceleration or deceleration of the traffic already on the roundabout</td>
<td>A driver enters a roundabout while the traffics on the roundabout accelerate or decelerate unexpectedly.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal</td>
<td>Going straight ahead</td>
<td>Traffic light changing to red</td>
<td>A driver misses the traffic light turning red when continuing to drive to follow the current traffic at the intersection.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario</td>
<td>Event</td>
<td>Description</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Making a U-turn</td>
<td>Signal</td>
<td>A driver makes a U-turn during a green light for a left turn traffic, and a vehicle or motorcycle approaches.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Going straight ahead</td>
<td>Multi-tasking</td>
<td>A driver is distracted to a secondary task while continuing to drive, and the leading vehicle makes a sudden deceleration or stop.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eye-catching roadside stimuli</td>
<td>A driver is distracted to eye-catching road-side ads while driving on a busy street, and the leading vehicle makes a sudden deceleration or stop.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changing lanes</td>
<td>A sudden acceleration or deceleration of traffics</td>
<td>A driver attempts to change a lane on a multilane roadway, and traffics accelerate or decelerate unexpectedly.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>An unexpected movement of a parked car</td>
<td>A vehicle standing or stopped at the side of the road moves towards the driver's lane unexpectedly.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Merging</td>
<td>A sudden acceleration or deceleration of a meeting traffic</td>
<td>A driver attempts to merge with the next lane, and meeting traffics accelerate or decelerate unexpectedly.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backing</td>
<td>A pedestrian or motorcycle invading the trajectory</td>
<td>While a driver attempts to back-up, a pedestrian or cyclist invades the driver's trajectory.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5. Illustrations of the 14 hazardous events presented in a simulated driving. In each illustration, an orange vehicle indicates the driver’s vehicle, and the red-colored object(s) indicate(s) the hazard that may collide with the driver’s vehicle.
a) #NI5: Highway merging
b) #I10: A j-walking pedestrian
c) #I1: Unprotected left-turn at a stop-sign
d) #NI2: Distracted to roadside ads
e) #I4: A cyclist approaching on the driver’s right side from behind
f) #NI3: Changing lanes
g) #I5: A pedestrian approaching from the left during a right-turn
h) #NI1: Multi-tasking
i) #I3: Unprotected left turn at a flashing signal
j) #I2: Pedestrians crossing during an unprotected left-turn at a stop-sign

k) #I14: A parked car merging into the driver’s lane

l) #I9: Traffic light changes to red

m) #I7: A pedestrian crossing after the driver completes a right-turn

n) #I6: The leading vehicle stopping after completing a right-turn
Figure 6. A list of images used for the road-side billboard ads in a simulated driving. The selected images were from a widely used image database, International Affective Picture System (IAPS; image# 2205, 2220, 2345.1, 2692, 2751, 2770, 2780, 9075, 9440, 2092, 1120, 2352.1, 9940)
**Figure 7.** Snellen chart (visual acuity test).

**Test Image**

**Figure 8.** An illustration of the visual contrast sensitivity test. (from https://www.vcstest.com/test/)
Figure 9. Comparisons of prior crash frequency by attentional functioning and compensatory behaviors groups. Results from a 2 x 3 ANOVA with attentional functioning (2 groups: superior vs. inferior group based on overall ANT RT) and compensatory behaviors (3 groups: high vs. mid vs. low compensation group) on the self-reported number of crashes occurred in the past 5 years (means with ± 1 SE).
REFERENCES


Appendix A

Study 1 - Online survey
Online ANT study-2015 June

The second part of the experiment is a survey. You will be presented with questions about yourself and your driving behaviors. The entire study will take about 30 minutes. Please note that all information collected will be held in the strictest confidentiality. Under no circumstances will personal data be revealed to any third party, for any purpose. If you have any questions or concerns you would like addressed before or after completing this questionnaire, please contact the researchers at acplab.ncsu@gmail.com. This online survey conducted by the ACP lab (Director: Dr. Jing Feng) in Human Factors and Applied Cognition program, Department of Psychology, NCSU.

**Please enter your Amazon Mechanical Turk Worker ID here**
Click NEXT to start the survey!

[I. Demographics & Driver Information]

Which state do you live in?

- Alabama
- Alaska
- Arizona
- Arkansas
- California
- Colorado
- Connecticut
- Delaware
- Florida
- Georgia
- Hawaii
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky
- Louisiana
- Maine
- Maryland
- Massachusetts
- Michigan
- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
Do you work at any of the following universities? (This question is asked for the purpose of university financial process.)

☐ Duke University
☐ University of North Carolina
☐ North Carolina State University
☐ Elon University
☐ Eastern Carolina University
☐ Wake Forest University
☐ N/A

What is your year of birth?
Enter Year (YYYY)
Enter Month (MM)

What is your gender?
☐ Male
☐ Female

Do you currently have a valid government issued driver’s license?
☐ Yes
☐ No
What is the level of your driver's license?
- Full license
- Learner’s license

When did you obtain your first driver's license or learner's license (after your knowledge test)?
   Enter Year (YYYY)
   Enter Month (MM)

When did you obtain your full driver's license? (You may skip this question if you only have a learner's license.)
   Enter Year (YYYY)
   Enter Month (MM)

Do you currently drive?
- Yes
- No

How many days per week do you normally drive?
- 1
- 2
- 3
- 4
- 5
- 6
- 7

On a typical day, how many trips do you make?

