

ROADWAY SAFETY INSTITUTE

Human-centered solutions to advanced roadway safety

Older Driver Support System Field Operational Test

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Final Report



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FINAL REPORT

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LIST OF ABBREVIATIONS

DALI-TLX: Driver Assessment Load Index

FARS: Fatality Analysis Reporting System

GPS: Global Positioning System

MMSE: Mini Mental State Exam

MPFT: Mental Paper Folding Test

mph: Miles Per Hour

m/s²: Meters per Second Squared

NASA-TLX: NASA Task Load Index

NHTSA: National Highway Transportation Safety Administration

RSME: Rating Scale of Mental Effort

EXECUTIVE SUMMARY

Older drivers represent the second highest injury and fatality rate, after younger drivers, per 10,000 licensed drivers and are first in fatalities per 100 million miles driven (IIHS, 2015; FARS, 2010). Furthermore, a 286% increase in older driver fatalities is projected from 1995 to 2025 (Hu et al., 2000). The disproportionate fatality risk is linked to several known factors, ranging from maladaptive driving behaviors, such as failure to yield (Vachal & Malchouse, 2010), to cognitive limitations, such as poor visual search (Dickerson et al., 2007), to poor survivability, such as lack of seatbelt use (Koppel et al., 2011) and overall fragility. These risks may be manifested in measurable driving behaviors, such as hard braking or failure to respond to speed limits and could be mitigated by effective coaching in real-time by an in-vehicle support system.

A previous 300 teen field operational test examined the efficacy of a real-time coaching app to reduce risky driving behaviors in the first year of licensure and found success in reducing speeding and excessive driving maneuvers, such as hard braking and turning (Creaser et al., 2015). The app was redesigned to support all drivers, regardless of age, following universal design guidance, rather than specializing the design for any single group (Mace, 1997). The newly designed app, named RoadCoach, was previously found to have high usability and user acceptance among older drivers through a series of focus groups, usability tests, and controlled field test (Morris, Craig, Libby, & Cooper, 2018). The previous work, however, did not examine its effect on driving behavior, although nearly all users indicated they would use the app if it were available.

Therefore, this study investigated the impact of RoadCoach feedback on risky driving behaviors among older adults, the presence of short-term changes in driving behavior once the feedback was removed, and the user acceptance of this technology over an extended period, compared to the brief controlled-field test. The study conducted a field operational test of the app that included 28 drivers age 65 and older ($M=69.5$, $SD=2.93$), 14 from Wichita, Kansas, and 14 from Minneapolis-St. Paul, Minnesota. The study measured driving performance with an ABA design (i.e., reversal design) that included three weeks of baseline driving behavior, 6 weeks of driving behavior with RoadCoach feedback, and three weeks of follow-up with no feedback. The app was downloaded onto the participant's own Android smartphone and activated via Bluetooth synchronization (Bluetooth adapters provided to those drivers with non-Bluetooth equipped vehicles). Driving metrics included hard braking, excessive accelerations, aggressive turning, stop sign violations, speed warnings, speed violations, and distance traveled, among other metrics.

Results generally indicated a positive effect of RoadCoach on driving performance while the feedback was active. Repeated measure analyses of speeding warnings, speeding violations, hard braking, and stop sign violations indicated either significant improvement or a trend toward improvement for these measures from the baseline phase to the feedback phase. Speeding metrics, however, showed worse performance in the post-feedback and no-feedback phases, indicating there was no training effect with the applied treatment schedule for speeding. Importantly, hard braking and stop sign violations showed

sustained improved performance in the no-feedback phase, indicating some training effect with the RoadCoach app may have occurred for those driving behaviors.

Similar to past examinations of the usability of the RoadCoach app among older drivers, the subjective measures from the field operational test revealed that little mental effort and stress was imposed on drivers through the app's use, as measured by the Rating Scale of Mental Effort (RSME) and the Driving Activity Load Index (DALI). The usability scores of the app, as measured by the System Usability Scale (SUS), were above average, but not as high as measured from its short-term use in the controlled field test by Morris and colleagues (2018). The annoyance caused by the auditory factors of the app appeared to influence the usability scores since the app sometimes intruded on the drivers' attention through its alerts and alarms. Finally, a questionnaire was administered to assess the degree of user trust in the RoadCoach app and system, and it received a moderately high degree of trust from the drivers, indicating relatively high reliability.

Overall, the field operational test demonstrated that RoadCoach may be an effective tool to reduce certain types of risky driving behaviors, especially related to hard braking and stop sign violations. It may also help assist drivers in their ability to pay attention to the task of driving. Further research should examine whether a longer treatment period, or greater study power, would reveal a significant reduction in speeding behaviors through the app's feedback, whether a training effect can be attained, or whether unintended consequences of riskier driving behavior through speeding could occur through feedback cessation. Importantly, the app demonstrated that it was a useful tool through its high user acceptance. Feedback gained through focus groups conducted by Morris and colleagues (2018) found that some drivers were anxious about the potential loss of their driving independence and open to the use of technology to help retain it. Future research should examine the extent to which in-vehicle coaching could help prolong safe driving among older drivers or even improve it.

CHAPTER 1: INTRODUCTION

The proportion of the United States population over age 65 will increase significantly in the coming decades (Administration on Aging, 2015). In 2009, this age group numbered 39.6 million in the United States, is estimated to exceed 55 million by 2020, and is expected to eclipse 72 million by 2030 to account for roughly one-fifth of the U.S. driving population (Administration on Aging, 2015). The increase in the total number of older drivers has coincided with an increase in the length of time that they have postponed driving cessation (Gwyther & Holland, 2011). Much of this can be attributed to improvements in healthcare and overall life expectancy, which is significant on both an individual and societal level (Administration on Aging, 2015).

This is because driving is not simply a means of “getting around,” but rather it is the primary and preferred means of transportation in America (Hu & Reuscher, 2004). Maintaining individual mobility has been shown to be especially essential among older adults and has been correlated with greater levels of happiness, autonomy, and overall quality of life (Cobb & Coughlin, 2000; Glasgow & Blakely, 2000). However, the increasing number of older adult drivers on our nation’s roads and highways in coming years will pose several challenges to transportation safety researchers and engineers.

It has been well documented that significant age-related declines in vision (Owsley & McGwin Jr, 2010), attentional capabilities (Cuenen et al., 2015), cognitive functioning (Aksan et al., 2014), and motor skills (Smither et al., 2004) are highly correlated with decreases in driver performance as well as an increase in crash-risk. This is supported in examination of traffic crash data that shows an increase in driver crash risk after age 65 for all types of crashes (i.e., property damage only, injury, and fatal; Tefft, 2017). While the fatal crash rate for older drivers has declined in recent decades, in 2017, drivers over age 70 had the second highest fatal crash rate per 100,000 people (NHTSA, 2018).

Despite the associated increase in crash-risk with age, a large portion of older drivers do not suffer from significant age-related declines and have accumulated driving experience that translates into them being safer drivers (McGwin & Brown, 1999). Older drivers that do experience declines in driving ability may choose to adopt strategies to compensate for these decrements (Glasgow & Blakely, 2000). They accomplish this by reducing the amount of time spent driving at night, in inclement weather, and during rush-hour and make fewer left-hand turns at busy intersections (Yassuda, Wilson, & Von Mering, 1997). However, aging is highly individual and as such, declines due to general aging are often subtle and gradual, which can result in many drivers being unaware of any effect aging may have had on their ability to safely navigate the roadway (Holland & Rabbitt, 1992). Because many drivers are unaware of the impact of age-related changes, they may fail to adjust their driving habits accordingly (Horswill, Sullivan, Lurie-Beck, & Smith, 2013).

Rather than relying on individuals to self-moderate, it may be beneficial for them to be well informed regarding their driving behavior, which would allow them to more accurately assess their current skill level and performance (Broberg & Willstrand, 2014). While a battery of tests has been developed to assess and predict the abilities of aging drivers (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Broberg &

Willstrand, 2014; Wood, Horswill, Lacherez, & Antsey, 2013), it is unclear to what extent the feedback of such assessments would be able to help mitigate crash involvement of older drivers (Horswill, Kemala, Wetton, Scialfa, & Pachana, 2010). Horswill, Garth, Hill, and Watson (2017) examined the effect of feedback on drivers' hazard perception abilities in a video-based hazard perception test and found that teen drivers were more likely to improve their performance, as well as their self-ratings of their performance, relative to control groups when feedback was given.

In an effort to assess the benefits of driver assessment and feedback on real-world driving, Creaser et al. (2015) conducted a 12-month, on-road study with 300, newly licensed teen drivers. That study compared the effects of an in-vehicle driver support system that monitored and provided drivers with real-time feedback whenever they exhibited risky driving behaviors (e.g., speeding, hard braking) compared to a control group. The study found significant improvements in the prevalence of risky driving behaviors known to be associated with an increased crash-risk for the drivers who received real-time feedback about their driving compared to those who did not receive feedback. The results were attributed to drivers being able to learn in real-time and adapt their behavior accordingly based on the feedback they received. These results were consistent with the findings of Yanko & Spalek (2013), which found that when drivers were prompted to pay attention to the roadway, they were more likely to react quickly to both central and peripheral events along the roadway. To date, however, there has been little research examining the real-world effects of feedback for driving behavior among the elderly.

The current study examined the efficacy of real-time feedback on driving behaviors associated with an increased crash-risk for older adult drivers. Providing drivers with real-time feedback may help draw attention to hazards or changes in their own driving behavior and allow them to make appropriate adjustments. Additionally, measures of user experience and satisfaction were taken to identify the likelihood of users adopting such a support system in the future as well as to identify design issues and make recommendations for potential changes to the current system.

This effort will begin with an in-depth review of recent trends in crash data among different age groups to understand how the types of crashes and the circumstances around them change with age. Next will be a review of how the effects of aging contribute to performance measures of driver behavior associated with crash-risk. Finally, the role of telematics in driving, specifically in an aging population, will be examined to better understand the potential benefit that can be gained from its implementation. This is encapsulated by a theoretical framework for understanding how attentional selection supports hazard perception and a means for understanding how the effects of aging impact attentional selection in driving.

CHAPTER 2: LITERATURE REVIEW

2.1 REVIEW OF DRIVING SAFETY

2.1.1 Review of Traffic Crash Trends

Motor vehicle collisions are a major worldwide health concern. In 2017, more than 1.35 million people died in traffic crashes (World Health Organization, 2018). In the United States alone the same year, there were 37,133 traffic-related fatalities and more than 4.5 million crashes in which passengers were severely injured enough to require medical treatment (NHTSA, 2018). Traffic fatalities were the 11th leading cause of death in the United States and were 4th in non-chronic related deaths in 2017 (Centers for Disease Control, 2018).

Encouragingly, the overall number of driving-related fatalities as well as the fatality rate (per 100 million miles traveled) has decreased significantly over the past forty years from 50,331 (3.26 fatalities per 100 million miles) in 1978 to 37,133 (1.16 fatalities per 100 million miles) in 2017 (NHTSA, 2018). Increases in anti-alcohol enforcement, seatbelt usage, and an increase in overall crash survivability may explain much of the decrease in driving-related fatalities (Cicchino & McCartt, 2014; NHTSA, 2018; Pickrell & Ye, 2009). Despite these improvements in roadway safety, surface transportation is still risky enough that both researchers and legislators continually strive to reduce through both education and policy changes. Reducing the number of traffic crashes requires, among other things, modifying driver behavior (e.g., persuading them to change their knowledge, expectations, and behaviors; Gwyther & Holland, 2011; Cuenen et al., 2015) or by modifying the environment (e.g., changes in vehicle and roadway design; Classen et al., 2006).

Improvements through environmental modifications (e.g., cable median barriers, wider shoulders, improved intersection design, safer vehicles) have been shown to be useful in reducing traffic crashes and their corresponding severity, though the benefit may be partially offset by the risky behavior that a safer environment affords (Vanderbilt, 2008; Farmer & Lund, 2006). While road safety changes may afford drivers more room for error, driver error is still a contributing factor in approximately 95% of all traffic crashes (Cicchino & McCartt, 2015). This emphasizes the importance of continued efforts to modify driver behavior and awareness, especially among the most at-risk driving populations, teenagers and aging drivers (65+), who are significantly more likely to be involved in a serious or fatal injury crash relative to middle-aged drivers (NHTSA, 2018). However, before attempting to implement changes to reduce the crash-risk of these more vulnerable populations, it is first necessary to understand the most common types of crashes and the circumstances surrounding those crashes.

2.1.2 Impact of Behavioral Modifications on Novice Driver Safety

Novice drivers, specifically teenagers, have long been a concern due to their inexperience, propensity to overestimate their abilities, and, especially among male drivers, a tendency for risk-taking (Lee, 2007; Mayhew, Simpson, & Pak, 2003). Teen drivers are known to engage in risky driving behaviors (e.g.,

speeding, lack of seatbelt) associated with increased crash-risk (Groeger & Brown, 1989; Laapotti, Keskinen, Hatakka, & Katila, 2001; Renner & Anderle, 2000). They are also more likely to engage in impaired driving (NHTSA, 2018) and inattentive or distracted driving (Klauer, Guo, Simons-Morton, Ouimet, Lee, & Dingus, 2014). Driver inexperience has also been shown to impact hazard perception as younger, inexperienced drivers demonstrate poorer visual scanning patterns relative to more experienced drivers (Mourant & Rockwell, 1972; Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003).

Historically, teen drivers have had the highest fatality rates among all but the very oldest of drivers, per licensed driver per mile driven (IIHS, 2018; Li, Braver, & Chen, 2003; Ferguson, Teoh, & McCartt, 2007). This is especially evident when examining the fatal crash rate of drivers ages 16-17, which was nearly 4.5 times that of drivers ages 30-59, with a fatal crash rate of 3.75 per 100 million miles driven (Tefft, 2017), and resulted in 2,734 teen driver fatalities in 2016 (FARS, 2018). While these crash rates are considerably high, they do represent a significant decrease over the past 20 years, as the number of teen driver fatalities was 5,819 in 1996 (FARS, 2018).

A portion of this can be attributed to improvements in roadway and vehicle design, but the largest factor has been the stricter enforcement of impaired driving (Compton & Ellison-Potter, 2008; NHTSA, 2018). In the mid 1970's, alcohol was the leading factor in vehicle fatalities and the primary contributing factor in over two-thirds of fatal crashes among persons 16-20 year of age (NIH, 2010). The number of alcohol-related deaths in this same age group decreased from 3,456 in 1982 to 1,475 in 2017 (IIHS, 2018).

Additionally, the implementation of novice driver training programs (Creaser et al., 2015; McGehee et al., 2007; Simons-Morton et al., 2013), and graduated driver licensing (GDL) for teen drivers (Ferguson, Teoh, & McCartt, 2007; Regev, Rolison, & Moutari, 2018; Zhu, Cummings, Zhao, Coben, & Smith, 2015) have been shown to be effective in moderating crash-risk among teen drivers. Crash-risk decreases significantly for teens for each year of driving experience they have. The per mile crash rate of 16-year-olds is triple that of 18-year-olds and ten-fold that of adult drivers (McKnight & Peck, 2003; Williams & Ferguson, 2002). Driver's crash risk continues to decline significantly by year until their mid-20's, where it remains relatively consistent until around age 70 at which, on average, it begins to increase yearly (Tefft, 2017; FARS, 2018). However, the causes of this increased crash-risk and corresponding types of crashes older drivers are involved with varies significantly from teens, which necessitates a different approach for reducing older drivers' likelihood of being in a crash (Cicchino & McCartt, 2015; Shen & Neyens, 2015).

2.1.3 Crash Trends among Aging Drivers

In 2015, people age 65 and older accounted for 15% of the population (U.S. Census Bureau, 2018). There was a 34% increase in the number of licensed drivers over age 65 during this same period (NHTSA, 2017), indicating that not only are there greater older drivers on the road than ever before, but they are also remaining behind the wheel for longer (Broberg & Willstrand, 2014). There was, however, a 3.1% decrease in the deaths per 100,000 people age 70 and older during this period (IIHS, 2018). Therefore,

while the population of older drivers has been increasing sharply, there has been a drop in the overall fatal crash rate. This seems to largely attributable to increases in crash survivability, as individuals tend to increase in frailty as they age (Tefft, 2017; Cicchino & McCartt, 2014; Li, Braver, & Chen, 2003), but there are improvements in roadway design, vehicle safety, and improvements in both the overall health of older adults and medical emergency response times (Cicchino, 2015).

In 2017, there were 6,764 people 65 and older killed in traffic crashes, accounting for more than 18% of all motor vehicle-related deaths (FARS, 2018). There were also an estimated 240,000 drivers over age 65 injured in 2015, which accounted for approximately 10% of all non-fatal injury crashes (NHTSA, 2017). Encouragingly, since peaking in the late 1980s, the fatal crash rate of older drivers has been decreased significantly, until 2014 when it began slightly increasing (Cicchino & McCartt, 2014; FARS, 2018; IIHS, 2018). Older adult drivers are the least likely of any age group to be involved in a fatal crash (NHTSA, 2017), but are significantly more likely to be in a non-fatal crash than middle-age drivers (NHTSA, 2017, 2018) and the crash risk for drivers over age 75 is similar to that of teenage drivers and exceeds it after age 85 (IIHS, 2018; NHTSA, 2017).

This is interesting because unlike novice drivers who are inexperienced and tend to engage in risky driving, older drivers, conversely, tend to drive much more cautiously than other age groups (Elander, West, & French, 1993; McNamara, Chen, George, Walker, & Ratcliffe, 2013). They are less likely than other age groups to be involved in a fatal crash where speed was a primary contributing factor (NHTSA, 2018). They also have the lowest incidence of alcohol-related fatalities of any age group. A BAC of .08 or higher is a primary contributing factor in 20% of all fatal crashes, but only 8% of fatal crashes for drivers over age 65 (NHTSA, 2017). Additionally, older drivers have been observed to wear their seatbelts more frequently relative to other age groups (Tefft, 2017; Pickrell & Ye, 2009). Furthermore, it is often shown that some older drivers may modify their driving to avoid more dangerous scenarios such as driving at night or in rush-hour traffic when crash rates are higher (Eby, Molnar, Shope, Vivoda, & Fordyce, 2003; Gwyther & Holland, 2011; McGwin & Brown, 1999). This is evidenced by 74% of older driver fatal crashes occurring during the daytime relative to 49% of crashes for all other age groups. Additionally, 70% of fatal crashes involving older drivers occur on weekdays compared to 59% for all other drivers (NHTSA, 2017).

The most common types of crashes among senior drivers also tend to differ as well, as they are at an increased risk for being involved in a multi-vehicle collision relative to younger cohorts of drivers. In 2016, 67% of fatal crashes involving drivers over age 65 involved more than one motor vehicle in transit compared to 44% of fatal crashes for all other age groups (FARS, 2018). As drivers age, they are more likely to be in a right-angle collision at an intersection crossing (Cooper, 1990) and these crashes make up approximately half of older driver multi-vehicle collisions (Cicchino & McCartt, 2015; Hakamies-Blomqvist, 1993), the vast majority of which occurred when they were making left turns (Keskinene, Ota, & Katila, 1998; NHTSA, 2017). They are also significantly more likely than other age groups to be at-fault in a crash where the primary contributing factor is 'Failure to Yield Right of Way' (NHTSA, 2017).

Despite being less likely to exhibit risky driving behaviors and having a wealth of driving experience, the crash-risk per licensed driver per mile is higher for older adults than any other age group except for those aged 16-24 (Cerrelli, 1998; Cicchino & McCartt, 2015; IIHS, 2018). This examination of driver crash data suggests there is an effect of aging on driving performance, which has been well supported in the literature (Horswill et al., 2008; Owsley & McGwin, 2010; Verhaeghen & Cerella, 2002; Wood, 2002). Although a significant number of seniors are quite safe drivers, the rapidly growing number of older drivers necessitates an understanding of the effects of aging on driving performance for the development of practical interventions to aide drivers in safely maintaining their mobility as they age.

2.2 THE EFFECTS OF AGING ON DRIVING

2.2.1 The Effect of Age on Vision and its Role in Driving

As we age, we exhibit clear individual differences in many different skills and driving is no exception. It is thus widely understood that it would be inappropriate to restrict driving based on an individual's age, but rather that driver eligibility should be based on the ability to drive safely. This has led to numerous studies investigating differing aspects of driver performance in aging drivers in an attempt to understand the difference in crash-risk and crash characteristics between older and younger drivers (Gwyther & Holland, 2011; Horberry, Anderson, Regan, Triggs & Brown, 2005; Verhaeghen & Cerella, 2002).