How many miles do you drive in a normal week?

In a normal week, about what percent of your overall travel (miles driven) occurs at night? (between 1 - 100%)

Over the last year, how many miles did you drive?
- None
- Under 1,000
- Between 1,000 and 5,000
- Between 5,000 and 10,000
- Between 10,000 and 15,000
- Between 15,000 and 20,000
- Over 20,000
- I do not know
What kind of area do you live in?
- The city
- The suburbs
- A rural area

Do you do most or all of your driving close to home?
- Yes
- No

On a scale of 1 to 10, with 1 being very unsafe and 10 being very safe, how safe a driver do you think you are?

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<th>1</th>
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<th>4</th>
<th>5</th>
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<th>7</th>
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</tr>
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</table>

In the past five years, how many times have you been stopped by a police officer and received a WARNING (but no citation or ticket) for a moving violation (i.e. speeding, running a red light, running a stop sign, failing to yield, reckless driving, etc.)?
- Enter a number (enter 0 for none)

In the past five years, how many times have you been stopped by a police officer and received a CITATION OR TICKET for a moving violation?
- Enter a number (enter 0 for none)

**[II. Driving Confidence]**

How confident do you feel in the following activities?

- Driving in your local area?
- Driving in heavy traffic?
- Driving in unfamiliar areas?
- Driving at night?
- Driving with people in the car?
- Responding to road signs/traffic signals?
[III. Driving Behaviors]

Nobody is perfect. Even the best drivers make mistakes, do foolish things, or bend the rules at some time or another. For each item below you are asked to indicate HOW OFTEN, if at all, this kind of thing has happened to you. Base your judgments on what you remember of your driving. Please indicate your judgments by selecting ONE of the options next to each item. Remember we do not expect exact answers, merely your best guess; so please do not spend too much time on any one item.

How often do you do each of the following?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never</th>
<th>Hardly Ever</th>
<th>Occasionally</th>
<th>Quite Often</th>
<th>Frequently</th>
<th>Nearly all the time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Try to pass another car that is signaling a left turn.</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
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</tr>
<tr>
<td>Select the wrong turn lane when approaching an intersection.</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
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<td>☒</td>
</tr>
<tr>
<td>Fail to ‘Stop’ or ‘Yield’ at a sign, almost hitting a car that has the right of way.</td>
<td>☒</td>
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</tr>
<tr>
<td>Ignore speed limits late at night or very early in the morning.</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
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<td>☒</td>
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</tr>
<tr>
<td>Misread signs and miss your exit.</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
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<td>☒</td>
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</tbody>
</table>
How often do you do each of the following?

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>Hardly Ever</th>
<th>Occasionally</th>
<th>Quite Often</th>
<th>Frequently</th>
<th>Nearly all the time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fail to notice pedestrians crossing when turning onto a side street.</td>
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</tr>
<tr>
<td>Drive very close to a car in front of you as a signal that they should go faster or get out of the way.</td>
<td></td>
<td></td>
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<tr>
<td>Forget where you parked your car in a parking lot.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>When preparing to turn from a side road onto a main road, you pay too much attention to the traffic on the main road so that you nearly hit the car in front of you.</td>
<td></td>
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<tr>
<td>When you back up, you hit something that you did not observe before but was there.</td>
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</tr>
<tr>
<td>Pass through an intersection even though you know that the traffic light has turned yellow and may go red.</td>
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</tr>
<tr>
<td>When making a turn, you almost hit a cyclist or pedestrian who has come up on your right side.</td>
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</tr>
<tr>
<td>You get angry at the behavior of another driver and you chase that driver so that you can give him/her a piece of your mind.</td>
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</table>

[IV. Crash Characteristics]

How many CRASHES, that you were the driver of one of the vehicles involved (regardless of at-fault), did you have in the past 3 years? Crash includes any contact with an object, either moving or fixed, at any speed. It includes other vehicles, roadside barriers, objects on or off of the roadway, pedestrians, cyclists, or animals.

How many Near-Crash events, that you were the driver of one of the vehicles involved (regardless of at-fault), did you have in the past 6 months? Near-crash includes any circumstance that requires a rapid, evasive maneuver by the participant vehicle, or any other vehicle, pedestrian, cyclist, or animal, to avoid a crash. A rapid, evasive maneuver is defined as steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities.

* For each crash and near-crash event, the following list of questions was repeated.

Please provide following information regarding to your [1,2,3,4…]th crash/near-crash event.

When did the crash occur? If you don’t remember exact time, please provide your best guess.

Month
Year
What’s the estimated percentage of your fault or responsibility contributing to the crash, between 0 to 100 percent?

Were you involved in any of the following driving tasks prior to or during the crash?
- 1) Left Turn at an intersection with stop-sign control.
- 2) Left turn at an intersection with signal control.
- 3) Right turn in a channelized right-turn lane, merging with traffic approaching from the left.
- 4) Merge at a yield sign onto a limited access highway.
- 5) Lane change on a multilane roadway.
- 6) None of the above

Were you involved in any of the following driving performance errors prior to or during the crash?
- 1) Failure to visually detect potential conflicts, hazards, or traffic control information
- 2) Gap judgment error (i.e., inability to accurately estimate closing speed and distance)
- 3) Inability to predict the development of future conflicts from current traffic and contextual information
- 4) Slowed vehicle control response
- 5) Inadequate visual search/improper lookout, or Attentional failure (includes "looked but didn’t see")
- 6) Slowed decision-making; traffic situation has changed by the time a maneuver is initiated, resulting in potential conflict
- 7) Lack of understanding of rules of the road
- 8) Lack of understanding of safe driving practices (e.g., aiming mirrors, positioning within intersection to increase sight distance) (does not include willful or aggressive driving)
- 9) Inappropriate response (e.g., pedal errors)
- 10) None of the above

What was the locality?
- Rural (<30% developed)
- Mixed (30% to 70% developed)
- Urban (>70% developed)

What was the site type?
- Farms, woods, pastures
- Residential
- Commercial
- Institutional
- Industrial
- Unknown

What was the weather condition?
- Clear
- Cloudy
- Raining
- Snowing
- Fog, Smog, Smoke
- Wind
- Other: ____________________
- Unknown
What was the lighting condition?
- Daylight
- Dusk-Dawn
- Dark-lighted roadway
- Dark-roadway not lighted
- Dark-Street lights not functioning
- Other: ____________________
- Unknown

What was the roadway surface condition?
- Dry
- Wet
- Snowy-Icy
- Slippery (Muddy, Oily, etc.)
- Other: ____________________
- Unknown

What was the traffic control type (e.g., traffic signal) of the crash site?
- No control present
- Stop sign
- Yield sign
- Stop and go signal
- Flashing signal
- Railroad gate, flasher, or crossbuck
- Human control
- Warning sign
- School zone signs
- Double yellow line, no passing zone
- Other: ____________________

Did the crash involve with any any of followings?
- Pedestrian
- Other motor vehicle(s)
- Parked motor vehicle
- Bicycle
- Animal
- Fixed object
- Other object: ____________________

What was the estimated original speed? (Estimated speed in miles per hour for the vehicle you drove. Estimates should reflect the speed of the vehicle at the moment you initially perceived an existing hazard.)

( )
What was the movement of YOUR vehicle preceding the collision? (Check all that apply)
- Stopped
- Going straight ahead
- Ran off road
- Making right turn
- Making left turn
- Making U Turn
- Backing
- Slowing or Stopping
- Passing other vehicle
- Changing lanes
- Parking maneuver
- Entering Traffic
- Other unsafe turning
- Crossing into opposing lane
- Merging
- Traveling Wrong way
- Other: ____________________

Please indicate if any of following ROAD circumstances contributed the crash. Check all that apply.
- None (no unusual conditions)
- Road surface condition
- Debris
- Rut, holes, bumps
- Work zone (construction, maintenance, utility)
- Worn travel-polished surface
- Obstruction in roadway
- Traffic control device inoperative, not visible or missing
- Shoulders low, soft or high
- No shoulders
- Non-highway work
- Other: ____________________
- Unknown

Please indicate if any of following DRIVER circumstances that YOU were involved in contributed the crash. Check all that apply.
- No contributing circumstances identified
- Disregarded yield sign
- Disregarded stop sign
- Disregarded other traffic signs
- Disregarded road markings
- Exceeded authorized speed limit
- Exceeded safe speed for conditions
- Failure to reduce speed
- Improper turn
☐ Right turn on red
☐ Crossed centerline/going wrong way
☐ Improper lane change
☐ Use of improper lane
☐ Overcorrected/Oversteered
☐ Passed on hill
☐ Passed on curve
☐ Other improper passing
☐ Failed to yield right of way
☐ Improper backing
☐ Improper parking
☐ Inattention
☐ Driver distracted (talking, eating, etc.)
☐ Absorbed in mind wandering
☐ Improper or no signal
☐ Followed too closely
☐ Operated vehicle in erratic, reckless, careless, negligent or aggressive manner
☐ Swerved or avoided due to wind, slippery surface, vehicle, object, or non-motorist
☐ Visibility obstructed
☐ Alcohol/Drug use
☐ Physical impairment due to illness/medical condition
☐ Fatigue
☐ Fall asleep, fainted, loss of consciousness
☐ Other: ____________________
☐ Unknown

Was there any mechanical problem of the vehicle contributing the crash?
☐ Yes
☐ No

If above questions do not apply for the crash, explain in narrative.

[V. Attention during Driving]

Please indicate how often the following situations have happened to you in the last six months. Using the scale at top right as a guide, please indicate in the appropriate scale.