Much of this research has focused on the role of vision in driving. It has been estimated that as much as 90% of the information used in driving is visual (Hills, 1980; Kline et al., 1992). Because driving is such a highly visual task, it has been suggested that the increased incidence of visual impairment of older individuals may contribute to the increase in crash rates among aging drivers (Shinar & Schieber, 1991; Shinar, McDowell, Rackoff & Rockwell, 1978). Indeed, there has been a wide body of research examining the influence of specific visual impairment on driving performance (Freeman, Munoz, Turano & West, 2005; Kline et al., 1992; Sifrit, 2005; Underwood, Chapman, Brocklehurst, Underwood & Crundall, 2003).

For visual perception, age-related declines occur for visual acuity, contrast sensitivity, motion-in-depth, gaze stability, critical flicker frequency, and absolute thresholds (Ball, Owsley, Sloane, Roenker & Bruni, 1993; Smither et al., 2004). Furthermore, older drivers have changes in color vision and increased sensitivity to glare (Smither et al., 2004, Wood, 2002). These age-related shifts lead to the following concerns for older drivers: inability to see or easily discriminate roadway information (e.g., signs and traffic controls), difficulty seeing with low illumination, poor adjustment to glaring light, difficulty processing color-coded information on the road, impaired gap-judgment, and impaired tracking of objects (Ball et al., 1993; Freeman et al., 2005; Kline et al., 1992; Owsley & McGwin, 2010).

The role of visual acuity, which measures the ability to discriminate fine details, has been one of the most widely studied visual assessments, primarily due to its role as the standard visual screening test for driving eligibility (Ball et al., 1993; Wood, 2002). Despite its ubiquitous use among state licensing

bureaus, research examining the validity of visual acuity in predicting driving safety has yielded ambiguous results. In a study of more than 13,000 drivers, Hofstetter (1976) found higher crash rates among drivers with poorer visual acuity, which is similar to the results of several other similar large-scale studies (Davison, 1985; Shinar, 1977). Conversely, Burg (1967, 1968), one of the first to assess the role of visual acuity and driving safety, found that visual acuity was not associated with crash involvement for young and middle-age drivers and observed only mild correlations among older drivers. These findings have been replicated in several other studies that also found little to no evidence of an association between visual acuity and crash involvement (Hills & Burg, 1977; Humphries, 1987; Owsley, Stalvey, Wells, Sloane, & McGwin, 2001).

While visual acuity has not been shown to be a good predictor of driver safety, measures of contrast sensitivity have yielded more encouraging results regarding its validity in assessing driver crash-risk. Studies examining the crash history of older adults found that poorer measures of contrast sensitivity were correlated with recent crash involvement (Decina & Staplin, 1993; Ball et al., 1993). Additionally, multiple studies have also found a strong association between contrast sensitivity and driving performance (Horswill et al., 2009; McGwin, Chapman, & Owsley, 2000; Wood & Troutbeck, 1995; Wood, Dique, & Troutbeck, 1993). Furthermore, Hennessy & Janke (2009) assessed the contrast sensitivity of drivers at a state licensure department who were renewing their license and found drivers who failed were more likely to be involved in a crash in the years following than those who passed their assessment.

While this demonstrates the association between contrast sensitivity and crash involvement, it is important to note that several prospective studies assessing contrast sensitivity have reliably predict future crash involvement (Cross et al., 2009; Rubin et al., 2007). Nonetheless, the use of contrast sensitivity assessments for driver license renewals would seemingly be beneficial due to the high incidence of cataracts with age, which are known to impair contrast sensitivity (Owsley et al., 2001). However, since cataracts can often be treated with surgery, researchers have sought to understand how driver performance is impacted among individuals after cataract removal (Owsley et al., 2002). In a study examining the effect of contrast sensitivity on driving performance, Wood and Cranberry (2004) found that drivers with cataracts, and subsequently poorer contrast sensitivity, performed significantly worse on a closed-course relative to drivers who had recently had cataract surgery.

In addition to visual acuity and contrast sensitivity, there is a breadth of research on several other aspects of visual function, including visual field, color vision, visual processing speed, binocular vision, and dynamic visual acuity. Several comprehensive reviews of these visual assessment methods have been performed (Ball et al., 1993; Kline et al., 1992; Owsley & McGwin, 2010; Wood, 2002). Similar to the findings on visual acuity's effect on driving safety, these measures of visual processing have produced conflicting results regarding the efficacy of their ability to accurately predict crash involvement and the role they play in driver performance.

Although it is difficult to draw direct associations between visual impairment on both driving safety and performance, there are distinct visual perception declines associated with aging that may present challenges for older adults under certain driving scenarios. In a review of the literature on perception and driving, Smither et al. (2004) outline how these age-related shifts lead to the following concerns for older drivers: inability to see or easily discriminate road signs, difficulty seeing with low illumination, poor adjustment to glaring light, difficulty processing color-coded information, impaired gap-judgment, and impaired tracking of objects. While the results of this review of visual impairment may have implications for older driver safety, visual assessments alone may not be able to fully assess an individual's capacity for safe driving, in part because drivers may adapt to avoid more challenging conditions (e.g., nighttime, inclement weather, sunset [Ball et al., 1993; Broberg & Willstrand, 2014]). Additionally, despite driving being a highly visual task, it also requires the coordination of several subtasks and involves some level of multi-tasking (Aksan, Anderson, Dawson, Uc, & Rizzo, 2014). Because of this, numerous studies have also investigated the role of cognition in driving and the effect aging has on cognitive functions associated with driving.

2.2.2 The Effects of Age on Cognition and its Role in Driving

Although many older adults still enjoy good health and are quite safe drivers, it is understood that aging can influence cognitive functions associated with driving performance and safety (De Raedt & Ponjaert-Kristoffersen, 2000; Verhaeghen & Cerella, 2002). A recent retrospective longitudinal study of crash involvement among older drivers provides some credence to the association between functional skills and older driving safety. Fraade-Blanar et al. (2018) found that over a seven-year period, older drivers who scored significantly worse on a battery of cognitive assessments had a crash involvement rate ratio of 1.26 relative to older individuals who demonstrated higher levels of cognitive function. It is important to note, however, that the term "older adult" can be vague and is often poorly defined. Charness (2008) argued that it may be more appropriate to separate aging individuals into separate categories: young-old (65-74), middle-old (75-84), and old-old (85+). The reason for this is that there seem to be considerable age-related differences between these groups. This is indeed reflected in crash data where crash-risk is shown to increase substantially after age 75. This continuum of age is relevant to keep in mind when considering the following review and its implications for driving.

Given the understanding that age affects cognitive functioning, a battery of tests has been developed and used by investigators to assess how cognitive functioning predicts different dimensions of driver safety and performance among older individuals. Multiple studies have utilized various standardized tests measuring neuropsychological aspects such as the MMSE, Trail Making Test, copying complex figures, digit symbol substitution, and block construction (Anderson et al., 2012; Dawson et al., 2010, Lafont et al., 2010; Odenheimer et al., 1994; Uc et al., 2009). Additionally, other investigators have relied on measures related to cognitive processing and motor response (e.g., reaction time) to record driver response to environmental stimuli (Anstey & Woods, 2011; Woods et al., 2008).

Despite many investigators using such cognitive tests in conjunction with the visual assessments discussed previously to examine the effect of aging on driving, the lack of uniformity in test selection between studies often makes it difficult to summarize or generalize their results regarding age-related visual and cognitive impairment (Aksan et al., 2014; Cuenen et al., 2015; Owsley & McGwin, 2010). Furthermore, while individual aspects of visual and cognitive functioning clearly play their role in driver performance, there is still debate regarding which assessments are most useful and valid in determining driver eligibility (Freeman, Munoz, Turano & West, 2005; Horswill et al., 2008; Ball, Owsley, Sloane, Roenker & Bruni, 1993).

One reason for this is that much of the research on aging focuses on driving performance. Driving performance can be defined as the behaviors exhibited when operating a vehicle and can be measured either by a trained evaluator or through physical measures (e.g., speed, lane keeping, braking, accelerating, reaction time). Driving safety, conversely, refers to involvement in unfavorable driving-related events, typically vehicular crashes. While these two metrics should conceivably be correlated, there is often little evidence that directly connects them (Koppel et al., 2016, 2017; Owsley & McGwin, 2010; Ratz, 1978). This is primarily due to assessments of safety coming from a person's lifetime of driving compared to assessments of performance, which only measure an individual's ability during the relatively small timeframe of a research study or assessment.

What may be of greater interest is a driver's ability to properly integrate aspects of visual and cognitive functioning within a complex, quickly changing environment and detect critical events whenever they may arise (Hoyer & Plude, 1982; Sekuler & Ball, 1986; Shinar et al., 1978). The uncertainty in normal driving associated with when and where these events will occur has led many aging researchers to examine the relationship between visual attention and both driving performance and safety (Ball et al., 1993; Ball, Owsley et al., 1991; Sifrit, 2005; Wood et al., 1993). Visual attention refers to a person's ability to direct information processing resources to task-relevant events within the environment and has been shown to be critical in crash avoidance (Ball et al., 1993; Matas, Nettlebeck, & Burns, 2014). Thus, if visual attention is impaired either through normal aging or through the onset of a degenerative neurological disease, it could have significant safety implications for drivers.

The Useful Field of View (UFOV) is a validated assessment for measuring visual attention first tested among aging drivers by Ball, Owsley, & Beard (1990) that has been widely used in assessing older driver performance and safety. Ball et al. (1993) found that older drivers with moderate to severe reduction in their UFOV were significantly more likely to have been involved in a crash within the previous five years. These retrospective results have also been replicated in numerous other studies examining UFOV scores and crash involvement of older drivers, providing further validation for its use in assessing driver capacity (Ball, 2006; Clay et al., 2005; Cross et al., 2009; Owsley et al., 1991, 1998). Measures of UFOV have also shown to be effective in prospectively predicting crash risk. Owsley et al. (1998) found that even when accounting for older driver age, functional capability, race, gender, and driving exposure, individuals with greater than 40% impairment on the UFOV were more than twice as likely to be involved in a crash in the three years following compared to drivers with normal UFOV scores.

It has, however, been argued that UFOV may potentially be more of a measurement of cognitive capacity and is not as dependent on the age-related constricting of a person's physical useful field of view (Seiple, Szlyc, Yang, & Holopigian, 1996). Indeed, multiple studies have found that older adult driving performance, while predictive through UFOV scores, was only correlated levels of cognitive functioning, not visual functioning (Coeckelbergh et al., 2004; Fiorentino, 2008; Sekuler, Bennet, & Mamelak, 2000). While it may not be entirely certain which underlying mechanisms of visual attention best predict crash-risk, it remains one of the most reliable assessments for predicting driver safety (Edwards et al., 2005; Goode et al., 1998; Owsley & McGwin, 2010; Wood et al., 2012). Additionally, UFOV scores have been highly correlated to measures of hazard perception ability among older adults (Horswill et al., 2008, 2009; Wetton et al., 2010; Wood et al., 2012), which has been argued to be the only advanced driving skill associated with crash involvement (Horswill & McKenna, 2004).

2.2.3 The Effects of Age on Hazard Perception

Hazard perception can be defined as a driver's ability to anticipate potentially hazardous situations on the roadway and is the only driving ability that has consistently been highly correlated with crash involvement (Horswill & McKenna, 2004; Horswill et al., 2009; Wetton et al., 2010). Typically, hazard perception is assessed by measuring driver response times to the onset of potential hazards in a variety of traffic situations using either driving simulators (Quimby et al., 1986; Watts & Quimby, 1979) or, more commonly, video sequences captured from real-world driving, as shown in Figure 2.1 (Burge & Chaparro, 2018; Hill, Horswill, Whiting, & Watson, 2019; Horswill, 2016).

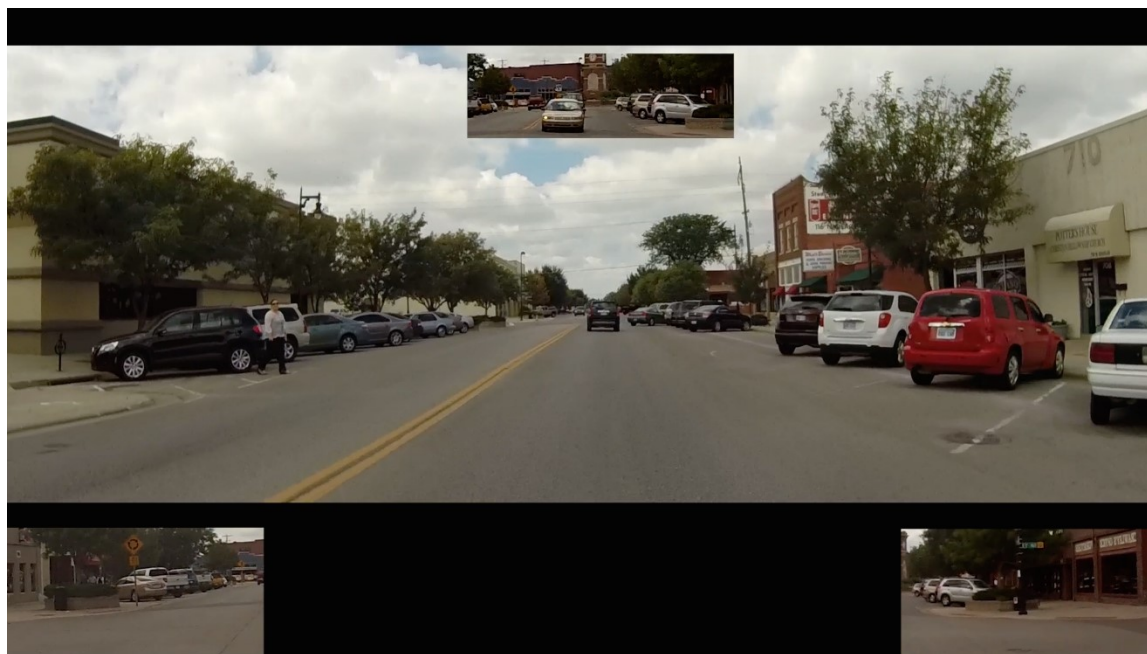


Figure 2.1 Sample Screenshot of hazard perception video (Adapted from “An investigation of the effect of texting on hazard perception using fuzzy signal detection theory” by Burge & Chaparro, 2018).

Of all fitness to drive assessments, tests of hazard perception may have the most compelling argument due to its ability to predict not only driver performance but also driver safety through both retrospective and prospective studies of crash involvement (Horswill, 2016; Horswill, Hill, & Wetton, 2015). Drummond (2000) summarized a large-scale study conducted by the Australian Council of Educational Research on over 100,000 probationary, novice drivers who completed a hazard perception assessment. They found that those who scored low on the test were more than twice as likely to have been involved in a fatal crash in the year following relative to those who scored well on the test. These results have been replicated in several other prospective crash studies measuring hazard perception (Darby et al., 2009; McKenna & Horswill, 1999; Wells et al., 2008). Additionally, multiple retrospective studies have found that drivers who performed poorer on hazard perception assessments were significantly more likely to have been involved in a police-reported crash in the two years prior to their assessment (Horswill & McKenna, 1999; McKenna & Crick, 1991).

Since hazard perception heavily relies on a driver's awareness and ability to predict where hazards may occur, it is considered to be associated with driving experience (Horswill et al., 2010; Horswill, Garth, Hill, & Watson, 2017). One of the earliest studies on hazard perception by Quimby & Watts (1981) found that hazard perception latency was fastest for drivers age 35-54 and slowest for drivers under 25 and over 65. In multiple other studies of hazard perception, novice drivers tend to exhibit poorer response times relative to middle-aged drivers who can rely on years of experience to aide them (Horswill, 2016; Horswill et al., 2008; McKenna & Crick, 1991; Smith et al., 2009). Because hazard perception relies on visual scanning of the environment, these results make sense given the differences in visual scanning between novice and experienced drivers.

Mourant & Rockwell (1972) compared the visual processes and fixation patterns of novice and experienced drivers. They found that, in contrast to experienced drivers, novices were more likely to fixate on smaller areas of the roadway, most of which were directed towards the area just ahead of the vehicle or to the right of the roadway and were less likely to use their side or rear-view mirrors. In addition to these findings, more recent studies have shown that novices tend to have longer fixation durations, demonstrate poorer search patterns, and often fail to properly direct their attention to potentially hazardous areas of the roadway (Crundall & Underwood, 1998; Pradhan et al., 2005; Underwood, Chapman, Bowden, & Crundall, 2002). This indicates that lack of experience translates to poorer visual scanning and prediction of potential hazards, which would seem to explain the difference in hazard response times associated with driving experience.

Interestingly, hazard perception has been shown to decline with age, indicating that it is not a skill solely reliant on driving experience (Quimby & Watts, 1981). Horswill et al. (2008) found a significant association between age and hazard perception response times in a study of 118 drivers 65 years and older. Furthermore, retrospective studies measuring hazard perception ability among older adults found that drivers with significantly slower mean response times were 2.32 times more likely to have been involved in a crash within the past five years (Horswill et al., 2010). However, the onset of decline in hazard perception may not become as pronounced until quite later, as Horswill et al. (2009) found that

healthy young-old drivers (65-75) and middle age drivers (35-55) had similar response times to hazards, but healthy middle-old (75-84) drivers had significantly slower response times than both younger groups, which is congruent with crash rates that increase much more so for drivers after age 75 (NHTSA, 2018). This effect of age on hazard perception ability suggests that declines in functional capabilities that play a role in hazard perception.

As mentioned earlier, measures of UFOV have often been assessed, as well as contrast sensitivity, in hazard perception studies, particularly among those studying older drivers. The results indicate that these measures of cognitive and visual functioning have been shown to be equally reliable as hazard perception ability in predicting crash involvement (Horswill et al., 2008, 2009, 2010a, 2010b; Matas et al., 2014; Wetton et al., 2010; Wood et al., 2012). The implication of this is that the visual and cognitive functions underlying visual attention likely play a very similar role in mediating hazard detection (Horswill et al., 2008). These decreases in hazard perception, the most predictive skill associated with crash involvement, which seems to be driven by cognitive and perceptual declines, could be one reason that largely explains the increase in crash-risk among older drivers, despite their exhibiting more cautious driving behaviors than all other age groups (Glasgow & Blakely, 2000; McGwin & Brown, 1999).

This idea is reinforced by Elander, West, & French (1993) who, after an extensive review of road-traffic crashes concluded that crash involvement most often stemmed from the combination of driving style (e.g., speeding, willingness to commit violations) and driving skill (e.g., hazard perception latency, vehicle control). Regarding the latter, which would seem to particularly apply to older drivers, they determined that both the ability to identify visual targets and attention were paramount. This is consistent with the finding that driver inattention is a major contributing factor in motor vehicle crashes, especially among novice and aging drivers (Klauer et al., 2014; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Regan, Hallet, & Gordon, 2011). Thus, when considering potential interventions to mediate older driver crash-risk, in addition to understanding the effect aging may have on functional capabilities and consequently, hazard perception ability, it is also necessary to understand the role of attentional allocation in driving. Furthermore, in the context of aging drivers, the term driving style may be better re-framed as driving habits, given that older drivers will have developed a certain approach over their many driving years, given repeated exposure in relation to their behind-the-wheel experience.

2.2.4 The Role of Attention in Driving

2.2.4.1 Framework for Selective Attention

Before discussing the effect of *inattention*, it is first useful to define to what *attention* refers. While there are nearly as many definitions of attention as there are attempts to define it, the definition put forth by Streff and Spradlin (2000) encapsulates many of these definitions of attention as *the process of concentrating or focusing limited cognitive resources to facilitate perception or mental activity*. Inattention, conversely, can then be assumed some type of failure of attention. Although the role of inattention has been studied rather extensively within the field of driving safety, the term “driver

inattention,” while frequently used in the literature, is inconsistently defined and may refer to several specific types of inattention (Regan et al., 2011). This is important to note when attributing inattention as a contributing factor to a vehicular crash because one could easily infer this to mean that a crash could have been avoided if the driver had been paying *enough* attention. However, in a review of driver inattention literature, Regan et al. (2011) note that inattention, as it pertains to driving, encompasses numerous elements: insufficient attention, cursory attention, selection of irrelevant information, lack of attention, orienting attention to daydreaming (i.e., mind wandering), drowsiness, rubbernecking, and engaging in secondary activities. This review of driver inattention led the authors to summarize its definition as *insufficient attention to activities critical for safe driving*. In other words, it is not simply the amount of attentional resources allocated to the task of driving, but rather the act of appropriately selecting what to attend to within the environment that dictates safe driving. However, defining where attention should be directed is often ambiguous and dependent on the scenario and is contingent on several factors, including, driver experience, route familiarity, driver’s physical and mental state, traffic complexity, weather, time of day, and vehicle speed.

The lack of consistency in defining *driver inattention* along with the difficulty of defining where attention should be allocated under differing driving scenarios has led some researchers to propose a theory of attentional selection to unify the research of driver inattention (Trick, Enns, Mills, & Vavrik, 2004; Trick & Enns, 2009). They provide a two-dimensional framework (See Figure 2.2) for attentional selection when driving: 1) selection with or without awareness (controlled & automatic) and 2) selection with no goal or goal-directed selection (exogenous & endogenous). The model postulates four modes of selection: 1) reflex (automatic-exogenous); 2) habit (automatic-endogenous); 3) exploration (controlled-exogenous); and, 4) deliberation (controlled-endogenous).

This theory provides an outline for understanding the role selective attention plays in hazard perception. Furthermore, it provides a means for predicting how age-related declines in functional capabilities may affect the anticipation of dangerous traffic situations under varying driving scenarios. This is further supported when exploring the circumstances of the most frequent types of crashes in the older driver population.

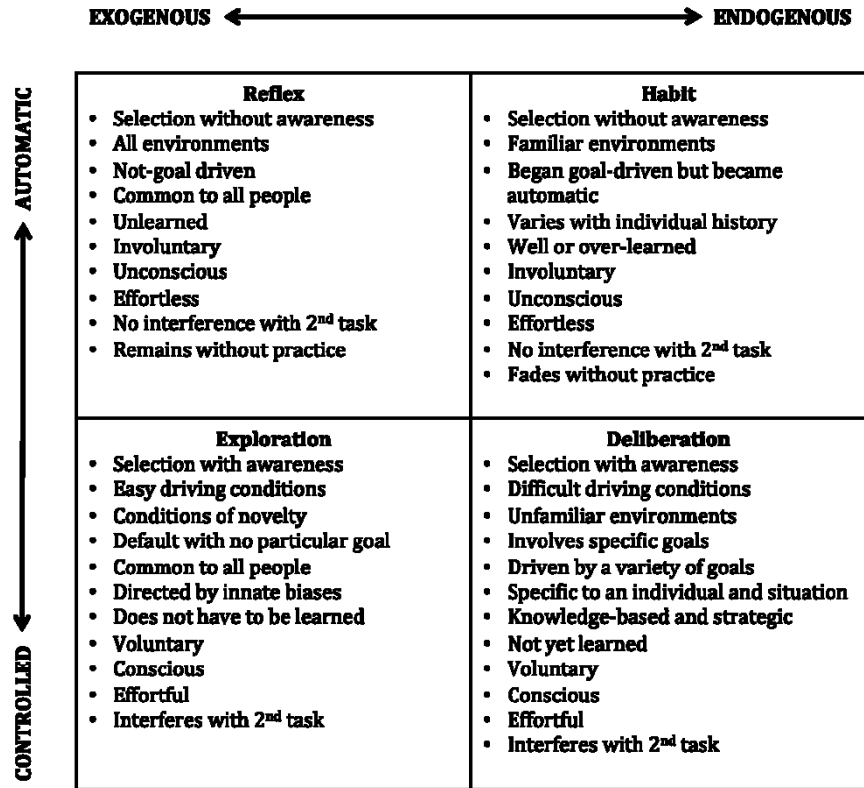


Figure 2.2 Two-dimensional framework of selective attention (Adapted from “Paying attention behind the wheel: a framework for studying the role of attention in driving” by Trick et al., 2004)

2.2.4.2 Reflexive Attention Selection

Reflexive selection (automatic-exogenous) refers to the attentional selection that is processed automatically, without driver awareness. Automatic processes, in driving, are effortless and can be carried out in addition to other driving-related processes without compromising performance. Automatic-exogenous (reflexive), then, refers to automatic attentional responses to external stimuli in or around the roadway. These reflexive responses are not goal driven, nor are they dependent on experience, as they can be seen even among novice drivers, meaning they may very well be inaccurate and counterproductive responses. Visual illusions are one of the most common types of stimuli that elicit reflexive selection among drivers. Certain configurations of stimuli may be selected and processed to create a situation where what is perceived is at odds with what the driver understands about the environment.

Because this reflexive selection is involuntary and not goal-directed, it has little to no role in hazard perception, which is thought to be a goal-oriented, conscious process, requiring higher levels of attention and cognitive processing (Gugerty, 2012; Horswill et al., 2008; Horswill & McKenna, 2004). However, reflexive selection of irrelevant stimuli may impede hazard perception. For example, a dancing, air-inflated man used to attract attention to a car lot at a busy intersection, may divert a driver’s attention away from the busy intersection they are approaching. To overcome this reflexive

attentional response, the driver must deliberately control their attention to maintain focus on the approaching intersection. This ability to inhibit attention to irrelevant stimuli may be impaired with age as older adults have been shown to be poorer at task-irrelevant inhibition (Schooler, Neumann, Caplan, & Roberts, 1997; Sullivan & Faust, 1993; Verhaeghen & Cerella, 2002). Poorer inhibition may potentially have adverse consequences then, especially during more complex scenarios, such as navigating busy intersections.

2.2.4.3 Habitual Attention Selection

Habitual selection (automatic-endogenous) refers to the selection that, like reflexive, is unconscious and effortless; however, it is predicated on behaviors that were once goal-driven but have become automatized with experience. When goals are repeatedly enacted and carried out, they can become habitual and unconscious, requiring little to no effort. Once an action has become habitual, it becomes possible to carry out that action while engaging in a second task with minimal interference. Driving skills are, in large part, habits that drivers have developed over years of repeatedly carrying out specific actions, particularly among familiar routes (Charlton & Starkey, 2011). One of the reasons novice drivers are thought to be more prone to crashes relative to experienced drivers is their lack of automated motor skills necessary for driving, which may result in them being particularly susceptible to interference from a secondary task (Klauer et al., 2014; McGwin & Brown, 1999). Because habitual selection relies on experience, hazard perception would presumably be impacted by the automatized visual search patterns of drivers, especially in areas they are more familiar with. The role of experience in search patterns is reinforced by multiple studies that have examined the visual search differences between novice and experienced drivers, where novices have shorter fixation durations, narrower scanning patterns, and attend to more relevant areas of the roadways less often (Crundall et al., 2002; Maltz & Shinar, 1999; Romoser & Fisher, 2009).

Despite the benefits of experience, there may also be counterproductive effects of habitual selection that occur with age, particularly under more complex driving environments that require multiple coordinated motor responses. Hakamies-Blomqvist, Mynttinen, Backman, and Mikkonen (1999) measured the use of car controls during normal driving for older and middle-aged drivers, and found that unlike middle-aged drivers, older drivers tended to use less than four controls during complex driving scenarios, suggesting a shift to less cognitively complex movements in later ages. This is further illustrated in work by Belanger et al. (2015) who found that older drivers crashed more frequently in a simulated driving environment for events that required multiple synchronized reactions (e.g., braking and steering).

2.2.4.4 Exploratory Attention Selection

The third mode of the framework is exploratory selection (controlled-exogenous). This mode of selection is effortful, conscious, and voluntary. This mode of selection governs where drivers allocate their attention when there is no specific goal towards which the drivers are working. When drivers are not fully occupied with the task of driving, they may be prone to exploring the roadside (e.g., billboards,

buildings, trees) as well as within the vehicle (e.g., in-vehicle screens). Because hazard perception is goal-directed, exploratory selection would seemingly play little role in the task of hazard detection other than if a potential threat was discovered during exploration. However, exploratory selection may impede hazard perception latency if a driver is overly distracted with their surroundings.

Because hazard perception relies on deliberate attention, familiarity with an environment may impede the amount of deliberate attention a driver allocates toward task-relevant stimuli. Young, Mackenzie, Davies, and Crundall (2018) conducted an on-road driving study with experienced drivers along both familiar and unfamiliar driving routes. They found that even while under observation, driver eye movements toward driving-irrelevant stimuli along the roadside increased significantly along familiar routes. This undesirable change in visual attention along familiar routes may have potential consequences for crash-risk. Indeed, multiple studies have found that when driving along a familiar route, experienced drivers exhibit reductions in their responses to abrupt or unexpected hazards (Charlton & Starkey, 2013; Yeung & Wong, 2015). Yanko & Spalek (2013) compared response times to hazardous scenarios among drivers for routes they were familiar and unfamiliar with. They found that when on a familiar route, drivers exhibited lower detection rates and slower response times to hazards, which was attributed to mind wandering due to route familiarity. While these effects are relevant to drivers of all ages, they may be especially pertinent to older drivers, as they have been shown to restrict their driving patterns to places that are familiar and closer to home much more so than any other age group (Braitman & McCartt, 2008; Gwyther & Holland, 2011).

2.2.4.5 Deliberate Attention Selection

Deliberate selection (controlled-endogenous) is the most flexible and cognitively demanding of all. This mode of selection involves goal-oriented behaviors that are specific to the current driving environment. Because hazard perception relates to the ability to anticipate potentially dangerous situations on the roadway and is considered a highly goal-oriented task, requiring significant cognitive effort, this form of selection is the primary form of attentional allocation required for hazard perception. This form of selection is then necessary for a variety of driving scenarios: 1) under challenging conditions (e.g., heavy traffic, unexpected events, intersections, inclement weather); 2) when acting strategically rather than just reactively to traffic scenarios; 3) when performing dual-task activities that require attention to secondary tasks as well as continued environmental monitoring; and, 4) when drivers must monitor their behavior to overcome potentially maladaptive habits and reflexes.

Selection through deliberation may, however, be impacted due to differing age-related declines. In conditions when stimulus visibility is degraded, older drivers may have difficulty compensating for the low-quality perceptual information. Ni, Bian, Guindon, and Andersen (2012) found that older drivers performed more poorly relative to younger drivers on a collision detection task under a simulated dense fog. Additionally, the extent to which a driver will be able to utilize this higher level of selection will be heavily dependent on the complexity level of the driving environment (Belanger et al., 2015; Lavie,

2006) as well as their overall attentional capacity, which has been shown to decline with age (Cuenen et al., 2015; Plude, Enns, & Brodeur, 1994).

2.2.4.6 Summary of Selective Attention

This framework by Trick et al. (2004) provides a useful means of understanding how potential age-related effects in driving may affect hazard perception among older drivers under varying traffic circumstances. Maladaptive behaviors may occur under any mode of attentional selection due to aging as well as individual differences in driving attitudes and skill. Because maladaptive behaviors during automatic modes of selection can be compensated for and overcome through controlled modes of selection, generating and maintaining effective controlled attentional selection is paramount.

Trick and Enns (2009) suggest that generating positive changes in habitual selection may be best achieved through either aversive or pleasant feedback regarding those behaviors. Indeed, Freedman, Lerner, Zador, Singer, and Levi (2007) found that seat belt reminders that persist until seat belts are buckled were demonstrated to significantly improve compliance, even among groups such as teenagers that have relatively lower seatbelt usage. Mitigating problematic behaviors that occur during deliberate selection may be best accomplished through attitude changes and education of drivers (Broberg & Willstrand; 2014; Eby et al., 2003; Trick & Enns, 2009). As mentioned earlier, modifying driver behavior is one, and perhaps the most important, approach to reducing traffic crashes (Johnson, 2010; Trick & Enns, 2009). The implications of this framework are useful when attempting to mediate crash-risk among aging drivers, particularly through changes to endogenous modes of selection.

2.2.5 Summary of the Role of Aging in Driver Safety

Driving ability has been shown to decrease with age, and this reduction in driver capacity is associated with age-related declines in visual and cognitive functioning. Assessments of fitness-to-drive (e.g., UFOV, hazard perception, contrast sensitivity) may be useful in identifying which drivers are likely to present a risk to themselves and other drivers, however, driving cessation has been shown to have a myriad of negative consequences (Cobb & Coughlin, 2000; Glasgow & Blakely, 2000). With the rapidly increasing number of senior drivers on the roadway, one potential solution is to develop interventions that can aid older drivers in safely preserving their mobility. The purpose of this review was to provide an understanding of the role aging might have on driver behavior, specifically concerning driving environments that are shown to present the most difficulty for seniors. A comprehensive understanding of aging effects driving allows for the development of more informed approaches aimed at mediating older driver crash-risk.

Considering most older drivers tend to be much more cautious than younger cohorts, increased enforcement is unlikely to have the same effect that it has had on novice drivers. Because the most common types of crashes involving at-fault senior drivers are primarily attributed to factors associated with failures of attention (e.g., failure to yield, improper merge, improper lane usage, disregard traffic sign, following too closely; IIHS, 2018 NHTSA, 2017), it may be most useful to focus on mediating

behaviors associated with these factors. Thus, interventions should focus on effective behavioral modifications that improve hazard perception, specifically for through improvements to habitual and deliberate modes of selective attention.

2.3 INTERVENTIONS FOR DRIVER SAFETY

2.3.1 Understanding Driver Safety

Eliciting behavioral modifications that improve driving safety first necessitates an understanding of the tenets of driver safety. Anstey, Wood, Lord, & Walker (2005) proposed the Multifactorial Model of Driving Safety based on an in-depth review of literature evaluating driving safety and crash-risk among older adults. They concluded that crash-risk among older drivers was predicated on two factors: 1) their capacity to drive safely; and 2) their self-monitoring and beliefs about their own driving capacity. They proposed that driving capacity, which is the ability to avoid crash involvement, was predicted by three functional factors: 1) cognitive function; 2) sensory function; and, 3) physical function. However, accurate self-monitoring of these functions was also determined to play a large role in their driving behavior as well. This model is accordant with the conclusions of Elander et al. (1993), whose review of crash data and driving safety literature determined that driving skill, specifically hazard perception, and driving style, which was defined by the propensity to commit risky driving behaviors, intentionally or unintentionally, were the factors most likely to predict crash involvement. The combination of these two models is illustrated in Figure 2.3.

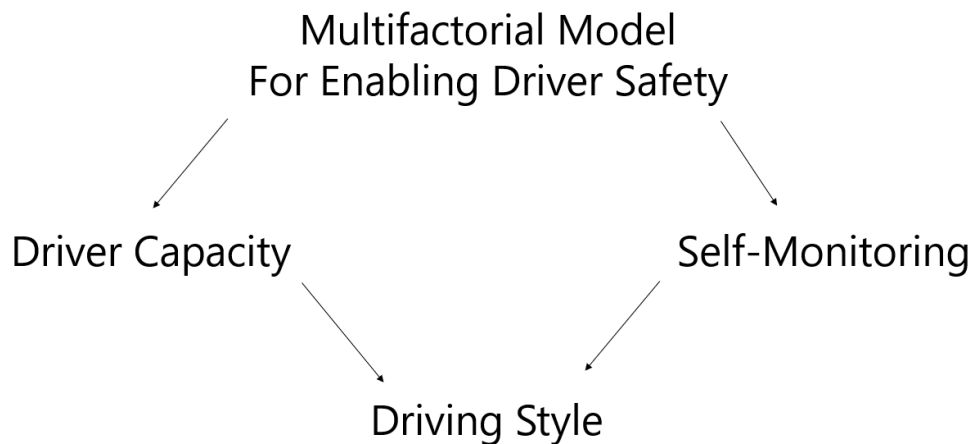


Figure 2.3 Image depicting the combination of the proposed models of driving safety by Anstey et al. (2005) and Elander et al. (1993).

Considering the conclusions of these two studies, driving safety can be determined to be a result of some combination of functional capability, self-monitoring of driving habits, and driving style. Both habitual and deliberate attentional selection play a role in all three of these driving safety-related traits. Age-related declines in functional capability may result in changes to habitual selection, which in turn

may have negative effects on driving style (e.g., braking too hard or poor speed maintenance). If a driver is unaware (i.e., poor self-monitoring) of negative changes to their habitual selection, they are unlikely to attempt to mediate those poor behaviors through deliberate attentional selection. Additionally, if aging negatively influences deliberate attentional selection, which is valuable for more complex traffic environments (e.g., intersection navigation), their driving capacity will likely be adversely affected. Because of this, solutions that focus on improving habitual and deliberate modes of attention should positively influence driver capacity, driving style, and self-monitoring, thus reducing crash-risk.

2.3.2 Improving Driver Capacity

While experience in any task is likely to improve performance, experience alone does not always equate to better performance, as is the case for many with driving. Achieving and maintaining acceptable levels of performance have been shown to benefit from deliberate effort, training, and feedback (Ericsson & Lehmann, 1996; Salas et al., 1999). These have all been investigated within the field of driving performance, however, there have been mixed results, particularly among aging drivers.

Many studies investigating the effect of training on driving performance among older adults have failed to find any benefit in actual crash-risk (Fisher et al., 2002; Groeger & Banks, 2007; Shinar, 2017). This may, however, be due to training programs focusing on aspects of driving (e.g., lane deviation) that are not well associated with crash-risk among aging drivers. Yet even studies examining the effects of hazard perception training, which has been shown to be highly correlated with crash involvement, have found that simply repeatedly exposing drivers to hazardous scenarios does not improve their performance in hazard detection (Horswill et al., 2010; Wetton, Hill, & Horswill, 2013). This is likely because learning with little to no adequate feedback occurs much more slowly (Ericsson & Lehmann, 1996; Ericsson & Ward, 2007).

Indeed, Horswill et al. (2017) examined the effect of three types of feedback on hazard perception performance: 1) graph-based feedback that showed participants their results compared to average and expert drivers; 2) video-based feedback between the same three groups; and, 3) both video and graph-based feedback. They found that when providing novice drivers with any of the three types of feedback during a hazard perception training task, they performed significantly better than a control group, with those receiving both forms of feedback improving the most. Similarly, Romoser and Fisher (2009) found that when older drivers were given active feedback about their visual scanning patterns while navigating turns in a driving simulator, they exhibited significantly more effective visual scanning patterns during a follow-up, on-road driving assessment. A control group and a group that received passive, classroom-based feedback regarding where to look when navigating turns at intersections demonstrated no improvement during the same post-study, on-road assessment.

These reports provide support not only for the potential benefit of training of older drivers but also especially for training that incorporates active feedback. The addition of feedback allows drivers to be more deliberate in how they manage their attention while driving, which has been shown to be useful in

navigating more complex driving scenarios (Trick & Enns, 2009; Trick et al., 2004). However, there is a question regarding the durability of laboratory training effects, as few studies have been able to find post-training improvements beyond one month (Horswill, 2016). This potential limitation in the effects of laboratory-based training has led some researchers to investigate the effects of in-vehicle feedback on driver behaviors associated with crash-risk and crash survivability.

Spyropoulou, Karlaftis, and Reed (2014) found that when drivers were provided with auditory and visual alerts regarding their speed, they demonstrated significant reductions in speeding propensity, which is known to increase crash-risk and reduce survivability. Despite being more cautious drivers, this is still quite relevant for older drivers as proper speed maintenance is the most frequently reported aspect they struggle with while driving (Broberg & Willstrand, 2014). Additionally, Creaser et al. (2015) found that providing novice drivers with real-time feedback when they exhibited excessive braking maneuvers resulted in significant decreases in the frequency of heavy braking. Hill et al. (2019) found that drivers who had higher rates of heavy braking during real-world driving scored significantly worse on a hazard perception test, which further supports the validity of hard braking maneuvers as a measure of driver skill associated with hazard perception. Given that hazard perception relies on a driver's ability to anticipate and predict hazards, it is reasonable that drivers who are more adept at this would be less likely to exhibit abrupt such abrupt behaviors as frequently.

In addition to improving driver behavior, in-vehicle feedback may also be useful in maintaining driver awareness, even in familiar environments where driving has been shown to become more automated. Charlton and Starkey (2013) found that after having participants drive the same route regularly for three months, they reported lower levels of mental demand associated with the task and improved performance of metrics associated with vehicle control. However, this increased level of familiarity also resulted in greater levels of inattentive blindness for changes along the roadside, demonstrating an automatized effect of visual scanning associated with route familiarity. These results are similar to those of Yanko and Spalek (2013) who found that when drivers were more familiar with the roadway, they were slower to detect and respond to both braking lead vehicles and pedestrians entering the roadway. However, they found that any effects of familiarity were eliminated when drivers were prompted to attend to the roadway.