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>Hardly Ever</th>
<th>Occasionally</th>
<th>Quite Often</th>
<th>Frequently</th>
<th>Nearly All the time</th>
</tr>
</thead>
<tbody>
<tr>
<td>When entering a roundabout or intersection, you fail to notice vehicles that are not straight ahead.</td>
<td>☐</td>
<td>☐</td>
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<tr>
<td>You continue to follow the traffic, without noticing that the light at an intersection has turned red.</td>
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<td></td>
<td>Never</td>
<td>Hardly Ever</td>
<td>Occasionally</td>
<td>Quite Often</td>
<td>Frequently</td>
<td>Nearly All the time</td>
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<tr>
<td>Before switching lanes, you are so focused on the traffic in the lane that you wish to join and you fail to notice promptly that the vehicle in front of you brakes.</td>
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<tr>
<td>You are looking for a specific point at the road, and you fail to promptly notice that the car in front of you brakes.</td>
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<tr>
<td>When preparing to turn onto a main road, you pay so much attention to the traffic on the main road that you nearly run into the car in front of you.</td>
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<tr>
<td>When you are talking on a phone, you fail to promptly notice that there is a vehicle or pedestrian in your way.</td>
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<tr>
<td>On a busy street, you fail to notice a ‘Stop’ or ‘Yield’ sign, almost hitting a car that has the right of way.</td>
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<tr>
<td>When checking the rear-view or side mirrors, you fail to promptly notice that the car in front of you brakes.</td>
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<tr>
<td>You start to cross the intersection once the oncoming vehicles are moving, but then realize that your light has not turned green yet.</td>
<td></td>
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</tr>
<tr>
<td>Before switching lanes, you are so focused on the traffic in the lane that you wish to join and you fail to notice promptly that the vehicle in front of you brakes.</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>You fail to notice an animal coming onto the road and you nearly hit the animal.</td>
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<td></td>
</tr>
<tr>
<td>You are so focused on the road ahead that you fail to promptly notice a car in the next lane attempting to merge into your lane.</td>
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<td></td>
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</tr>
<tr>
<td>You fail to promptly notice vehicles and pedestrians in your way when driving along a busy downtown street.</td>
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<tr>
<td>Roadside advertisements capture your attention while driving that you fail to promptly notice that the vehicle in front of you is slowing down.</td>
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</tbody>
</table>
[VI. Participant Information]

The following are standard questions that allow researchers to determine how representative the group of participants in a study is of the general population. Remember, filling out this questionnaire is voluntary. Skipping any question that makes you feel uncomfortable will not exclude you from the study. Are you (please select all that apply)

- A full time student
- A part time student
- Unemployed
- Retired
- Employed full time
- Employed part time
- A full time caregiver (e.g., children or elder)
- A part time caregiver (e.g., children or elder
- None of the above

Please describe the highest level of formal education you have completed.
- Some high school of less
- High school graduate
- Some college
- College graduate
- Some graduate education
- Completed graduate or professional degree (e.g., Masters, JD, PH.D., MD, etc)

Please describe your general health condition
- Excellent
- Very Good
- Good
- Fair

Are you currently taking any medication on regular bases? (e.g., Anti-depression or anti-anxiety medications)
- Yes
- No

If 'yes' in the question above, describe the name or type of the medication.

Do you wear glasses or contact lenses?
- Yes
- No

Are you color blind?
- Yes
- No
Do you have any other vision problems? Indicate below.
- Glaucoma
- Cataract
- Lazy eyes
- Others ____________________

Do you have any difficulty with your hearing?
- Yes
- No

Do you think your memory is worse than others of the same age groups as yourself?
- Yes
- No

Have friends/family expressed concerns about your memory?
- Yes
- No

This is the end of the survey. Your Code is for mTurk is $e://Field/mTurkCode$. Paste the code into the box on the Mechanical Turk page to receive compensation. Please press the NEXT button to submit your survey. Thank you for taking your time to complete the experiment! We appreciate your contribution to research.

ACP Lab at North Carolina State University.
Appendix B

Study 2 - Screening interview
Participant Recruitment Screening Interview

*Interview date: ______________ Database Participant ID: ______________
*First Name: ________________
*Last Name: ________________
Phone: ________________ Email: ________________

[Demographic]
*Date of Birth ________________
*Gender ________________

*Currently having a driver’s license? Yes / No
*Type of license: learner’s / full
*Currently driving on a regular basis? Yes / No

Health
Q) Please describe your general health: Excellent Good Fair Poor
Q) If you have any major medical problems, please describe/list them:

Vision
Q1) Do you wear glasses or contact lenses?
Q2) Any trouble reading ordinary print even with glasses?
Q3) Are you color blind?

Hearing
Q) Do you have any difficulty with your hearing?

Memory
Q1) Do you think your memory is worse than others of the same age group as yourself?
Q2) Have friends/family expressed concerns about your memory?

**Motion Sickness: If the person experience motion sickness often or easily, he/she is not eligible**
Q1) In the last 10 years, how often you experienced the following sickness?
Cars Never travelled Never felt sick Rarely felt sick Sometimes felt sick Frequently
Buses Never travelled Never felt sick Rarely felt sick Sometimes felt sick Frequently
Aircrafts Never travelled Never felt sick Rarely felt sick Sometimes felt sick Frequently
Boats Never travelled Never felt sick Rarely felt sick Sometimes felt sick Frequently

Q2) Have you ever watched a 3D or IMAX movie? Have you experienced any form of visual or motion sickness while watching the movies? Yes / No

Q3) How easily you get tired or feel sick while watching TV monitors or computer screens, or while playing video games?
Appendix C

Study 2 - Entry survey
Please note that all information collected will be held in the strictest confidentiality. Under no circumstances will personal data be revealed to any third party, for any purpose.

1. Do you currently have a valid government issued driver's license?
   - Yes
   - No

2. What is the level of your driver's license?
   - Full license
   - Learner's license

3. When did you obtain your first learner’s license (after your knowledge test)?
   - Year (_______)
   - Month (_______)

4. When did you obtain your full driver's license? (You may skip this question if you only have a learner's license.)
   - Year (_______)
   - Month (_______)

5. How many days per week do you normally drive? (circle one)
   - 1  2  3  4  5  6  7
   - If less than 1 day a week, (_______) a month or a year, or Never

6. Over the last year, how many miles did you drive?
   - Approximately, (___________) miles

7. On a scale from 0 (very unsafe) to 10 (very safe), how safe as a driver do you think you are? (Circle the number)
   - 0  1  2  3  4  5  6  7  8  9  10
   - (Very Unsafe)  (Very Safe)

8. Have friends/family expressed any concern about your driving safety? Y / N
9. In the past 5 years, how many times have you been stopped by a police officer and received a WARNING (but no citation or ticket) for a moving violation (i.e. speeding, running a red light, running a stop sign, failing to yield, reckless driving, etc.)?  