Despite driving ability having been shown to decline with age, specifically regarding more complex scenarios, there is evidence that these potential age-related declines can be mitigated through active training and feedback. The training and feedback may then provide drivers with the relevant information necessary to exert more deliberate effort aimed at reducing negative driving habits they may have developed over the years. However, for drivers who have more significant functional declines and may not be able to make behavioral changes to address their safe navigation of complex driving environments, regulating their driving to avoid more difficult driving scenarios may be necessary. Yet, to make regulatory changes related to when and where one chooses to drive requires some level of awareness of one's own limitations.

2.3.3 Improving Driver Self-Monitoring

As discussed earlier, there is evidence that many older adults restrict their driving by avoiding more problematic or congested traffic situations (e.g., nighttime, inclement weather, rush hour, weekends; Baldock et al., 2006; Horswill et al., 2013; Sullivan et al., 2011) and these restrictions may play a positive role in older driver crash-risk as they have significantly lower crash rates during rush hour, at night, and on weekends relative to novice and middle-age drivers (NHTSA, 2017). The likelihood of drivers choosing to restrict their driving is most dependent on age, low confidence levels, and gender (Gwyther & Holland, 2011; McNamara et al., 2013). This may serve to explain to some extent why women over the age of 70 are three times less likely than their male counterparts to be involved in a fatal crash, however, it is more likely that there are simply many more drivers who are not adequately, if at all, restricting their driving

This is because drivers, of all ages, tend to have a self-enhancement bias, where they consider themselves to be much better, on average, than other drivers (Freund, Colgrove, Burke, & McLeod, 2005; Horswill et al., 2011, 2013, McNamara et al., 2013). Koppel et al. (2018) conducted initial on-road assessments of over 200 older drivers, along with another assessment 12 months later. They found that driver self-reported assessment of driving ability was not associated with actual performance and risky driving behaviors, nor did drivers perceived self-ratings change over the 12 months, despite significantly more critical driving errors being observed during the follow-up assessment. This indicates that drivers not only have poor insight into their own driving ability but also are unlikely to change their self-perception of those abilities despite evidence that their abilities are declining. This is consistent with work by Horswill et al. (2013) who found no relationship between drivers perceived and actual hazard perception abilities.

The concern then is that if older drivers lack insight into their own driving ability, they are unlikely to regulate appropriately their driving strategies to compensate for any age-related declines in driving ability. Multiple assessment methods have been developed to give aging drivers a more accurate depiction of their driving ability, and these assessments often include recommendations for seniors regarding what types of driving environments to avoid (Broberg & Willstrand, 2014; Eby et al., 2003). However, one problem with driver assessments is that they only provide drivers with a snapshot of their ability at that point in time. If their behavior begins to deteriorate and they still believe themselves to be at a higher capacity for safe driving, they are unlikely to change. Thus, like driver capacity, driver self-monitoring may benefit from having more feedback about their driving style to make them more aware of changes in their behavior.

Horswill et al. (2017) found that when drivers were provided with feedback about their performance on a hazard perception test, their self-enhancement bias was eliminated, and their self-ratings of abilities became quite accurate relative to actual performance. Considering the Multifactorial Model for Enabling Driving Safety by Anstey et al. (2005), this is particularly important, as awareness of one's driving capacity seems to play a role in crash-risk in addition to their actual driving capacity. This provides

further evidence for the benefit of drivers having in-vehicle feedback of their driving behavior. Eby et al. (2003), in a study investigating the willingness of older drivers to accept feedback about their driving, found that aging drivers were very open to the idea of feedback and making appropriate adjustments to their driving, primarily for the sake of maintaining their license and independence. It is important, though, that feedback be related to specific behaviors rather than providing overall levels of performance. Dogan, Steg, Delhomme, and Rothengatter (2012) found that when drivers were given feedback about particular driving behaviors, they were highly receptive and willing to make changes regarding those behaviors, but when the feedback was related simply to overall performance, they were more likely to question the validity of the feedback.

Thus, in-vehicle driver support systems that provide feedback for specific driving traits and habits rather than providing overall ratings of driving ability are likely to have higher acceptance among drivers. Behavior-specific feedback may then be useful not only by helping drivers to improve specific behaviors, but also by making them more acutely aware of their own driving capacity. Having continuous feedback over time will also allow drivers to determine if their behaviors are deteriorating and make appropriate adjustments regarding self-restrictions of more difficult driving environments.

2.3.4 Summary of Driver Interventions

The rapidly increasing population of aging drivers presents a need for interventions that allow for the safe mobility and independence of seniors. While assessments of fitness-to-drive may determine which drivers are at-risk to themselves and other drivers or provide drivers feedback about their current skill level, they may be lacking in facilitating improvements in driver crash-risk. The Multifactorial Model for Enabling Driving Safety posits that crash-risk is predicated on driver capacity and their beliefs or awareness of that capacity. That is, there may not be a one-to-one association with driving ability and crash-risk because drivers can develop and adopt strategies to mitigate decrements in their driving abilities.

In-vehicle support systems that provide drivers with real-time feedback of specific behaviors, known to be associated with crash-risk, may then be of great use in keeping drivers more mindful of the roadway, aware of their own driving style, and possessive of relevant behavioral information needed to make deliberate adjustments aimed at reducing their crash-risk. Although many aging drivers are quite safe and present little risk to themselves or other drivers, it may still be useful for them to develop a baseline understanding of their driving behavior so that they can be aware if they begin to experience age-related changes that impact their ability to drive safely. Increased awareness of changes in behaviors may also be a more useful and discrete long-term solution for aiding drivers in deciding to restrict their driving.

2.4 PURPOSE OF THE CURRENT STUDY

The current study is an extension of several previous experiments completed by the HumanFIRST laboratory that utilized a smartphone-based driver support system to increase awareness of driving habits and decrease the propensity for risky driving behaviors. Early studies with teen drivers (Creaser et al., 2011; Manser et al., 2013; Creaser, et al., 2015) found that teen drivers who received real-time feedback were significantly less likely to exhibit driving behaviors associated with increased crash risk (e.g., speeding, excessive acceleration, hard braking, running stop signs, etc.).

The next step in this line of research was to develop a more user-friendly version of the driver support app for use with drivers of all ages (henceforth referred to as RoadCoach), which included several focus groups and simulator-based experiments to implement design changes based on user feedback (Morris, Craig, Libby, & Cooper, 2018). Researchers then conducted a Controlled Field Test (CFT) with eleven older adults over age 65 to get further feedback about user impressions regarding the efficacy, intuitiveness, and usefulness of the RoadCoach app. Drivers in this study rated the app very highly and were enthusiastic about its potential. These results led to the current study, which sought to determine if the in-vehicle RoadCoach app could be used to improve driving behavior among older adults as it did in previous studies with teen drivers.

To determine the real-world efficacy of such an application, a quasi-experimental design was necessary for researchers to understand the effects real-time feedback on driver behavior. Previous studies utilized short-term testing of RoadCoach via focus groups, a simulator study, and a controlled field test (CFT). However, the brief nature of these studies did not allow for adequate testing of the long-term effects of RoadCoach on driver behavior and safety, nor did it allow users the opportunity to experience the app for an extended time period so that they could provide more in-depth feedback regarding their experience with RoadCoach.

A field operational test (FOT) was conducted with drivers over the age of 65 for twelve weeks as they drove their normal, daily routes to determine how the presence of real-time feedback regarding their driving and the roadway influenced their driving behavior. Measures of user satisfaction and usability were also measured throughout the study to 1) determine the extent to which drivers were satisfied with RoadCoach from a design standpoint; 2) provide design recommendations for future iterations; and, 3) assess how likely users would be to adopt and utilize a driver support system in the future.

2.5 HYPOTHESES

Based on previous research with in-vehicle support systems by Creaser et al. (2015), it was expected that similar positive effects on driver performance would be observed due to the benefits of drawing driver attention to poor driving behavior. It was also expected that previous results from Morris et al. (2018) would extend to longer exposure durations of the driver support system, as shown with high user satisfaction ratings and ratings of both mental workload and mind wandering. This study had three main hypotheses (See Table 2.1).

Table 2.1 List of study hypotheses and measures

Hypotheses	Measure
1. Speeding, Hard Braking, & Stop Sign Violations will decrease with the presence of feedback	Frequency counts of speeding, braking, and stop sign violations before, during, and after intervention
2. If there are decreases in speeding during the intervention, speeding propensity will slowly return to baseline levels after the intervention is removed	Frequency counts of speeding violations before, during, and after intervention
3. Perceived mental workload and visual demand of RoadCoach will be rated relatively low	RSME and DALI-TLX scales of mental and visual demand

2.5.1 Hypotheses 1

It was expected that the speeding, hard braking, and stop sign alerts would have a main effect on behaviors during the intervention phase of the study. Previous research has shown that intelligent speed adaptation systems (Spyropoulou et al., 2014) and in-vehicle support systems (Freedmon et al., 2007; Creaser et al., 2015) have shown benefits with annoying and persistent alerts in fostering behavior change in drivers of all age groups.

2.5.2 Hypotheses 2

It was expected that upon cessation of feedback from RoadCoach, drivers' propensity to speed would slowly return to baseline measurements. This is because properly monitoring and maintaining vehicle speed is thought to be a near constant task, requiring dedicated driver attention (Broberg & Willstrand, 2014). Without persistent reminders from RoadCoach, it was likely that drivers would be less aware of their speeding behaviors and their speed levels would return to baseline levels. Conversely, it was expected that drivers who displayed a reduction in hard braking maneuvers during the intervention stage would continue to incur similarly lower instances of hard braking once the feedback was removed. Previous research has shown that for behaviors that require less monitoring, drivers are more apt to change their behaviors and retain these changes once they are no longer receiving feedback about the behaviors (Morris et al., 2018).

2.5.3 Hypotheses 3

It was hypothesized that perceived mental workload and visual demand of interacting with the in-vehicle support system would be rated very low. This is because previous studies with the same or similar versions of the app also resulted in very low levels of perceived mental workload as well as visual demand (Creaser et al., 2013; Morris et al., 2018). Morris et al. (2018) found that when using the same in-vehicle support system, average glance fixations to the system lasted on average less than 500ms and drivers made less than 1.5 glances per minute. These results were from a single-day study with the RoadCoach app, so it is believed that longer exposure with the app would result in even less visual demand.

CHAPTER 3: METHOD

3.1 DESIGN

The study was completed as a 2 (group) x 12 (time) mixed factorial design. Group was a between-subjects analysis, whereas time was a within-subjects analysis. Group-assignment was based on geographical location (Wichita, KS or Minneapolis, MN). Time was measured in weeks, as each week of data was summarized and counted as one measurement period. The measurement period followed an ABA design: drivers received no feedback for the first three weeks of the study, then received feedback for six weeks from RoadCoach, followed by no feedback for the final three weeks of the study.

Two Midwestern cities, Wichita, KS and Minneapolis, MN, were selected because the populations of both cities are very similar (Wichita population = 389,902; Minneapolis population = 413,651). However, as of 2016, Wichita, KS had a metropolitan population of 644,610 while Minneapolis had a metropolitan population of 3,551,036. This large difference in metropolitan populations translates to differences between the cities regarding traffic density, average traffic speeds, and commute time.

To control for the drastic differences in weather during winter months between Wichita and Minneapolis, this study was conducted from June through September. Driving during the winter also meant participants would be more likely to spend more time driving at night, which has been shown to be correlated with an increase in crash risk. This presented another safety concern that led to the study being conducted during the summer with more hours of daylight.

3.2 ROADCOACH VALIDATION TESTING

Prior to participant recruitment, researchers sought to ensure that the RoadCoach app was properly functioning and accurately recording data. Researchers spent several weeks in Wichita and Minneapolis testing the RoadCoach app for validity and reliability by recording when they drove, the distance of each drive, and violations they incurred. For safety purposes, certain violations like aggressive acceleration and aggressive turning were tested in empty parking lots. Researchers also wanted to be certain that the mapped data (e.g., posted speed limits, sharp curve warnings, stop sign locations, and advance speed warning) for both cities was accurate and consistent. The data recorded while driving was then compared to the data that was stored to the RoadCoach servers to ensure that all data was being properly recorded and uploaded. This also gave researchers the opportunity to make sure the Bluetooth auto-launch feature was working reliably. Multiple types of Android smartphones were used for the data validation since the study would be comprised of individuals using their own phones that were likely to vary in brand, model, and current Android system update.

3.3 PARTICIPANTS

Twenty-eight participants (Female = 14; Mean age=69.5, SD=2.93) were recruited from the Wichita, KS (N=14) and Minneapolis, MN metropolitan areas (N=14) to participate in a 12-week on-road driving

study. The age range was 65 to 78. All participants were required to own a smartphone, suggesting at least a basic familiarity with technology. To determine the number of participants needed for this study, a power analysis was conducted using G*Power (Faul, Erfdelder, Buchner, & Lang, 2009). To achieve an effect size of .30 with .80 power for a repeated measures within-between ANOVA with 12 measurements, 10 participants total were required (Faul, et al., 2009). Additional participants were recruited to both accommodate any attrition or unforeseen complications that might occur due to the length of the study as well as to replicate the sample size of other similar on-road studies. Recruitment methods included posting ads (See Appendix A) at local senior centers, parks, churches, Craigslist and Facebook (See Appendix B), and by word-of-mouth. An initial screener was given to all participants prior to their enrollment in the study (See Appendix C), which screened for any history of physical or cognitive problems that might preclude them from safely participating in the study.

Several matching criteria were used to make the groups from both cities as equivalent as possible to eliminate potential confounding variables from the general group differences. The main matching criteria used were age, gender, driving experience, and cell phone use. All participants were active drivers, with at least 10 years of driving experience ($M=51.4$ years, $SD=6.3$), drove over 4,000 miles per year, spoke Mainstream American English as their first language (Bergman et al., 1976), were the primary driver of their vehicle, and were required to provide proof of a current driver's license and insurance policy. All participants owned and used their own an Android touchscreen phone to ensure familiarity with the cell phone that they would use for the duration of the study. At the end of the study, participants were paid \$10 per week of participation. Due to the requirements for participation of this study, more than 80 individuals were not permitted to take part in the study, with cell phone type (i.e., iPhone users) and visual function being the primary exclusion criterion.

3.4 MATERIALS

3.4.1 Visual Assessments

Prior to participating in the study, participants were screened using three visual assessments to ensure that they had no significant visual decrements that might impede their ability to interact safely with the RoadCoach app while driving. Snellen visual acuity was measured for all participants with a minimum requirement of 20/40 visual acuity to participate in the study. Ishihara's Tests for Color-Blindness (Ishihara, 1988) was administered to ensure all participants had normal color vision. This was necessary since the RoadCoach app uses color-coded messages. Lastly, participants were screened for contrast sensitivity using the Pelli-Robson Contrast Sensitivity Chart (Pelli, Robson, & Wilkins, 1988) with a score of 1.6 or better being required for participation in the study.

3.4.2 Cognitive Assessments

Prior to the start of the study, individuals were screened using three separate cognitive tests to ensure that all participants had no significant cognitive decrements that might affect their interaction with the RoadCoach app or impede their ability to interact with the RoadCoach app while driving.

3.4.2.1 Mini Mental State Examination

The Mini-Mental State Examination (MMSE) is a 30-point questionnaire used to detect and measure potential cognitive impairment. This test was used to determine, prior to the driving portion of the study, if any participants displayed any signs of cognitive impairment that would prohibit them from safely completing the experiment. The MMSE (See Appendix F) requires participants to demonstrate basic functionality in several areas, including recall, language, orientation, attention, and calculation. Individuals were required to score 25 or better in order to participate in the study.

3.4.2.2 Trail Making Test

The Trail Making Test (Reitan, 1958, 1992) is a two-part test (i.e., Part A and Part B) requiring task switching and visual attention. Part A of the test is intended to measure an individual's visuo-perceptual capabilities by having them connect circles with numbers in them, in numerical order. In part B (See Appendix L), participants connect circles with numbers to circles with letters in them as they alternate between numeric and alphabetic circles in an increasing fashion (i.e., 1-A-2-B-3-C-4-D-etc.). The purpose of this task is to measure attention-switching abilities between the numeric and alphabetic targets (Tun et al., 2002). This test was used firstly to ensure that participants had at least adequate baseline attention-switching abilities since that would be required at times in this study. Secondly, this was used to determine if a participant's attention-switching abilities were correlated with driving performance during the study. Thirdly, because this test requires a certain level of fine motor movement in a short time period, it also served as a basic measure of motor functioning. For this study, only Part B was used as Part A was considered unnecessary to administer since it is less sensitive than Part B. Scores were recorded as the amount of time (i.e., seconds) that it took participants to complete the task (See Figure 3.1).

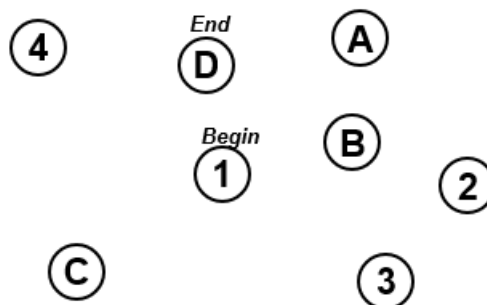


Figure 3.1 Example of the Trail Making Test Part B.

3.4.2.3 Mental Paper Folding Test

The Mental Paper Folding Test (MPFT) is designed to test three-dimensional spatial visualization abilities. The MPFT was also used because it requires users to demonstrate strong spatial reasoning skills that are also necessary for safe navigation of a roadway (De Raedt & Ponjaert-Kristoffersen, 2000). The MPFT (See Appendix K) consists of a sample problem (See Figure 3.2) and twenty additional problems where the participant must imagine the folding and unfolding of pieces of paper. For each problem, the participant is shown a figure of a sheet of folded paper with a hole going through the paper as well as how the sheet was folded. Participants must then imagine the paper being unfolded back to its original state, but now with the holes in it. They are then shown five drawings of unfolded pieces of paper, each with pencil holes in differing locations. They must then choose which of the five figures depicts how the folded paper would look like once it had a hole poked through it and was unfolded (See Figure 3.3).

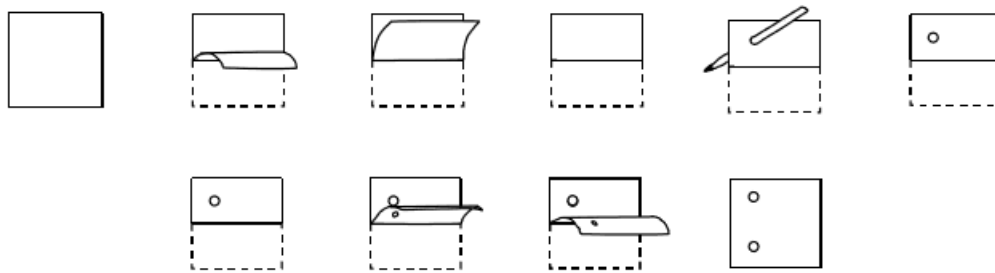


Figure 3.2 Mental Paper Folding Test Sample Instructions.

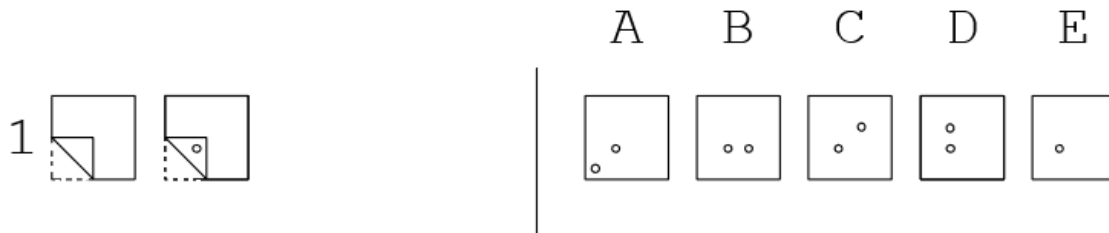


Figure 3.3 Sample Question from the Mental Paper Folding Test.