(________________)  

10. In the past 5 years, how many times have you been stopped by a police officer and received a CITATION OR TICKET for a moving violation?  

(________________)  

11. In the past 5 years, how many CRASHES, that you were the driver of one of the vehicles involved (regardless of at-fault), did you have? Crash includes any contact with an object, either moving or fixed, at any speed. It includes other vehicles, roadside barriers, objects on or off of the roadway, pedestrians, cyclists, or animals.  

(_______________)  

11.1 Were any of your previous crashes occurred within the past 5 years involved in the following driving tasks prior to or during the crash?  

☐ Attempting to merge at a yield sign onto a main traffic or onto a limited access highway  
☐ Entering or exiting a roundabout  
☐ Changing a lane in a busy traffic or on a multilane roadway  
☐ Making a left turn at an intersection with stop-sign control  
☐ Making a left turn at an intersection with a flash signal  
☐ Making a right turn in a channelized right-turn lane with yield sign  
☐ Making a right turn from a side road onto a busy main road  
☐ Making a right turn from a busy main road onto a side street  
☐ Following a lead vehicle or the main traffic, and the light at an intersection turning red  
☐ Driving on a street with eye-catching distractors such as roadside ads, crash scenes, etc.  
☐ Driving while multi-tasking such as talking on a phone, texting, eating, etc.  
☐ Checking a rear-view or side mirrors  
☐ Making a U-turn  
☐ Backing
12. Do you have any major medical problems? Please list them if yes.
_____________________________________________________________

13. Are you currently taking any medication on regular bases? (e.g., Anti-depression or anti-anxiety medications)
☐ Yes
☐ No

14. If 'yes' in the question above, describe the name or type of the medication.
(___________________)

15. Do you have any vision problems? Indicate below.
☐ Glaucoma
☐ Cataract
☐ Lazy eyes
☐ Others ___________________

Thank you for taking your time to complete the survey!
Appendix D

Study 2 – Interview material
Instructions for Interviewers:
- Turn on the recording device.
- Avoid using any technical terms. Explain terms in lay language.
- Do not read the script. Ask questions naturally. Encode answers in the numeric scale, but qualitative answers can also be collected. An interviewer can determine the scale if a participant doesn’t make a clear answer (e.g., a little bit..., I strongly noticed..., etc.)
- Write down all answers and comments. Especially, if they talk about particular episode, make notes about it.
- If they give answers that may apply for a later question, do not ask again. Use the previous answers.

Section 1 (Self-awareness of cognitive decline)

1) Alerting: There is an aspect of attentional ability called alerting.

- The alerting function is an ability to maintain a high level of attention or vigilance during a long period of time. For example, you’d need to maintain attention to read a book or while boiling water. Or, when you go to a pool with your grandkids, you’d need to constantly scan the water for prolong periods of time looking out for them.
- ALSO, Alerting function involves increasing readiness to respond after seeing or hearing a warning sign or signal. For example, when you start hearing emergency sirens, you should be alerted and prepared to respond the impending situation.
- Q1) How good do you think this aspect of your attentional ability is, compared to peers? 1-worse than most peers; 2-relatively worse than peers; 3-neither worse nor better than peers; 4-relatively better than peers; 5-better than most peers
- Q2) Over the past 5 or 10 years, or more recently, have you noticed this type of attentional function being more difficult or challenging in your everyday life? 1-definitely not and 5-definitely yes.
- How about during driving? For example, you’d need to maintain vigilance during a long drive, or increase readiness for a deer crossing after you see a sign indicating a deer crossing area.
- Q3) Have you noticed it being more difficult or challenging to maintain attention during driving over the past 5 or 10 years, or more recently? 1-definitely not and 5-definitely yes.

2) Orienting: Another aspect of attentional ability is orienting.

- The orienting function is an ability to selectively focus on the most relevant information.
- For example, you’d need to focus particularly on your grandkid when he/she is playing with other kids in the playground, or when there is a flashing button on the computer screen, you’d need to orient your attention to the area to check the information.
- Q1) How good do you think this aspect of your attentional ability is, compared to peers? 1-worse than most peers; 2-relatively worse than peers; 3-neither worse nor better than peers; 4-relatively better than peers; 5-better than most peers
- Q2) Over the past 5 or 10 years, or more recently, have you noticed this type of attentional function being more difficult or challenging in your everyday life? 1-definitely not and 5-definitely yes.
- How about during driving? For example, you’d need to orient your attention to road signs or exit signs in order to make a turn or exit at the right location. Or, when you are merging, you’d need to direct your attention to check multiple locations (e.g., merging traffic, current traffic, etc).
- Q3) Have you noticed this type of function being more difficult or challenging during driving over the past 5 or 10 years, or more recently? 1-definitely not and 5-definitely yes.
3) **Executive**: The last aspect of attentional function is executive attention.