3.4.3 Documentation

Upon completion of the six visual and cognitive tests, the nature and purpose of the experiment was explained to all participants who gave their informed consent (See Appendix P) to participate in the experiment. They then completed a detailed background survey on their driving behavior, driving opinions, driving history, and cell phone use (See Appendix D). A self-assessment questionnaire was also given to participants which asked them to rate several other aspects of their driving, including how good of a driver they thought they were, how good they would like to be, if they thought their driving ability had changed at all over the years and in what ways, and if they had made any adaptations to their driving behavior or views over the years to compensate for their age (See Appendix N). Participants then

completed a sensation-seeking questionnaire (See Appendix E) used to determine their general level of thrill-seeking.

The purpose of the driving history and opinions questionnaires as well as the sensation-seeking questionnaire was to determine if any differences in personality type predicted driving behavior. Specifically, researchers were interested in identifying what, if any, individual differences in thrill seeking and driving style predicted propensity for risky driving behaviors during the study, as well the degree to which individual behavior was affected by the presence of feedback from the RoadCoach app. If general differences existed between driving style and the likelihood that drivers adjusted their behaviors, this would be of interest in future studies.

3.4.4 Weekly Emails

Participants were instructed that at the end of each week of the study, they would receive an email requesting information about their experience with the RoadCoach app. They were shown the two types of emails they would receive, one during the baseline condition and the other during the intervention condition. The purpose of the emails during the baseline condition was to check-up on drivers and served as a reminder to them to ensure they were keeping their phone's Bluetooth turned on, had the phone placed in the cell phone mount for each drive, and were always keeping the phone and Bluetooth receiver, if they had one, charged.

The email sent during the intervention condition included a rating of mental workload using the Rating Scale of Mental Effort (RSME) to assess their perceived mental effort by using the app while driving. This was done so researchers could determine if any participants were finding driving with the RoadCoach app on to be overly mentally demanding. Participants were given instructions on how to respond to each email as well as any necessary contact information for the researchers should they experience any difficulties or problems during the study. Researchers also informed each driver that they would be able to monitor their daily driving logs and would contact them if they went more than three days without logging any drives to ensure there were no problems occurring with the data collection.

3.5 ROADCOACH

3.5.1 RoadCoach Tutorial and Set Up

Once participants had completed the consent process and background questionnaires, they were given a PowerPoint tutorial describing the RoadCoach driving app. The purpose of the tutorial was to educate users on the functions and use of the app including the visual and verbal display messages. The tutorial included screenshots of every message they might see with explanations of their meaning as well as the corresponding audio for each icon. After the tutorial, the RoadCoach app was downloaded to their Android smartphone and participants were shown how to log into the app. Once logged in, they were shown how to connect the phone to the Bluetooth in their vehicle. Any participants who did not have Bluetooth already in their vehicle were provided with a Bluetooth receiver setup. The importance of

keeping the Bluetooth function always turned to ON was stressed as the RoadCoach app auto-launches once it connects to the vehicle's Bluetooth and disconnects once the vehicle is turned off. The primary purpose of having the app launch automatically when connecting to the vehicle's Bluetooth was to eliminate the need for participants to remember to launch and shut off the app each time they drove. Participants were also instructed to turn off their phone's Bluetooth if they were ever a passenger while someone else drove their vehicle. They were also instructed to notify researchers if this occurred and they forgot to shut off their vehicle so that the data from that drive could be removed from the analysis.

A windshield-mounted cell phone holder was also provided to all participants. Participants were instructed that they were required to always drive with their phone secured in the mount to reduce the need for them to look down at their phone whenever a notification or warning from the RoadCoach was presented to them. Figure 3.4 depicts where the cell phone mount was placed in each vehicle. Aside from eliminating the need to look down at the phone for feedback, the importance of mounting and securing the phone in the phone holder was to eliminate any additional movement of the phone in the vehicle, which could potentially produce inaccurate data that relied on the phone's accelerometer. Additionally, all participants who did not already have one were provided a 12-volt charger and cable for their cell phone and Bluetooth device to prevent the loss of power during the data collection process. Once the vehicle was configured for the study, participants took a short drive (approximately 10 minutes) with a researcher so they could practice using the RoadCoach app in real-world driving conditions. Participants also practiced how to navigate in and out of the RoadCoach app while driving in case they needed to access other functions of their cell phone momentarily while driving (e.g., answering a phone call or checking their GPS [Global Positioning System]). This gave all participants experience with the app as well as an opportunity to ask the researcher any clarifying questions.

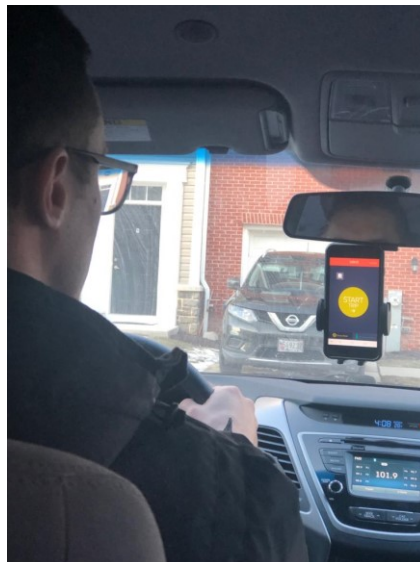


Figure 3.4 Depiction of the location of the Windshield-Mounted Cell Phone Holder.

3.5.2 Information, Reminders, & Warnings

The interface of RoadCoach allows for the presentation of only one visual message or warning at a time. The default message on the screen is to display the current posted speed limit, as shown in Figure 3.5. The RoadCoach application was designed to utilize GPS information for the location of the phone and show the associated posted speed limit of the roadway on which the driver is currently traveling. Most major highways and city streets have been mapped out and have their corresponding speed and roadway information stored in the RoadCoach database that is accessed to give drivers the current applicable information. The images displayed on the screen change depending on the behaviors of the driver or upcoming changes in the roadway (e.g., changes in the speed limit, sharp curves ahead, stop sign warnings, etc.).



Figure 3.5 Default display image of current posted speed when not speeding.

3.5.3 Speeding

RoadCoach informs drivers whenever they are speeding by using an intelligent speed adaptation system with three levels of speed notification. The default image displayed on the screen is the current posted speed limit, which looks like a standard roadside speed limit sign (see Figure 3.5). The background of the posted speed limit on the screen changes to yellow whenever the vehicle travels anywhere between 2.5 miles per hour (mph) to 7 mph over the known posted speed limit, (see Figure 3.6) to indicate that they are exceeding the speed limit. This range was chosen based on prior testing and feedback from drivers identifying the range of speeds perceived to be excessive. Within this range, no auditory warning accompanied this first level of speeding notification. Once drivers began driving more than 7 mph over the posted speed limit signs, the background of the screen changed to red. This was accompanied by an auditory message of *"Exceeding speed limit, please slow down."* If drivers continued to exceed the speed limit by more than 7 mph, they would receive the same audio warning. If the speeding continued, a third auditory warning of *"Please slow down. Violation will be recorded if speeding continues"* would play after five more seconds of speeding. If the speeding persisted, a message of *"Violation has been recorded"* would play (see Figure 3.8). The alert sequence would then desist for thirty seconds before the cycle of auditory warnings would begin again.

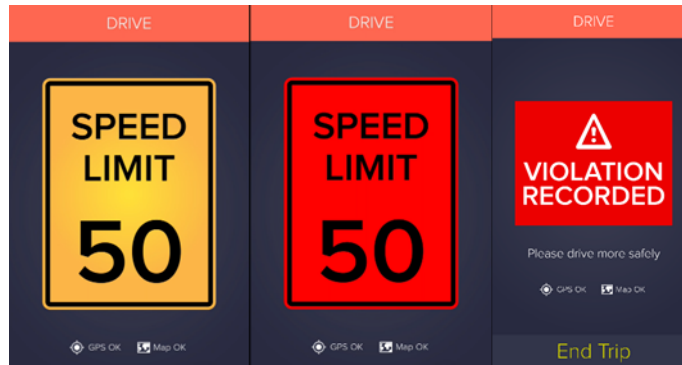


Figure 3.6 Displays sequence of images displayed when speeding by 2.5-7 mph, more than 7mph, and when speeding violation has been recorded.

Drivers were also provided with notifications of any upcoming changes in the posted speed limit in the roadway. If a driver were in a 60 MPH speed zone and approaching a 50 MPH speed zone, they would be given an auditory message as they approached the new speed zone of *“Speed limit changes to 50 mph ahead.”* Once the vehicle entered the new speed zone the image on the screen of the posted speed limit would change and be accompanied by an auditory message of *“Speed limit 50 mph”* (see Figure 3.7).

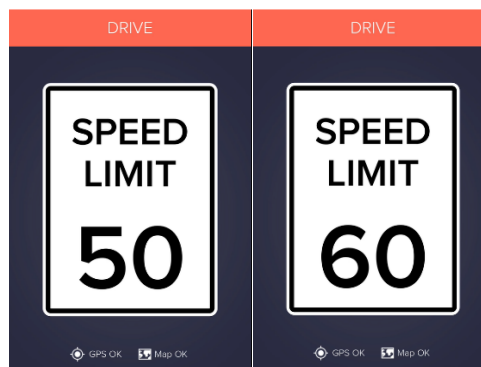


Figure 3.7 Images of advanced speed notifications.

3.5.4 Advance Curve Notification

RoadCoach identifies curves up to 55m ahead of the vehicle and provides drivers with advance curve warnings by looking ahead at the current road of travel (up to 55m). As a driver approaches a curve in the road, they received an auditory warning of *“Left/Right curve ahead”* as well as an accompanying visual icon depicting the relevant warning sign (see Figure 3.8). When the precise direction of the curve was unknown, or was more complex, such as an S-curve, the audio feedback will simply state *“curve ahead, please slow down.”* This provided drivers ample time to slow the vehicle in anticipation of the approaching curve.



Figure 3.8 Images of advanced curve notifications.

3.5.5 Aggressive Maneuvering

Using the smartphone’s accelerometer, the RoadCoach algorithms identified excessive acceleration, deceleration, and turning and provided visual and audio feedback to the driver as well as recorded violations for these maneuvers. If a driver had an excessive acceleration (3.5 m/s^2) they would receive a visual warning (see Figure 3.9) as well as an auditory warning of “*Excessive acceleration, use caution*” while recording a violation in the driver’s account. If drivers decelerate too quickly (-3 m/s^2), they would receive a visual warning (see Figure 3.9), as well as an auditory warning of “*Hard braking detected, violation has been recorded.*” The RoadCoach recorded the violation onto the driver’s website account. Aggressive turning was also recorded when drivers turned too sharply, (6.5 m/s^2) which triggered a visual warning (see Figure 3.10) along with an auditory warning of “*Excessive turning, use caution.*” This violation also was recorded and uploaded to the driver’s website account. The algorithms and thresholds used for determining aggressive driving behaviors were based on industry standards that insurance companies use for in-vehicle monitoring devices of driver behaviors.



Figure 3.9 Image of aggressive acceleration & hard braking warning.



Figure 3.10 Image of aggressive turning warning.

3.5.6 Stop Sign Violations

The software for RoadCoach contains a database for stop signs at major roads and queries this database to determine if the drivers came to a complete stop at these intersections. If a driver continued through an intersection with a stop sign and does not reduce their speed to less than 5 mph, they received a violation. The interface displayed a visual warning (see Figure 3.11) as well as an auditory message of “Failed to stop at stop sign, violation has been recorded.” The 5-mph threshold was implemented to reduce false alarms of stop sign violations where the system failed to detect a stop due to its low sampling rate of the GPS signals used to assess driving speed where the driver may have come to a complete stop, but it was not fully detected.



Figure 3.11 Image of stop sign violation warning.

3.5.7 Additional Driving Data Collection

In addition to the parameters about which RoadCoach provides drivers feedback, the app also recorded other driving parameters, including the total number of trips, with a trip being each time the RoadCoach app is launched upon the vehicle turning on and then shut off each time the vehicle is turned off, and the total distance (miles) traveled each week. Since the RoadCoach app is reliant upon GPS signal to provide drivers with map location data (e.g., posted speed limit and stop sign locations) there are times when drivers would not receive feedback if their phone’s GPS signal is too weak. The RoadCoach app

records the total miles driven as well as the number of 'valid' miles driven where the GPS signal is strong enough to provide drivers with real-time feedback. This allowed researchers to parse out the amount of driving where RoadCoach was actually providing the driver feedback. The aggressive driving behaviors are not reliant upon GPS signal, but rather the phone's accelerometer. They are unaffected by GPS signals and would always provide drivers feedback. RoadCoach would detect if the phone's screen was on and if the app was in the foreground or not. Additionally, it recorded the total number of miles driven with the app running in the foreground of the phone, which allowed researchers to see how often drivers were receiving both visual and auditory feedback. Lastly, the app separated the distance traveled into six different bins based on the vehicles speed relative to the posted speed limit: 1) miles driven 2.5 MPH or more under the speed limit; 2) miles driven +/- 2.4 MPH of the speed limit; 3) miles driven 2.5 – 7 MPH over the speed limit; 4) miles driven 7.1-10 MPH over the speed limit; 5) miles driven 10.1-15 MPH over the speed limit; and 6) miles driven 15.1 MPH or more over the speed limit. This allowed researchers to not only know how often drivers were speeding, but the extent to which they were speeding.

3.6 PROCEDURE

3.6.1 Study Phase One

The experiment consisted of five phases. In the first phase, participants were given the three visual assessments. The order of these was counterbalanced to reduce the potential for order effects. Participants then completed the MMSE, the Trail Making Test Part B, and the Mental Paper Folding Test. The order of these was also counterbalanced to reduce the potential for order effects.

If participants passed all six of these assessments, they then completed a consent form, a driving history and background questionnaire, a self-assessment questionnaire about their driving performance, and a sensation-seeking questionnaire. Next, participants were given a tutorial on how the RoadCoach app worked and what each visual and auditory message it presented meant. After this, the RoadCoach was downloaded to each participant's phone, a cell phone holder was installed on their windshield, a 12-volt phone charger and cable were provided, and a Bluetooth receiver was also installed in the car if the vehicle did not already have Bluetooth. Once the participant's phone was paired with the Bluetooth, they then drove for approximately ten minutes with the researcher while the RoadCoach app was running. This was done to allow participants to be accommodated to driving with the app active while also being able to ask any questions of the researcher. Lastly, they were instructed on replying to a weekly email regarding their driving and use of the RoadCoach.

3.6.2 Study Phase Two

The second phase of the study consisted of a baseline condition. For three weeks, drivers drove, with their phone plugged in and in their windshield-mounted cell phone holder. During this phase, the RoadCoach app recorded all driving data, while running in the background, providing drivers no feedback. At the end of each week, drivers were asked to respond to an email regarding their driving

and whether they were making sure their phone was connected to the vehicle’s Bluetooth and positioned in their windshield-mounted cell phone holder. A breakdown of all driving data collected can be seen in Table 3.1.

Table 3.1 List of all recorded RoadCoach data

Violation or Data	Type of Data Collected
Hard Braking	Whenever a driver decelerates more than -3m/s^2
Excessive Acceleration	Whenever a driver accelerates at more than 3.5m/s^2
Aggressive Turning	Whenever a driver makes a turn at more than 6.5m/s^2
Stop Sign Violation	Records when a driver goes past a stop sign without slowing down to 5mph or less
Speeding Warnings	Records the number of times drivers received a verbal warning for speeding
Speeding Violation	Records the number of times drivers received a speeding violation for continuing to drive more than 7mph over the speed limit
Speed Bins	Records the total miles spent speeding at 0-2.4 mph, 2.5-7 mph, 7-10mph, 10.1-15mph, & 15.1mph+
Total Distance Traveled	Recorded the total distance traveled while RoadCoach was connected to Bluetooth
valid miles driven	Records the total distance traveled while RoadCoach had a GPS signal
Total number of trips	Records the total number of trips drivers took
Total Miles with app in the foreground	Records the number of miles drivers had RoadCoach in the foreground of their phone

3.6.3 Study Phase Three

Phase three of the study lasted six weeks. During this phase, drivers drove, while placing their phone in the windshield-mounted cell phone holder. However, for this phase, drivers received continuous real-time visual and auditory feedback from the RoadCoach app regarding the roadway and their driving performance. At the end of each week, they were asked to respond to an email regarding their driving. The emails queried whether they had been ensuring to mount their phone properly, as well as to indicate how distracting and mentally demanding they felt using the app while driving was. The purpose of this was to identify if a participant was finding the study to be overly distracting or mentally demanding so that they might be removed from the study for their own safety. However, no participants rated the feedback of RoadCoach to be overly demanding or distracting at any point during the study.

3.6.4 Study Phase Four

Phase four of the study lasted three weeks and was identical to the second phase of the study. Drivers no longer received any type of feedback from RoadCoach, but it continued to collect all data on their driving behavior. Drivers were still asked to respond to the weekly email that was also the same as the second phase of the study.

3.6.5 Study Phase Five

The fifth, and final, phase of the study consisted of several questionnaires and a semi-structured interview. The semi-structured interview consisted of several open-ended questions that allowed for a lengthy discussion between researchers and participants about their likes, dislikes, suggestions, and overall thoughts and feedback regarding their interaction and use with RoadCoach. Participants also completed several questionnaires about their use of RoadCoach: (1) System Usability Scale (SUS), which was used to gauge how user-friendly participants found the app (See Appendix H); (2) The RSME is a scale of mental effort used to measure how much mental effort was required by participants from using and interacting with RoadCoach while driving (See Appendix G); (3) A questionnaire gauging how much participants felt using RoadCoach affected their driving behavior during and after the feedback phase of the study (See Appendix O); (4) The DALI-TLX (Driver Assessment Load Index), a modified version of the NASA-TLX, which is mental workload scale specifically intended for driving, was used to measure what aspects of RoadCoach participants felt were the most mentally demanding (See Appendix M); (5) The nine-point usability scale is a quick method for measuring users' perceived user-friendliness of an interface such as RoadCoach (See Appendix I); (6) A modified trust questionnaire was used to see the extent to which drivers trusted the information RoadCoach provided them as well as how much they valued that information (See Appendix J). Lastly, participants were debriefed about the purpose of the study and any final questions they had were answered prior to being thanked and compensated for their participation in the study. The interview and debrief process lasted 1.5-2 hours.

CHAPTER 4: RESULTS

In order to account for effects of region (Minnesota, Kansas), and gender (male, female) on the driving performance measures, two one-way ANOVAs with region and gender as factors were conducted on the speeding, hard braking, and stop sign violation variables. There were no significant effects of region (all $ps > .05$), and no significant effects of gender (all $ps > .05$) except for the count of speeding warnings in the no feedback phase, $F(1, 26) = 4.455$, $p = .045$. Therefore, with the exception of speeding warnings, gender and region are not considered further in the following analyses.

4.1 HYPOTHESIS ONE

The first hypothesis was that speeding, hard braking, and stop sign violations would decrease with the presence of feedback. The results below indicate partial support for this hypothesis.

4.1.1 Speeding warnings

As indicated in Table 3.1, the speeding warnings variable indicated the number of times that drivers received a verbal warning for speeding. Given the observed effect of gender on speeding warnings in the no feedback phase (see preliminary analysis section), gender was included as a factor for this analysis. A 3×2 factorial ANOVA with three levels of feedback phase (baseline, feedback, no feedback) as a repeated measures variable and two levels of gender (male, female) as a between-subjects variable was conducted on the speeding warnings variable. The effect of phase was significant, $F(2,52) = 7.422$, $p = .001$, $\eta_p^2 = .222$. The baseline phase ($M = 28.106$, $SD = 27.870$) was not significantly different from the feedback ($M = 20.57$, $SD = 15.935$), $t(27) = 1.835$, $p = .078$ and no feedback phases ($M = 37.81$, $SD = 30.43$), $t(27) = -1.960$, $p = .06$, see Figure 4.1. The feedback phase and no feedback phase were significantly different for speeding warnings, $t(27) = -3.911$, $p = .001$. There was no main effect of gender, although the significance could be considered marginal, $F(1,26) = 3.667$, $p = .061$, $\eta_p^2 = .124$, see Figure 4.2. There was no phase by gender interaction, $F(2,52) = 1.195$, $p = .311$, $\eta_p^2 = .044$.