- It is an ability to ignore distracters or to resolve any conflicts among competing information in the environment. For example, when you try to listen to an audio book, but there can be some noises from outside of your house. Then, you’d need to ignore the distracting sounds and focus on the sound that you are listening to.
- **Q1** How good do you think this aspect of your attentional ability is, compared to peers? 1-worse than most peers; 2-relatively worse than peers; 3-neither worse nor better than peers; 4-relatively better than peers; 5-better than most peers
- **Q2** Over the past 5 or 10 years, or more recently, have you noticed this type of function being more difficult or challenging in your everyday life? 1-definitely not and 5-definitely yes.
- **Q3** Have you noticed this type of function being more difficult or challenging during driving over the past 5 or 10 years, or more recently?

### Other cognitive functions while driving

When driving, have any of the following driving situation or task become more difficulty or challenging over the past 5 or 10 years, or more recently? **IMPORTANT**: it is about changes, not about your current level of competency.

<table>
<thead>
<tr>
<th>1. To read or check signs or traffic signals</th>
<th>1 – Definitely Not</th>
<th>2 – Probably Not</th>
<th>3 – Might or might not</th>
<th>4 – Probably Yes</th>
<th>5 – Definitely Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. To know when you have the right-of-way to proceed at an intersection (through or turn)</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
<td>5 – Definitely Yes</td>
</tr>
<tr>
<td>3. To judge gaps in Traffic</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
<td>5 – Definitely Yes</td>
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<tr>
<td>4. To detect other vehicles or pedestrians in the periphery</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
<td>5 – Definitely Yes</td>
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<tr>
<td>5. To keep up with the flow of traffic (on high speed roads)</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
<td>5 – Definitely Yes</td>
</tr>
<tr>
<td>6. To judge when other drivers are going to do in traffic (anticipating hazards)</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
<td>5 – Definitely Yes</td>
</tr>
<tr>
<td>7. To pay attention to everything at the same time</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
<td>5 – Definitely Yes</td>
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<td></td>
<td>To merge at a yield sign</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
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<td></td>
<td>To enter or exit a roundabout</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
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<td>To change lanes on a multilane roadway</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
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<td>To make a unprotected left turn at an intersection (e.g., stop-sign, flash signal, etc.)</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
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<td></td>
<td>To make a right turn in a busy area (lots of pedestrians, bicycles, etc.)</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
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<td>12.</td>
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<td></td>
<td>To pay attention to signal light changes</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
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<td></td>
<td>To ignore distracting roadside scenes</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
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<td>14.</td>
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<td></td>
<td>To multi-task during driving (e.g., eating, talking, etc.)</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
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<td>To check a rear-view or side mirrors</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
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<td></td>
<td>To make a U-turn</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
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<td></td>
<td>To do backing-up</td>
<td>1 – Definitely Not</td>
<td>2 – Probably Not</td>
<td>3 – Might or might not</td>
<td>4 – Probably Yes</td>
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<td>18.</td>
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</table>

Is there any other traffic situation or particular driving task that you find it become more difficult for you over the past 5 or 10 years, or more recently? (If answered ‘yes’) What is it?

________________________________________________________________________________________

________________________________________________________________________________________

________________________________________________________________________________________

________________________________________________________________________________________

________________________________________________________________________________________
Section 2: (Use of Compensatory Strategies during Driving)

(Open ended question) Have you changed any driving habits or plans over the past 5 or 10 years, or more recently? Please describe what, if any changes you have made in your driving behaviors.

__________________________________________________________________________________________
__________________________________________________________________________________________
__________________________________________________________________________________________

Have you changed your driving habits over the past 5 or 10 years, or more recently, in any of the following ways? These are just simple yes / no questions, but feel free to elaborate if you want.

<table>
<thead>
<tr>
<th>Yes / No (Any Comments?)</th>
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<tbody>
<tr>
<td>1. Drive fewer miles</td>
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<td>2. Make fewer trips per week</td>
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<td>3. Limiting or being more careful in night driving</td>
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<td>4. Limiting or being more careful when driving in unfamiliar areas</td>
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<td>5. Limiting or being more careful when driving far from home</td>
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<td>6. Limiting or being more careful in high speed roads</td>
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<td>7. Limiting or being more careful in freeways/expressways</td>
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<td>8. Limiting or being more careful in high traffic roads</td>
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<tr>
<td>9. Limiting or being more careful when driving at rush hour</td>
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<td>10. Limiting or being more careful when changing lanes or merging</td>
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</table>
Appendix E

Study 2 - Macular degeneration test
1. Tape this page at eye level where light is consistent and without glare.
2. Put on your reading glasses and cover one eye.
3. Fix your gaze on the center black dot.
4. Keeping your gaze fixed, try to see if any lines are distorted or missing.
5. Mark the defect on the chart.
6. TEST EACH EYE SEPARATELY.
7. If the distortion is new or has worsened, arrange to see your eye doctor at once.
8. Always keep the Amsler’s Chart the same distance from your eyes each time you test.

The AMDF is a 501(c)(3) non-profit, publicly supported organization as described in sections 509(a)(1) and 170(b)(1)(A)(vi) of the Internal Revenue Code. Contributions to the Foundation are tax deductible to the extent allowed by law.
Appendix F

Study 2 – Experimenter scripts
SET-UP
1) Please arrive at least 20 - 30 minutes before a participant is scheduled to arrive.