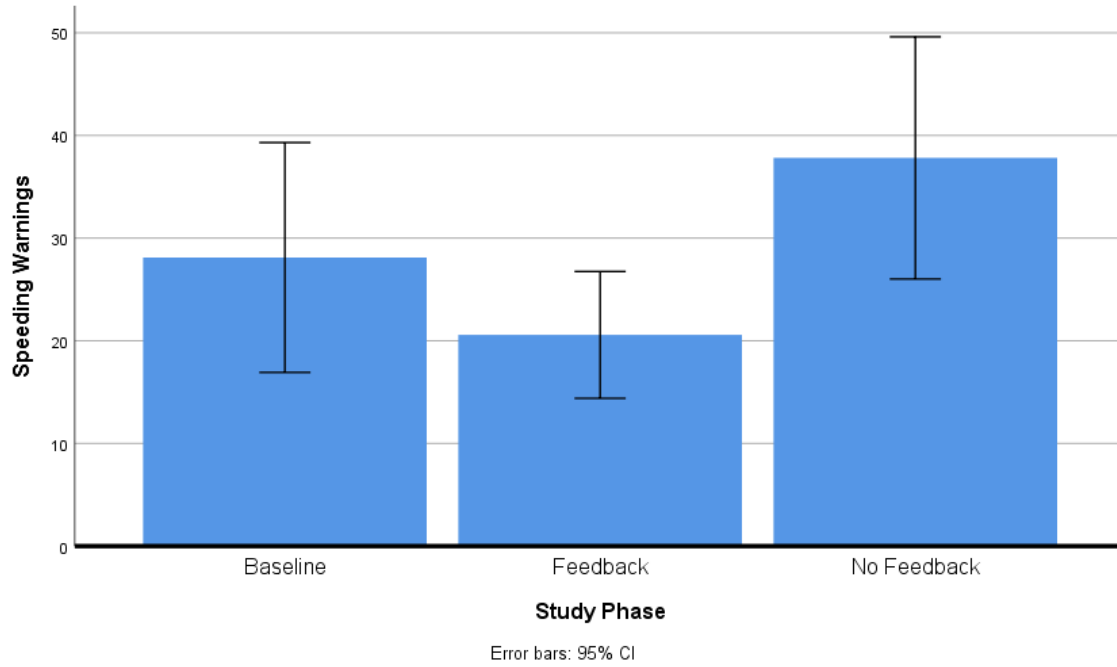


Figure 4.1 Speeding warning by feedback phases.

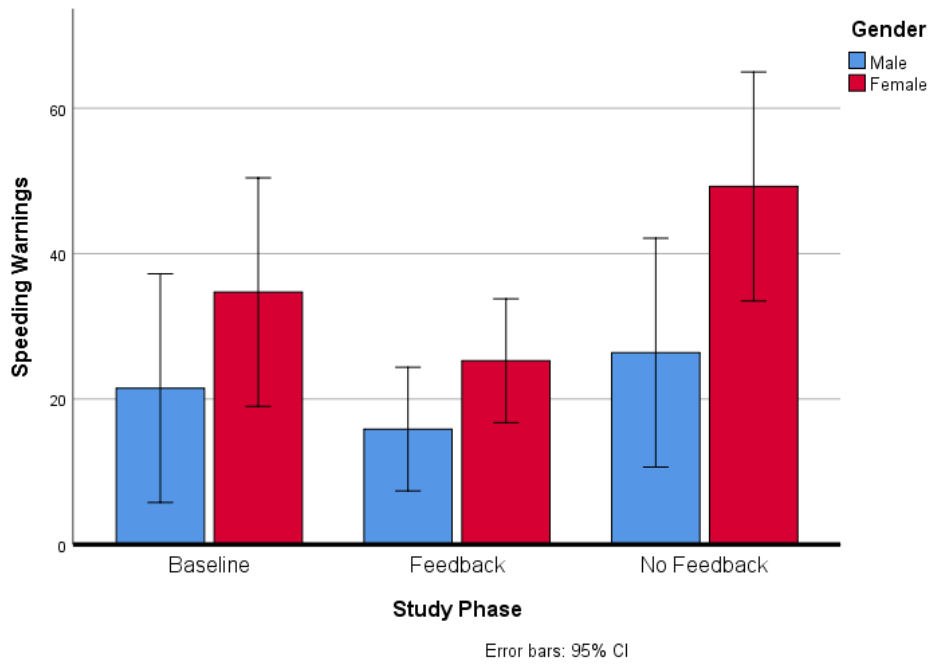


Figure 4.2 Speeding warning by feedback phases and gender.

4.1.2 Hard braking

Hard braking occurs whenever a driver decelerates more than -3 m/s^2 . A repeated measures ANOVA with three levels of feedback phase (baseline, feedback, no feedback) was conducted on hard braking counts. The effect of phase was significant, Greenhouse-Geisser corrected, $F(1.18, 31.86) = 32.159, p < .001, \eta_p^2 = .544$. The baseline phase ($M = 10.24, SD = 7.05$) was significantly different from the feedback ($M = 2.02, SD = 2.20$), $t(27) = 6.330, p < .001$, and no feedback phases ($M = 2.77, SD = 3.99$), $t(27) = 5.358, p < .001$, see Figure 4.3. The feedback phase and no feedback phase were not significantly different for hard braking, $t(27) = 1.586, p = .124$.

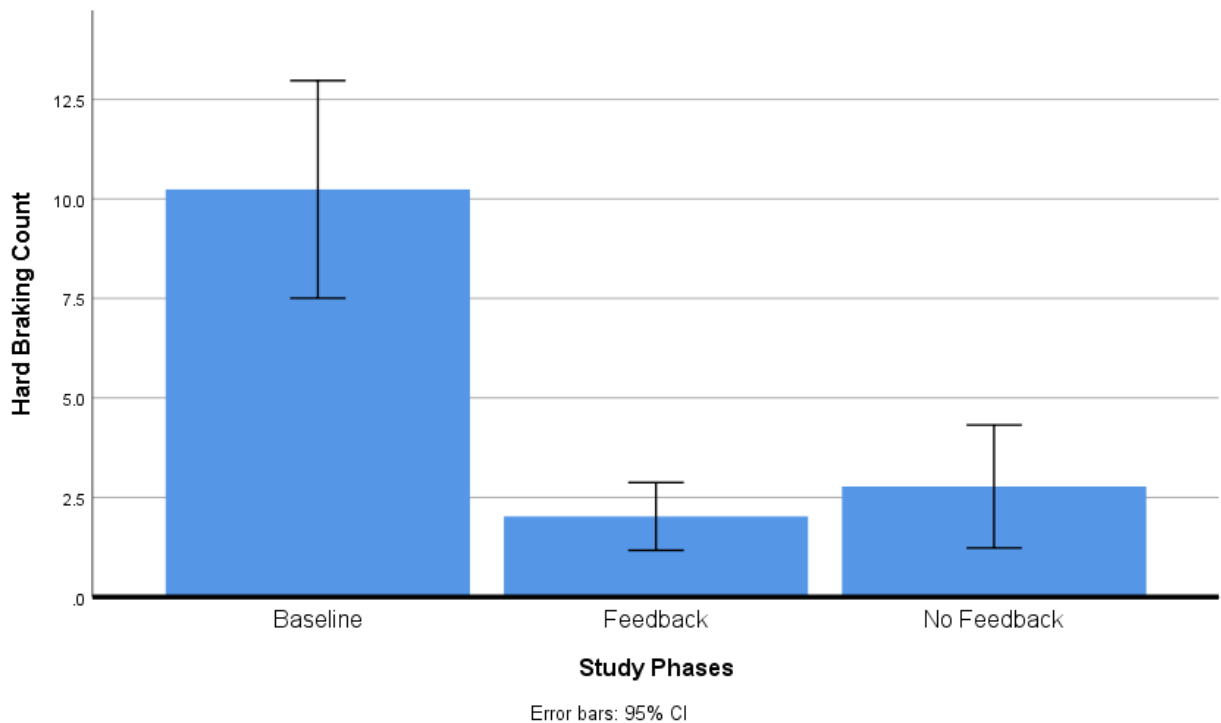


Figure 4.3 Hard braking by feedback phases.

4.1.3 Stop sign violations

The stop sign violation variable indicated the number of times that a driver went past a stop sign without slowing down to 5 mph or less. A repeated measures ANOVA with three levels of feedback phase (baseline, feedback, no feedback) was conducted on stop sign violations. The effect of phase was significant, Greenhouse-Geisser corrected, $F(1.123, 30.331) = 17.333, p < .001, \eta_p^2 = .391$. The baseline phase ($M = 3.05, SD = 2.64$) was significantly different from the feedback ($M = 0.7979, SD = 0.7797$), $t(27) = 4.284, p < .001$ and no feedback phases ($M = 0.6425, SD = 1.077$), $t(27) = 4.220, p < .001$, see Figure 4.4. The feedback phase and no feedback phase were not significantly different for stop sign violations, $t(27) = .953, p = .349$.

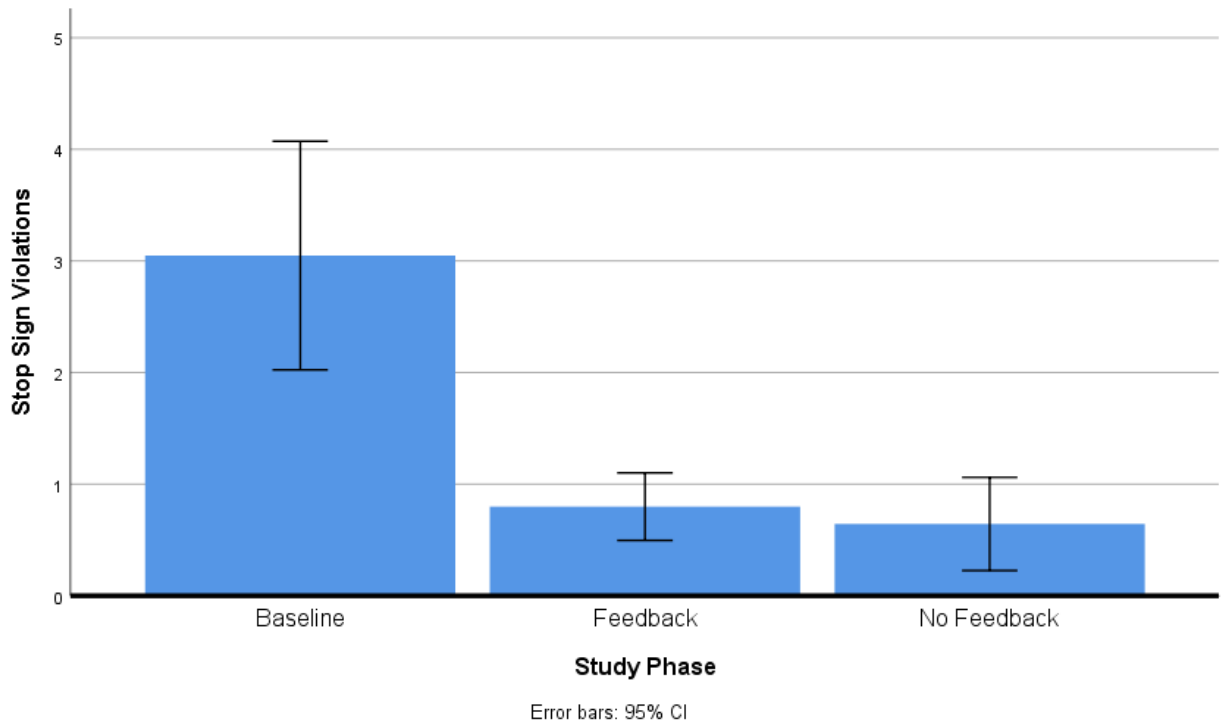


Figure 4.4 Stop sign violations by feedback phases.

4.2 HYPOTHESIS TWO

The second hypothesis was that decreases in speeding propensity would slowly return to baseline levels after the intervention was removed, as measured by speeding violations. The results below suggest partial support for hypothesis two.

None of the other speeding measures (see Table 3.1) emerged as significantly different (all $F_s < 1$).

4.2.1 Speeding violations

As indicated in Table 3.1, the speeding violation variable indicated the number of times that drivers continued to drive more than 7 mph over the speed limit. A repeated measures ANOVA with three levels of feedback phase (baseline, feedback, no feedback) was conducted on the speeding variable. The effect of phase was not significant, $F(2,54) = 2.618, p = .082, \eta_p^2 = .214$. The baseline phase ($M = 5.77, SD = 10.72$) was not significantly different from the feedback ($M = 2.95, SD = 4.63$), $t(27) = 1.749, p = .092$ and no feedback phases ($M = 6.49, SD = 7.94$), $t(27) = -.371, p = .714$. The feedback phase and no feedback phase were significantly different for speeding violations, $t(27) = -2.72, p = .012$, see Figure 4.5.

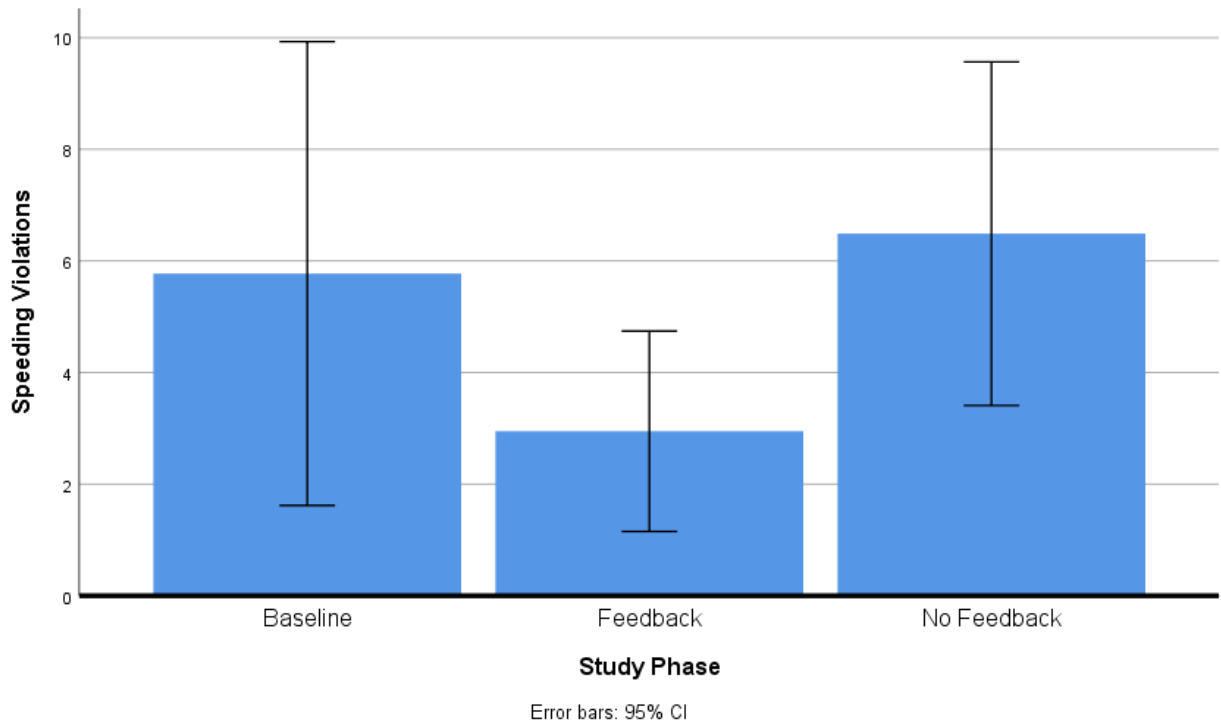


Figure 4.5 Speeding violations by feedback phases.

4.3 HYPOTHESIS THREE

The third hypothesis was that the perceived mental workload and visual demand of the RoadCoach app would be rated relatively low. This was measured directly with workload questionnaires, and indirectly with usability metrics.

4.3.1 Rating scale of mental effort (RSME)

The Rating Scale of Mental Effort, or RSME (See Appendix G) was first administered via email at the end of each week of Phase 3 of the study. This was done to ensure that participants were not finding the feedback from RoadCoach to be too mentally demanding to interact with while driving. At the end of the study, participants completed the RSME again.

The workload scale ranges from 0 (Absolutely No Effort) to 150 (Extreme Effort). The average RSME score was 29.50 (SD = 11.55), which correlates to the scale's descriptive term of "a little effort." This rating suggests that participants did not believe that using the RoadCoach during their drive required a substantial amount of mental effort. These RSME ratings are similar to those of Morris et al. (2018), who conducted a one-hour, controlled field test with the RoadCoach system active while older adults drove an instrumented vehicle around the Minneapolis, MN area, indicating that prolonged exposure did not seem to affect the perceived level of mental workload associated with interacting with the system.

4.3.2 Driving activity load index (DALI)

The Driving Activity Load Index (DALI) was used to assess perceived mental workload associated with interacting with RoadCoach. The DALI is a revised version of the NASA-TLX, adapted for driving-related tasks. The DALI utilizes a rating scale procedure defined by six pre-defined factors: 1) Effort of Attention; 2) Visual Demand; 3) Auditory Demand; 4) Temporal Demand; 5) Interference; and, 6) Situational Stress. A scale rating procedure is defined for the six pre-defined factors, which is then followed by a weighting procedure (See Appendix M). This results in a global scale of mental workload for the driving task.

The global workload scale ranges from 0 (No Effort) to 100 (High Effort). The average DALI score was 35.98 (SD = 13.49), which is a relatively low level of mental workload. This rating suggests that, similar to the results of the RSME, participants did not find their interaction with RoadCoach to be very mentally demanding while driving.

Table 4.1 shows the ranking of all six pre-defined factors the factor rated as most mentally demanding, Situational Stress, to the lowest, Interference Level. Situational Stress refers to how much outside factors affect a driver's ability or desire to attend to RoadCoach, meaning, participants were most likely to feel that when the difficulty level of external factors increased, they were less likely to want to attend to RoadCoach while they focused on the roadway. Each factor could receive a maximum individual score of 500 and a minimum individual score of 0.

Table 4.1 Individual ranking of six factors of DALI assessment

Task Factor	Mean (SD)
Situational Stress	132.62 (25.05)
Auditory Demand	100.71 (28.82)
Temporal Demand	89.76 (22.54)
Visual Demand	89.76 (19.64)
Effort of Attention	79.29 (14.37)
Interference Level	69.05 (11.77)

4.3.3 System usability scale (SUS)

Upon completion of the experiment, drivers were given the System Usability Scale (SUS) satisfaction survey to measure their overall acceptance of RoadCoach. The SUS measures satisfaction scores in a range from 0 to 100, with a larger number indicating a higher level of perceived satisfaction. Satisfying systems tend to produce SUS scores in the 70 – 100 range. A typical SUS score is 68.

The RoadCoach interface received an average SUS score of 78.50 (SD = 11.60) from participants. An average score of 78.50 indicates that drivers were relatively satisfied with the design and user-friendliness of the interface and found it to be quite usable overall. This was also further reflected in the post-experiment interviews with participants. Previous studies examining the user satisfaction of RoadCoach during a one-hour controlled field test yielded a SUS score of 93.86 (SD = 8.01), indicating

that there may have been an effect of novelty in shorter studies that resulted in higher user scores, or that a more in-depth interaction with the system, may have resulted in the decrease in user satisfaction.

4.3.4 Nine dimensions of quick usability

In addition to the SUS, participants also completed the Nine Dimensions of Quick Usability (See Appendix I) assessment at the end of the study. Participants rate nine levels of usability on a five-point scale based on positive and negative attributes of the system. Table 4.2 shows the mean scores for each factor of the assessment, with higher scores reflecting more positive levels of perceived usability and satisfaction. The factors that were rated as being the most favorable were that the system was useful, good, and raised alertness. While the most negatively rated factor was that the system was found to be somewhat annoying. Overall, these scores indicate a relatively favorable perception of usability and usefulness of RoadCoach.

Table 4.2 Average scores for nine dimensions of quick usability assessment

Factor	Mean (SD)
Useful/Useless	3.86 (1.04)
Pleasant/Unpleasant	3.07 (0.9)
Good/Bad	4.29 (0.71)
Nice/Annoying	2.75 (0.92)
Effective/Superfluous	3.46 (1.13)
Likeable/Irritating	3.25 (.084)
Assisting/Worthless	3.79 (0.99)
Desirable/Undesirable	3.64 (1.06)
Raising Alertness/Sleep-Inducing	4.71 (.053)

4.3.5 Trust questionnaire (modified)

Upon completion of the study, drivers also completed a modified trust questionnaire (See Appendix J) that measured how much trust they were willing to place in the driver support system. The questionnaire measures trust on a scale from 0 to 100, with a larger number indicating a higher level of trust for the system and its feedback. The RoadCoach interface received an average trust score of 73.86 (SD = 10.69) from participants. An average score of 73.86 indicates that drivers placed a moderately high amount of trust in the feedback they received from the system. This was also further reflected in the post-experiment interviews with participants.

4.4 FOLLOW-UP INTERVIEWS

The final portion of the fifth phase of the study concluded with a semi-structured interview with participants. The interview consisted of 11 primary questions (See Appendix Q). The general purpose of the interview was for researchers to obtain a more in-depth understanding of how participants felt about their experience interacting with RoadCoach, so that their feedback could be used to develop a

more user-friendly version of the driver support system for future testing and marketing. Table 4.3 and Table 4.4 summarize the most frequent responses from participants regarding the first eight questions in the interview. Analyses followed categorization approaches outlined by Kirwan and Ainsworth (1992).

Table 4.3 Summary responses to interview questions 1-4

1. Were there any ADVANTAGES to using RoadCoach?	2. Were there any DISADVANTAGES to using RoadCoach?	3. What did you like BEST about RoadCoach?	4. What did you like LEAST about RoadCoach?
It keeps your attention on the road	It might be distracting during difficult traffic situations	It kept driver focus on the road	The voice and some of the wording is annoying
It helps you to not speed so much	If information is inaccurate, there may be consequences	It informs you when you run a stop sign	The hard braking is too sensitive
It helps you to be more aware of your driving	The voice and wording are annoying enough that the app may be turned off at times	It tells you the speed limit, speed limit changes, and informs you when you are speeding	The speed limits and stop signs were inaccurate occasionally
It improves driving behavior		The simple and easy-to-use design of the system	The aggressive driving maneuver warnings seemed unnecessary for adults
Might be good for people who are having problems with vision or reaction time and cannot drive as well		The advanced curve warnings were nice when on unfamiliar roads	

Table 4.4 Summary responses to interview questions 5-7

5. In what scenarios do you feel RoadCoach would be MOST useful?	6. In what scenarios do you feel RoadCoach would be LEAST useful?	7. What, if anything, would you CHANGE about RoadCoach?
In unfamiliar areas when you do not know the speed limit	When traffic was very heavy, and you need to concentrate	Change the voice and the wording of auditory warnings
When there is not a lot of traffic and you may not pay attention to your speed	As long as you can turn the app on and off this will not be a problem for each driver	Allow users to customize their own speeding thresholds
Whenever you are distracted or not paying attention	When I have passengers in the vehicle that I am trying to communicate with	Integrate the app into newer vehicle onboard systems
For drivers who do not drive very much		Show the vehicle speed on the screen
		Change the aggressive driving signs to be more intuitive

Since the majority of participants provided answers related to the final three questions of the interview when answering previous questions, Table 4.5 summarizes the most frequent responses to follow-up questions that researchers had for participants about the final four questions in the interview.

Table 4.5 Summary responses to interview questions 8-11

8. What would you CHANGE about the audio warnings?	9. What would you want to CUSTOMIZE about RoadCoach?	11. Why would you WANT an in-vehicle driver support system?
Get rid of the word "violation"	The speeding threshold	I would not have to mess with downloading an app
Make the wording more positive	The sensitivity of the Hard Braking	It would free up my phone when driving
Use a male voice	The sensitivity for Stop Sign violations	So that I would not have to have my phone on the windshield
Make the notifications a little clearer in what they mean	The voice for the auditory warnings	So that it is more in-tune with my car and I do not have to look at my phone for information
		So it is incorporated with my GPS

CHAPTER 5: DISCUSSION

5.1 SUMMARY OF RESULTS

The general pattern of results indicates a positive effect from RoadCoach on driving performance while the device is active and providing feedback. Repeated measures analyses of speeding warnings, speeding violations, hard braking, and stop sign violations indicate either significant improvement or a trend toward improvement for these measures from the baseline phase to the feedback phase. Second, for the speeding metrics, performance in the post-feedback or no-feedback phase was worse than it was in the feedback phase, indicating no training effect with these feedback durations for speeding. Third, the measures of hard braking and stop sign violations showed sustained improved performance in the no-feedback phase, indicating some training effect with the RoadCoach app could have occurred for these driving behaviors.

Subjective metrics indicated that using the RoadCoach app did not appear to demand much mental effort from older drivers, as measured by the Rating Scale of Mental Effort (RSME) and the Driving Activity Load Index (DALI). The DALI indicated that the primary drivers of workload were situational stress (e.g., older drivers are less likely to attend to the app when there are significant external demands on their attention) and auditory demand. Besides the direct assessment of workload with mental demand questionnaires, the usability of RoadCoach was also considered. The System Usability Scale indicated an above-average usability score, although the score was not exceptionally above average as previously indicated in preliminary testing. The Nine Dimensions of Quick Usability Assessment indicated that the reduced usability may have been due to the annoyingness of the device, which may be due to its tendency to make alerts or alarm indications that intrude on driver attention. However, users did rate the system as alerting, assisting, and useful. These rating scores were corroborated by the statements made in the post-study interview questions. Finally, a questionnaire was administered to assess the degree of user trust in the RoadCoach app and system, and it received a moderately high degree of trust from the drivers, indicating relatively high reliability.

Overall, the field operational test demonstrated that RoadCoach is an effective tool to reduce certain types of risky driving behaviors over a short period, especially related to hard braking and stop sign violations. It may also help assist drivers in their ability to pay attention to the task of driving. Further research should examine whether a longer treatment period, or greater study power, would reveal a significant reduction in speeding behaviors through the app's feedback, whether a training effect can be attained, or whether unintended consequences of riskier driving behavior through speeding could occur through feedback cessation. Importantly, the app demonstrated that it was a useful tool through its high user acceptance. Feedback gained through focus groups conducted by Morris and colleagues (2018) found some drivers were anxious about the potential loss of their driving independence and open to the use of technology to help retain it. Future research should examine the extent to which in-vehicle coaching could help prolong safe driving among older drivers or even improve it.

5.2 REAL-WORLD IMPLICATIONS AND DESIGN RECOMMENDATIONS

The current study highlights the importance of studying the impact of in-vehicle feedback and telematic monitoring on driving safety. In recent years, the use of telematics to monitor, record, and transmit driver behavior has increasingly grown in popularity. To date, it has primarily been used by insurance companies, fleet services, and apps that allow parents to monitor their teen drivers. Multiple insurance companies have begun to offer safe-driving discounts to clients who are willing to install a monitoring device in their vehicle, but they must also avoid risky driving behaviors like speeding and hard braking to earn the discount. There is also an array of companies with large fleets of drivers that have begun to utilize telematic systems, such as GreenRoad, to monitor their drivers (GreenRoad.com). Companies are not only doing this to reduce risky driving but also to elicit more efficient fuel consumption among drivers. Additionally, multiple smartphone apps, such as DriveSmart and TrueMotion, have been developed recently to allow parents to monitor and track the behaviors and locations of their teenage children.

As telematics continue to grow in popularity, it will be necessary to continue to study the impacts of such systems to better understand both the positive and negative impacts that they may have among various driving populations and under varying road circumstances. These systems offer an additional potential means for changing driver behavior, as was demonstrated in the current study. To date, there has been little to no research examining the impact of telematic monitoring and in-vehicle feedback among older drivers.

While the results of this study offer only an initial starting point, the growing level of in-vehicle distractions, as well as the increasing popularity of telematic systems, particularly ones that provide real-time feedback, illustrate the importance of continued research in this field. As the number of older drivers on American roadways continues to grow, more research will be needed to understand how systems such as RoadCoach can best be utilized to curtail risky driving. It likely will not be enough to simply design effective systems; it will also be necessary to design systems that are both user-friendly and encourage safer driving. Increased adoption of such systems is likely to require greater awareness of the existence and utility of such systems, particularly among more vulnerable driving populations.

There was an effect of gender on the count of speeding warnings, particularly in the no-feedback phase. Some studies have found that older females have a higher crash risk than older males (Chipman, MacGregor, Smiley, & Lee-Gosselin, 1993; Kweon & Kockelman, 2003). An app such as RoadCoach could be particularly helpful to this group.

5.3 DESIGN RECOMMENDATIONS

The current study had two primary research concerns. The first was to determine if there was an effect of RoadCoach on driver behavior and to what extent. The second was to determine the overall usability and adoptability of such a system among older adults. While the system was shown to have a positive effect on multiple aspects of driver behavior, it is also important to understand how the system was

perceived by users to generate design recommendations in an attempt to produce a more user-friendly iteration of RoadCoach. The long-term goal of this line of research was to develop a system with a universal design that could be utilized by drivers of all ages but also one that could be especially useful to older adults by helping them to safely maintain their mobility. For users to be willing to adopt and utilize such a system, it is important that they feel the system is useful to them as drivers in addition to being highly usable and easy to adopt. While drivers did have positive overall opinions of the RoadCoach app in its current state, several recommendations for the system were derived from the users' comments in the post-study interview, which can be seen in Table 5.1.

Table 5.1 Recommended interface changes to RoadCoach

Consider including positive feedback based on safe driving so drivers are more positively engaged while driving. This may also include a general "Trip Score" at the conclusion of each trip a driver makes.

Consider including an option so users can see how their driving compares to that of the average RoadCoach driver as well as the best drivers utilizing RoadCoach so they can better determine how their driving compares to the driving of others.

Consider changing the system so it can operate under "picture-in-picture" mode, allowing users to utilize other apps, such as GPS, while still maintaining feedback about behaviors like speeding.

Add information during account creation that clearly informs users that all of their information is completely private and cannot be shared with outside entities.

Consider changing the wording of the auditory warnings to be viewed as less aversive.

Consider changing the braking violation sign to a side view of a vehicle with the nose tilted downward and tire marks behind the vehicle.

Consider changing the acceleration violation sign to a side view of a vehicle with the nose pointed upward.

Consider removing the "GPS ok" and "Maps ok" indicators on the main screen. Participants were uncertain of what these meant, and there was nothing users could do to change this information.

Consider giving users the ability to change the speed warning threshold.

Increase the reliability and accuracy of posted speed limits.

Consider changing the voice used for auditory warnings to one rated as being more pleasant to drivers.

Consider providing drivers more in-depth tracking of when they are exhibiting certain "risky" behaviors so that they may be more equipped to alter their behavior accordingly.

5.4 LIMITATIONS AND FUTURE DIRECTIONS

The current study utilized a quasi-experimental design so that the effects and user-perception of the driver support system could be measured. However, this resulted in a lack of control among participants regarding their individual usage of the RoadCoach app as well as the amount and types of driving environments in which each driver interacted with RoadCoach. As a result, the different ways in which each driver interacted with the app may have influenced the degree to which the system affected their

driving behavior as well as their perceptions of the system. Future research could benefit from more in-depth tracking of the types of driving environments that each participant is exposed to throughout the study so as to better understand the potential impact of the system under various driving circumstances.

Another limitation of the study was that it only utilized a relatively small sample (28 participants) of older adults who were primarily under 75 years of age, had no apparent physical, visual, or cognitive limitations, and had a history of safe driving. Because these types of older drivers are less likely to be involved in a crash relative to older drivers with some form of impairment, it is unclear as of yet how much the results of this study will generalize to older adults with some form of impairment known to affect driving behavior. Future studies could profit from exploring the impact of such a system on a larger population of drivers who fall into the old-old category and those who have mild forms of impairment to understand the effect of the system among older drivers who are more likely to be involved in a severe vehicular crash. As a related matter, in future studies focusing on the 'young-old', researchers may want to consider using the Montreal Cognitive Assessment (MoCA) rather than the MMSE as it is a more sensitive measure of mild cognitive impairment (Nasreddine, et al., 2005).

In the section on 'Driving Capacity,' it was noted that few studies have found training improvements beyond one month. However, the current project also only had a three-week follow-up (post-intervention). The present study may be better served with a follow-up study after three months or so to determine whether there were long-term effects on driving behavior.

In addition, even though this study sought to improve driver behaviors known to be associated with an increased crash-risk (e.g., speeding, hard braking), it is unclear to what extent improvements within these metrics actually improved individual driver safety. Future work should include more long-term studies to better understand how the use of and exposure to RoadCoach affects the crash risk of older drivers, as there is not yet any literature examining the long-term effects of such a driver support system.

Lastly, while participant feedback and reviews of the system were primarily very positive, many in the debrief interviews admitted to "gaming" the system regarding speeding violations. That is, just before they felt they were going to receive a speeding violation, they would slow down so as to reset the speeding violation tracker, then speed back up until they were about to receive a violation again, at which point they would repeat the process of slowing down and speeding up. This was reported to be due to the negative feeling of receiving a speeding violation. There could be advantages to future studies examining the effects of positive feedback from a driver support system on both driver behavior and driver opinion of the system. Currently, there are several other similar versions to the driver support system utilized in this study that are used for fleet service drivers, which provide drivers with a driving score after each trip. Exploring the impact of positive reinforcement could be useful in changing how drivers tend to "game" the system to receive more positive feedback through safer driving, rather than to avoid receiving negative feedback by only occasionally avoiding behaviors like speeding.

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APPENDIX A: RECRUITMENT FLYER

RECRUITMENT FLYER

Participants Needed for Driving Study

Join the University of Minnesota's HumanFIRST Laboratory in a
Driving and Messaging Technology Study!

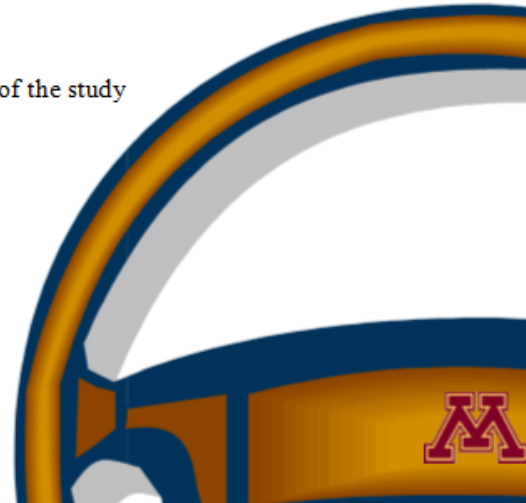
Eligibility:

- Must be at least **65 years of age**
- Must have normal or corrected vision of 20/40 or higher
- Must exhibit **NO** cognitive, physical, or health constraints that affect driving
- Must have **NO** hearing loss that inhibits everyday conversation
- Must have a valid driver's license and vehicle insurance
- Must use an android smartphone

Participation will involve:

- Driving your daily routes as normal
- Questions about driving history
- Responding to alerts from a smartphone
- A 12 week commitment
- A \$120 (\$10 per week) stipend at the end of the study

If you are interested in taking part
in this study, please contact us
by phone or email. Thanks!



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**APPENDIX B: ROADCOACH CRAIGSLIST AND FACEBOOK
ADVERTISING SCRIPT**

ROADCOACH CRAIGSLIST AND FACEBOOK ADVERTISING SCRIPT

The HumanFIRST Laboratory of the University of Minnesota is seeking volunteers ages 65-99 to participate in a driving study. In this study, you will be asked to drive normally for twelve weeks while evaluating a smartphone-based app that provides real-time feedback about the roadway and your driving behavior. Using your input, we hope to gain insight into the wants and needs of drivers in order to design a highly effective and usable system for assisting drivers. Participation in this study will constitute reimbursement in the form of \$120 cash. Our study will last 12 weeks.

To be eligible, we ask that you hold a current and valid driver's license and vehicle insurance, drive a minimum of 4,000 miles each year, have normal or corrected vision (20/40 or better), own an android smart phone, and have no cognitive, hearing, or physical constraints that may limit your driving performance. If you would like to participate, please contact one of the researchers in our lab: David Libby, 612-625-0447, dlibby@umn.edu; Nichole Morris, Ph.D., 612-624-4614, nlmorris@umn.edu

APPENDIX C: ROADCOACH SCREENING QUESTIONNAIRE

ROADCOACH SCREENING QUESTIONNAIRE

1. What is your age?
 - EXCLUDE IF NOT 65-99
2. Do you have an android smartphone?
 - EXCLUDE IF NO
3. Have you had a U.S. driver's license for at least two years?
 - EXCLUDE IF NO
4. Do you drive a minimum of 4,000 miles each year?
 - EXCLUDE IF NO
5. Do you have at least 20/50 visual acuity, either corrected or uncorrected? (i.e. persons that use corrective contact lenses which improve their vision to 20/40 may participate)
 - EXCLUDE IF NO
6. Do you have normal color vision?
 - EXCLUDE IF NO
7. Do you have any history of hearing loss which inhibits every day conversation?
 - EXCLUDE IF YES
8. Do you have any health problems that affect your driving?
 - EXCLUDE IF YES
9. Do you currently experience inner ear problems, dizziness, vertigo, or balance problems?
 - EXCLUDE IF YES
10. Have you been diagnosed by a physician as having any mild cognitive impairment, Alzheimer's, or dementia?
 - EXCLUDE IF YES
11. Are you suffering from any lingering effects of stroke, tumor, head trauma, or infection?
 - EXCLUDE IF YES
12. Do you or have you suffered from an epileptic seizure within the past 12 months?
 - EXCLUDE IF YES
13. Are you willing to have a cell phone holder temporarily mounted to the windshield of your vehicle for the duration of this 13-week study that you will agree to place your phone in each time while driving?
 - EXCLUDE IF NO

APPENDIX D: DRIVING HISTORY QUESTIONNAIRE

DRIVING HISTORY QUESTIONNAIRE

This questionnaire asks you to indicate some details about your driving history and related information. Please tick one box for each question.

1. Your age: _____ years

2. Your sex: Male
 Female

3. What is your highest educational level completed?

- High School / Vocational School
- Associates Degree
- Bachelor of Arts / Bachelor of Science
- Masters
- PhD

4. Are you currently taking any college level classes?

- Yes
- No

5. Please state your occupation: _____

6. Please state the **year** when you obtained your full driving license: _____

7. About how often do you drive nowadays?

- Never** **Hardly Ever** **Sometimes** **Most Days** **Every Day**

8. Estimate roughly how many miles you personally have driven in the past year:

- Less than 5000 miles
- 5000-10,000 miles
- 10,000-15,000 miles
- 15,000-20,000 miles
- Over 20,000 miles

9. About how often do you drive to and from your place of work or school?

- Never** **Hardly Ever** **Sometimes** **Most Days** **Every Day**

10. Do you drive frequently on...

- | | Yes | No |
|---------------------------------|-----------------------|-----------------------|
| Highways? | <input type="radio"/> | <input type="radio"/> |
| Main Roads other than Highways? | <input type="radio"/> | <input type="radio"/> |
| Urban Roads? | <input type="radio"/> | <input type="radio"/> |
| Country Roads? | <input type="radio"/> | <input type="radio"/> |
- _____

11. During the last three years, how many minor traffic crashes have you been involved in where you were at fault? A minor crash is one in which no-one required medical treatment, AND costs of damage to vehicles and property were less than \$1500.

Number of minor accidents _____ (if none, write 0)

12. During the last three years, how many major traffic crashes have you been involved in where you were at fault? A major crash is one in which EITHER someone required medical treatment, OR costs of damage to vehicles and property were greater than \$1500, or both.