To setup the Visual Contrast Sensitivity Test, go to https://vcstest.com/login/ and login with the following information. ID: hchoi8@ncsu.edu PW: acplab. Click on HeeSun, Dissertation Research and then start new test. The result will be automatically saved, but should be inputted into the vision testing spreadsheet.

2) To setup the Simulated Driving, open STISM application. For each participant you will need to add them to the drivers list. Click on add new driver and input their first and last name, along with the participants ID number.

3) To setup the ANT test, open the desktop icon. A screen will pop up and in the first box input the participants ID: #+Month+Day e.g. 01402 (first participant; conducted on Apr. 2nd); 72515 (72nd participant; conducted on May 15th)

4) Have the laptop ready. Open the data file. Encode the data during experiment. Also, observe participant’s behaviors and performance, and make notes anything you notice that may help the study. Also, if there was any event such as the wheel fell off during driving, make notes about it. While conducting interview, turn on the audio-recorder.

EXPERIMENT
1) Greet the participant in the lobby.
   a. Hi are you here for the Simulated Driving Study (state scheduled sign-up time)?
      i. Wait for participant to respond.
      1. Take note of their time of arrival for compensation later.

2) My name is ____ and I will be running the study today. The study should take approximately an hour and half. Do you need to use the restroom?
   a. Wait for participant to respond.
      i. If yes ➔ the restroom is straight across the hall.

3) Briefly explain the study to the participant.
   a. Thank you so much for taking the time out of your day to participate in our study! The experiments is broken down into 5 parts, including an entry survey, basic vision testing, computer-based testing, simulated driving and a closing interview. Again it should take approximately 1.5-2 hours to complete. But before we begin, if I could get you to fill out this consent form.
      i. Give the participant a minute or so to read over the form.

4) Collect the form once it has been completed.
   a. Thank you. Well to start off with, here is an entry survey. Essentially it’s going to ask you some basic questions about your driving history as well as general health conditions. Please fill it out to the best of your ability. If you feel uncomfortable answering a question feel free to skip it.
      i. Proceed through the entry survey
5) After completing the entry survey continue on to visual testing.
   a. Great, well next I have three short visual tests. If you happen to have reading glasses, please wear them. If you happen to have forgotten them, we can provide you with some standard glasses if needed.
      i. If the participant needs glasses help them find an appropriate pair
   b. For the first test I’m going to have you gaze at this chart. If you could cover your left eye with the instrument. With your gaze fixed on the black dot in the center, are any of the lines distorted or missing?
      i. Record the participant’s response in the spreadsheet.
   c. Excellent, now can you cover your right eye? With your gaze fixed on the black dot in the center, are any of the lines distorted or missing?
      i. Record the participant’s response in the vision testing spreadsheet.
   d. Alright for the next test I’m going to have you place your head in the chin rest.
      i. Allow the participant to put their head into the chin rest and adjust it as needed
      ii. Make sure you wipe off the chest rest in-between participants!
   e. Great, now covering your left eye could you please read row X.
      i. If the participant answers incorrectly \(\rightarrow\) Could you please read row X+
      ii. If the participant answers correctly \(\rightarrow\) Could you please read row X-
      iii. Record the result in the vision testing spreadsheet
   f. Now covering your right eye could you please read row X.
      i. If the participant answers incorrectly \(\rightarrow\) Could you please read row X+
      ii. If the participant answers correctly \(\rightarrow\) Could you please read row X-
      iii. Record the result in the vision testing spreadsheet
   g. Finally for the last visual test, I’m going to have you look at this laptop screen. When you start the test, you’ll be asked to cover your right eye, a test image will be displayed, and you’ll then indicate which direction the bars in the image are tilted (left, up, or right) by clicking or the corresponding response image below the test image.
      i. The instructions are also included on the website.
      ii. The results will be automatically saved but need to be input into the vision testing spreadsheet later.

6) After completing the vision test, move onto the Simulated Driving

Simulated driving instruction for experimenters:
   • To reduce motion sickness during simulated driving:
      1) We will still mention that they may experience minor motion sickness, but try not to too emphasize that because it may increase stress, thus increase the likelihood of motion sickness experience. Help them to be relaxed. Tell them don't get stressed or nervous. Try to create relaxed and comfort environment during driving.
2) Take down the chinrest after the acuity test. Get rid of keyboard, mouse, and anything within their sight before starting the driving.
3) Keep the lights off during driving. Turn one light switch back on in the rest period so their eyes can rest.
4) There is a bag of peppermint candies and gums. Provide a candy or a gum to a participant before starting the practice drive, and more during the rest between each drive.
5) During demonstration, demonstrate how to control the steering wheel and brake/gas pedals. During practice, assist participants as much as needed to help them get familiar with controls. If a participant hit the brake too often or make frequent unnecessary stopping during driving, ask him/her to avoid it. It will increase dizziness. Also, tell them to avoid over-steering and over-compensating the steering wheel (do not show rapid movement; it can create sickness).
6) Maintain the room temperature cool. After the ANT and between each drive, open the room door to circulate the air for a few minutes.
7) Give them rest period between drives. Ask them to leave the room and walk for a few minutes or drink some water during the rest period.
8) Participants should avoid fixating on near objects such as road lines or buildings. Looking at far in the visual field (e.g., looking at mountains in the background) will help.
9) If you had to stop the drive because they felt sick, ask them to have a rest period, drink waters, and get some fresh air. Then, ask if they are up for the second drive. If they are, resume the next driving session. Or, if they seem to need a bit more time to overcome, you can do the interview first, and ask if they are up to try the second driving after the interview. For future reference, ask if particular components or scene caused a sickness.

- During driving, if a participant seems to experience difficulty, an experimenter can involve and give further instructions how to use wheel and pedals, make turns, etc.

  a. Next, we will be moving onto the simulated driving. You will first have a practice drive. Then, you will complete two testing drive.
     1) We want the simulation to be as realistic as possible, and want you to drive as your normal do. You can make lane-changes, pass slow traffic, or whatever you would normally do to drive comfortably. Try to maintain the appropriate speed as directed by road speed limit signs. Crash can occur because of the nature of the experiment; don’t worry too much or be upset about making crashes.
     2) When driving, the program will instruct you when to make a left or right turn before an intersection. If no specific directions are given, follow the main traffic or go straight at the intersection.
     3) There are turn signal buttons behind the steering wheel, but it might feel unnatural to use. (An experimenter shows how to use turn signals) You can use them if you feel so inclined. If not, don’t worry about signaling a turn.
     4) While this simulated driving has no actual hazards, it is possible you might feel minor motion sickness. If you focus on near visual field or make rapid steering wheel rotations, it may increase the motion sickness. Please try to be relaxed during driving. No need to get stressed. If it is too severe, please let us know and we can stop the testing.

Select the demonstration file.
b. Now, before you practice, I will first demonstrate. Open the Demonstration scenario file. An experimenter shows one left and one right turn. Explain and demonstrate smooth wheel rotations.

   i. Set the pedals and wheels to fit the participant.
   ii. Ask the participant if they have any questions before starting.
   iii. Select the practice file
   iv. Set file name to **ID_Prac.dat**

c. Now, you will have a practice run. During the practice, there will be low traffic and none hazardous situations. Just try to familiarize yourself with the driving simulations. Feel free to try anything such as lane changes, turns, speeding, and stopping.

   i. After the participant has completed the practice proceed onto the first testing block.
      If an additional practice seems needed, repeat the practice.
   ii. Select the Drive 1 file
   iii. Change file name as **ID_Drive1.dat**

5) Now, you will have the first drive. While driving, at some point in time you might hear a few sentences, such as the capital of North Carolina is Raleigh. Whenever you hear sentences, you should verify if each played sentence is true or false. If the statement is true, press the horn.

   i. During drive, if the participant drives too slow, encourage him/her a little bit to maintain appropriate speed.
   ii. After the participant has completed the first trial proceed onto the second trial.
      Select the Drive2 file.
   iii. Change file name to **ID_Drive2.dat**

7) After completing the simulated driving, proceed onto ANT

   i. Throughout the explanation point to the appropriated printed out slides.
   ii. Ask the participant if they have any questions on the pervious information

b. Okay, next we will be doing a cognitive on this laptop. There will be a short practice then two 5 minute-testing blocks. During the test, I’m going to have you hold the mouse in both of your hands so that you can rapidly click left or right with your left and right thumbs. Throughout the task, there will be a cross (+) on the center of the screen. That is a fixation point where you should maintain your focus on. On the screen, you are going to see a set of objects either above or below the center area. Your task is to respond to the orientation of the center arrow. The center arrow will be oriented either left or right each time. Press the left button if the arrow is toward to left, and press the right button if the arrow is toward to right. There will be four objects displayed next to the target arrow; two on the left and two on the right. The neighboring objects can be flat lines, arrows going in the same direction, or arrows going in the opposite direction. Your task is just to look at the center target arrow and respond as quickly and accurately as possible.

c. Also, before target arrows are displayed, sometimes there will be some cues displayed on the screen. There will be different types of cues. First, one asterisk can appear at the center of the
screen. This cue indicates that the target will appear shortly, thus you should be prepared to
respond to the following target. Two asterisks can appear; one above and one below the
center. This type of cue also indicates the target will follow shortly. Finally, one asterisk can
appear either above or below the fixation cross. These spatial cues indicate that the
following target will appear at the location where the asterisk was displayed. If you see an
asterisk on the above the center fixation, the target will appear at the same spot. Sometimes,
there will be no cue before a target.

iii. Emphasize the meanings of different cues. During a practice, make sure they
understand accurately.
iv. Start the testing sessions whenever the participant is ready.

8) Structured Interview
   a. Awesome, well finally I have a structure interview. The interview is going to ask you more
      about your everyday cognitive functioning as well as your driving behaviors.
      i. Use the structured interview form (see the separate document). Do NOT just read the
         interview script. Get familiar with the interview material, and ask questions
         naturally.
      ii. Turn on the recording device.
      iii. Type while conducting an interview. Type as much in details as possible.

9) Wrapping up
   a. Awesome, that’s all the testing I have for you today! Again, thank you so much for taking the
time out of your day to participate in our study! The purpose of this research is to examine the
relationship (if any) on attentional function and driving performance of older drivers. Do you
have any questions?

   b. Again in appreciation of you coming into, we do provide a compensation of $15 an hour.
      i. Dispense funds, by writing a receipt. Record the compensation history on the excel
         spreadsheet (amount, name, etc.)
         ~1h: $15; 1h – 1h 20m: $20; 1h 20m – 1h 40m: $25; 1h 40m – 2h: $30

After
1) Encode all collected data for each participant into the spreadsheet right after the experiment (if time
allows) or by the next day of the experiment at the latest.
2) Turn off all the equipment after all sessions for the day are done.