Number of major accidents _____ (if none, write 0)

13. During the last three years, have you ever been convicted for:
- | | Yes | No |
|--|-----------------------|-----------------------|
| Speeding | <input type="radio"/> | <input type="radio"/> |
| Distracted, careless or dangerous driving | <input type="radio"/> | <input type="radio"/> |
| Driving under the influence of alcohol/drugs | <input type="radio"/> | <input type="radio"/> |

14. What type of vehicle do you drive most often?

- Motorcycle
- Passenger Car
- Pick-Up Truck
- Sport utility vehicle
- Van or Minivan
- Other, briefly describe: _____

15. Which type of cellular phone do you own, and/or use most often?

- Basic phone (camera equipped or not)
- Android Smartphone
- iPhone Smartphone
- Windows Smartphone
- Blackberry Smartphone
- I do not have a cell phone

16. Please select the type of navigation system you have used. (select all that apply)

- Built-in vehicle navigation systems
- Portable navigation systems (e.g. Garmin, TomTom)
- Smartphone-based navigation systems (Apple, Google maps)
- Other: _____

17. How frequently do you use a GPS or navigation system? (select one)

- Never
- Rarely (e.g. When alone on roadway)
- Sometimes (e.g. When stopped at a stoplight)
- Often (e.g. Cruising down the highway, stopped traffic)
- All the time (e.g. At any time while driving)

18. What are the primary uses for the navigation system? (choose all that apply)

- Driving in unfamiliar cities/neighborhoods
- Determining the best route to my destination
- Determining alternate route (i.e. in case of road construction or traffic)
- Determining my arrival time or trip time to my destination
- Getting directions to recent destinations
- Driving in familiar cities/neighborhoods
- Finding direction to return home
- Finding gas stations/restaurants/shopping locations etc.
- Fitness or exercise tracking
- Biking or walking directions
- Other

APPENDIX E: SENSATION SEEKING QUESTIONNAIRE

1 |-----| 2 |-----| 3 |-----| 4
Describes me very well Describes me somewhat Does not describe me very well Does not describe me at all

12. I like a movie where there are a lot of explosions and car chases.

1 |-----| 2 |-----| 3 |-----| 4
Describes me very well Describes me somewhat Does not describe me very well Does not describe me at all

13. I don't like extremely hot and spicy foods.

1 |-----| 2 |-----| 3 |-----| 4
Describes me very well Describes me somewhat Does not describe me very well Does not describe me at all

14. In general, I work better when I'm under pressure.

1 |-----| 2 |-----| 3 |-----| 4
Describes me very well Describes me somewhat Does not describe me very well Does not describe me at all

15. I often like to have the radio or TV on while I'm doing something else, such as reading or cleaning up.

1 |-----| 2 |-----| 3 |-----| 4
Describes me very well Describes me somewhat Does not describe me very well Does not describe me at all

16. It would be interesting to see a car accident happen.

1 |-----| 2 |-----| 3 |-----| 4
Describes me very well Describes me somewhat Does not describe me very well Does not describe me at all

17. I think it's best to order something familiar when eating in a restaurant.

1 |-----| 2 |-----| 3 |-----| 4
Describes me very well Describes me somewhat Does not describe me very well Does not describe me at all

18. I like the feeling of standing next to the edge on a high place and looking down.

1 |-----| 2 |-----| 3 |-----| 4
Describes me very well Describes me somewhat Does not describe me very well Does not describe me at all

19. If it were possible to visit another planet or the moon for free, I would be among the first in line to sign up.

1 |-----| 2 |-----| 3 |-----| 4
Describes me very well Describes me somewhat Does not describe me very well Does not describe me at all

20. I can see how it must be exciting to be in a battle during a war.


1 |-----| 2 |-----| 3 |-----| 4
Describes me very well Describes me somewhat Does not describe me very well Does not describe me at all

APPENDIX F: MINI-MENTAL STATE EXAMINATION

MINI-MENTAL STATE EXAMINATION

Patient's Name: _____ Date: _____

Instructions: Ask the questions in the order listed. Score one point for each correct response within each question or activity.

Maximum Score	Patient's Score	Questions
5		"What is the year? Season? Date? Day of the week? Month?"
5		"Where are we now: State? County? Town/city? Hospital? Floor?"
3		The examiner names three unrelated objects clearly and slowly, then asks the patient to name all three of them. The patient's response is used for scoring. The examiner repeats them until patient learns all of them, if possible. Number of trials: _____
5		"I would like you to count backward from 100 by sevens." (93, 86, 79, 72, 65, ...) Stop after five answers. Alternative: "Spell WORLD backwards." (D-L-R-O-W)
3		"Earlier I told you the names of three things. Can you tell me what those were?"
2		Show the patient two simple objects, such as a wristwatch and a pencil, and ask the patient to name them.
1		"Repeat the phrase: 'No ifs, ands, or buts.'"
3		"Take the paper in your right hand, fold it in half, and put it on the floor." (The examiner gives the patient a piece of blank paper.)
1		"Please read this and do what it says." (Written instruction is "Close your eyes.")
1		"Make up and write a sentence about anything." (This sentence must contain a noun and a verb.)
1		"Please copy this picture." (The examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles must be present and two must intersect.) 
30		TOTAL

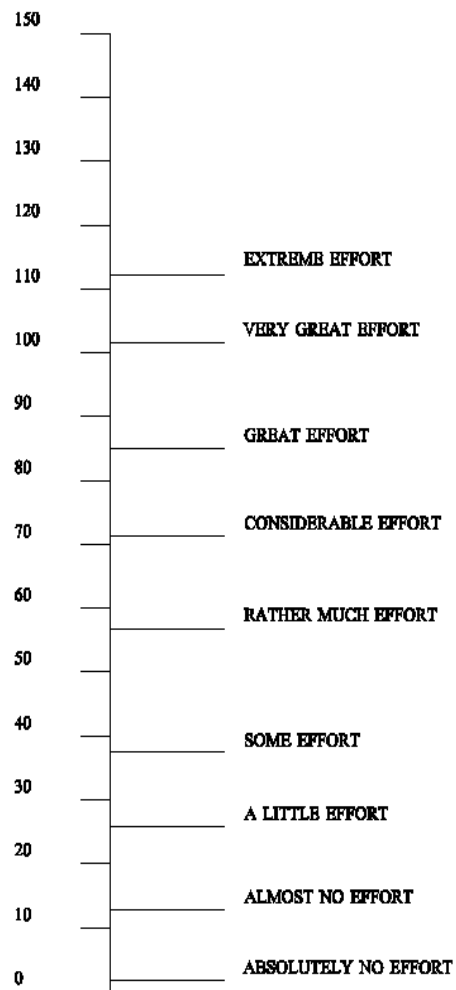
(Adapted from Rovner & Folstein, 1987)

APPENDIX G: RATING SCALE OF MENTAL EFFORT

RATING SCALE OF MENTAL EFFORT

Rating Scale Mental Effort

Please indicate, by marking the vertical axis below, how much effort it took for you to complete the task you've just finished



APPENDIX H: SYSTEM USABILITY SCALE

SYSTEM USABILITY SCALE

System Usability Survey SUS

For each of the following questions, place an "X" through the one number to indicate your response. "1" for strongly disagree, "3" for neutral- neither agree nor disagree, "5" for strongly agree.

1. I think that I would like to use this system frequently.

Strongly Disagree		Neutral		Strongly Agree
①	②	③	④	⑤

2. I found the system unnecessarily complex.

①	②	③	④	⑤
---	---	---	---	---

3. I thought the system was easy to use.

①	②	③	④	⑤
---	---	---	---	---

4. I think that I would need the support of a technical person to be able to use this system.

①	②	③	④	⑤
---	---	---	---	---

5. I found the various functions in this system were well integrated.

①	②	③	④	⑤
---	---	---	---	---

6. I thought there was too much inconsistency in this system.

①	②	③	④	⑤
---	---	---	---	---

7. I would imagine that most people would learn to use this system very quickly.

①	②	③	④	⑤
---	---	---	---	---

8. I found the system very cumbersome to use.

①	②	③	④	⑤
---	---	---	---	---

9. I felt very confident using the system.

①	②	③	④	⑤
---	---	---	---	---

10. I needed to learn a lot of things before I could get going with this system.

①	②	③	④	⑤
---	---	---	---	---

APPENDIX I: THE NINE DIMENSIONS OF QUICK USABILITY TEST

THE NINE DIMENSIONS OF QUICK USABILITY TEST

My judgements of the (...) system are... (please tick a box on every line)

- | | | | | | | |
|---|-------------------|--------------------------|--------------------------|--------------------------|--------------------------|----------------|
| 1 | useful | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | useless |
| 2 | pleasant | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | unpleasant |
| 3 | bad | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | good |
| 4 | nice | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | annoying |
| 5 | effective | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | superfluous |
| 6 | irritating | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | likeable |
| 7 | assisting | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | worthless |
| 8 | undesirable | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | desirable |
| 9 | raising alertness | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | sleep-inducing |
-

APPENDIX J: TRUST QUESTIONNAIRE

TRUST QUESTIONNAIRE

For each of the following questions, place an "X" through the one number to indicate your response.
"1" for Not at All, "4" for "Neutral", "7" for Extremely.

1. I am suspicious of the system's outputs

Not At All			Neutral			Extremely
1	2	3	4	5	6	7

2. I am wary of the system

1	2	3	4	5	6	7
---	---	---	---	---	---	---

3. The system's actions will have a harmful or injurious effect

1	2	3	4	5	6	7
---	---	---	---	---	---	---

4. I am confident in the system

1	2	3	4	5	6	7
---	---	---	---	---	---	---

5. The system provides security

1	2	3	4	5	6	7
---	---	---	---	---	---	---

6. The system has integrity

1	2	3	4	5	6	7
---	---	---	---	---	---	---

7. The system is dependable

1	2	3	4	5	6	7
---	---	---	---	---	---	---

8. The system is reliable

1	2	3	4	5	6	7
---	---	---	---	---	---	---

9. I can trust the system

1	2	3	4	5	6	7
---	---	---	---	---	---	---

10. I am familiar with the system

1	2	3	4	5	6	7
---	---	---	---	---	---	---

APPENDIX K: MENTAL PAPER FOLDING TEST

MENTAL PAPER FOLDING TEST







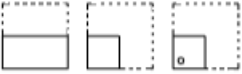

















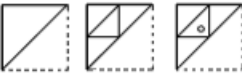











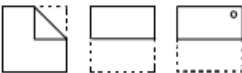























PART ONE (3 MINUTES)

		A	B	C	D	E
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

STOP

DO NOT PROCEED TO THE NEXT PAGE UNTIL ASKED TO DO SO

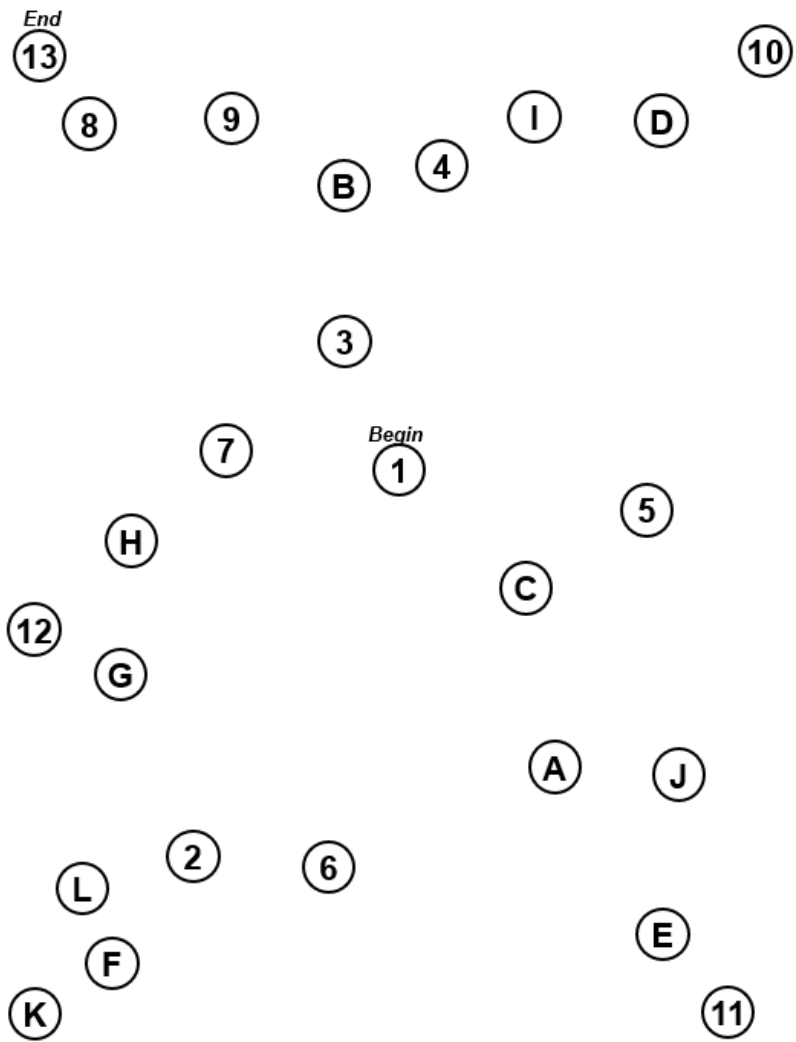
PART TWO (3 MINUTES)

		A	B	C	D	E
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

**STOP AND WAIT FOR FURTHER INSTRUCTIONS
DO NOT GO BACK TO PART ONE**

APPENDIX L: TRAIL MAKING TEST PART B

TRAIL MAKING TEST PART B



APPENDIX M: DRIVING ASSESSMENT LOAD INDEX

DRIVING ASSESSMENT LOAD INDEX

DALI Mental Workload Rankings

For each of the pairs listed below, circle the scale title that represents the more important contributor to workload in the display.

- | | | |
|---------------------|----|--------------------|
| Effort of Attention | or | Visual Demand |
| Effort of Attention | or | Temporal Demand |
| Effort of Attention | or | Auditory Demand |
| Effort of Attention | or | Situational Stress |
| Effort of Attention | or | Interference |
| Visual Demand | or | Temporal Demand |
| Visual Demand | or | Auditory Demand |
| Visual Demand | or | Situational Stress |
| Visual Demand | or | Interference |
| Temporal Demand | or | Auditory Demand |
| Temporal Demand | or | Interference |
| Temporal Demand | or | Situational Stress |
| Auditory Demand | or | Interference |
| Auditory Demand | or | Situational Stress |
| Interference | or | Situational Stress |

Definition of Task Demand Factor

Effort of Attention

How much mental effort did you have to exert to attend to the information that was conveyed to you by the RoadCoach app? Was it easy to understand and attend to or was it mentally taxing to attend to the information presented?

Visual Demand

How much visual attention was required to utilize the RoadCoach app while driving? Did it require you to take your eyes off the roadway frequently or infrequently? When you chose to look at the feedback on the screen, did it require brief or long periods of visual attention?

Temporal demand

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Auditory Demand

How much auditory demand was required to utilize the RoadCoach app while driving? How satisfied were you with your Auditory Demand in accomplishing these goals?

Interference level

To what extent did having RoadCoach active and in your field-of-view interfere with your ability to safely drive and navigate the roadway without distraction?

Situational Stress

How much did outside situational factors affect your ability or desire to attend to RoadCoach (this includes things like traffic, fatigue, annoyance with the app, etc.)?

DALI Mental Workload Rating Scale

Please place an "X" along each scale at the point that best indicates your experience with the display configuration.

Effort of Attention: How much mental effort did you have to exert to attend to the information that was conveyed to you by the RoadCoach app? Was it easy to understand and attend to or was it mentally taxing to attend to the information presented?

Low High

Visual Demand: How much visual attention was required to utilize the RoadCoach app while driving? Did it require you to take your eyes off the roadway frequently or infrequently? When you chose to look at the feedback on the screen, did it require brief or long periods of visual attention?

Low High

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Low High

Auditory Demand: How much auditory demand was required to utilize the RoadCoach app while driving? How satisfied were you with your Auditory Demand in accomplishing these goals?

Low High

Interference Level: To what extent did having RoadCoach active and in your field-of-view interfere with your ability to safely drive and navigate the roadway without distraction?

Low High

Situational Stress: How much did outside situational factors affect your ability or desire to attend to RoadCoach (this includes things like traffic, fatigue, annoyance with the app, etc.)?

Low High

APPENDIX N: DRIVING SELF-ASSESSMENT QUESTIONNAIRE

DRIVING SELF-ASSESSMENT QUESTIONNAIRE

1. On a scale of 1-10, with 10 being the best possible, how would you rate your driving ability?
2. On a scale of 1-10, with 10 being the best possible, where would you like your driving ability to be?
3. Do you think your overall driving ability has declined at all with age?
Very Much Somewhat A Little None
4. How often do you go 0-3 mph over the speed limit?
Always Frequently Sometimes Rarely Never
5. How often do you go 3-7 mph over the speed limit?
Always Frequently Sometimes Rarely Never
6. How often do you go 7-15 mph over the speed limit?
Always Frequently Sometimes Rarely Never
7. How often do you go over 15 mph over the speed limit?
Always Frequently Sometimes Rarely Never
8. How often do you roll through a stop sign without coming to a complete stop?
Always Frequently Sometimes Rarely Never
9. Relative to other drivers, which quartile do you believe your driving skill level falls within?
1-25% 26-50% 51-75% 76-99%
10. Do you feel like any aspects related to your ability to safely maneuver a vehicle have declined with age? If so, please describe them.

APPENDIX O: ROADCOACH POST-STUDY QUESTIONNAIRE

ROADCOACH POST-STUDY QUESTIONNAIRE

1. Do you believe you were less likely to drive 3-7 MPH over the speed limit (Yellow Speed Warning) while you were receiving feedback from RoadCoach? Yes / No
2. If yes, do you believe you were also less likely to drive 3-7 MPH over the speed limit once you were no longer receiving feedback (final 3 weeks) from RoadCoach? Yes / No
3. Do you believe you were less likely to drive more than 7 MPH over the speed limit (Red Speed Warning) while you were receiving feedback from RoadCoach? Yes / No
4. If yes, do you believe you were also less likely to drive more than 7 MPH over the speed limit once you were no longer receiving feedback (final 3 weeks) from RoadCoach? Yes / No
5. Do you believe you were less likely to roll through a Stop Sign while you were receiving feedback from RoadCoach? Yes / No
6. If yes, do you believe you were also less likely to roll through a Stop Sign once you were no longer receiving feedback (final 3 weeks) from RoadCoach? Yes / No
7. Do you believe you were less likely to incur a 'Hard Braking Violation' while you were receiving feedback from RoadCoach? Yes / No
8. If yes, do you believe you were also less likely to incur a 'Hard Braking Violation' once you were no longer receiving feedback (final 3 weeks) from RoadCoach? Yes / No
9. Do you believe you less likely to incur an 'Excessive Turning Violation' while you were receiving feedback from RoadCoach? Yes / No
10. If yes, do you believe you were also less likely to incur an 'Excessive Turning Violation' once you were no longer receiving feedback (final 3 weeks) from RoadCoach? Yes / No

APPENDIX P: PARTICIPANT CONSENT FORM

PARTICIPANT CONSENT FORM

Title of Research Study: Effects of an In-vehicle warning system on Real-World Driver Behavior

Investigator Team Contact Information: Nichole Morris

For questions about research appointments, the research study, research results, or other concerns, call the study team at:

Investigator Name: Nichole Morris Investigator Departmental Affiliation: Mechanical Engineering Phone Number: 612-625-0323 Email Address: nlmorris@umn.edu	Student Investigator Name: Phone Number: Email Address: Study Staff (if applicable): David Libby Phone Number: 612-625-0447 Email Address: dlibby@umn.edu
Co-Investigator Name: Rui Ni Investigator Departmental Affiliation: Department of Psychology, Wichita State University Phone Number: 316-978-3886 Email Address: rui.ni@wichita.ed	

Supported By: This research is supported by funding from the Roadway Safety Institute at the University of Minnesota.

Key Information About This Research Study

The following is a short summary to help you decide whether or not to be a part of this research study. More detailed information is listed later on in this form.

What is research?

The goal of research is to learn new things in order to help people in the future. Investigators learn things by following the same plan with a number of participants, so they do not usually make changes to the plan for individual research participants. You, as an individual, may or may not be helped by volunteering for a research study.

Why am I being invited to take part in this research study?

We are asking you to take part in this research study because you indicated that you were interested in volunteering in this study. We ask that you read this form and ask any questions you may have before agreeing to be in the study. You are invited to be in a research study to discuss your driving history and technology use habits, drive for twelve weeks with an app installed on your phone that will record all of your driving behavior, receive feedback from the app for six weeks of the study, and share your opinions and feedback on our smartphone app that provides you real-time feedback about the roadway as well as your driving behavior. Your participation in this study will help aid the development and design of the RoadCoach smartphone app.

What should I know about a research study?

- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

Why is this research being done?

The purpose of the proposed study is to develop an effective, user-centric in-vehicle messaging technology that informs and alerts drivers in real-time about their driving behavior as well provide drivers with roadway information such as upcoming sharp curves, current speed limits, and upcoming changes in the speed limit. In order to evaluate the effectiveness of the system, the study must examine application performance and driver behavior in a naturalistic setting over the course of twelve weeks. The proposed study aims to investigate the effectiveness of an in-vehicle messaging technology that informs and alerts drivers of any aggressive driving behavior or roadway information as they navigate the roadway.

How long will the research last?

We expect that you will be in this research study for 13 weeks.

What will I need to do to participate?

You will be asked to drive as you normally would for twelve weeks, but with an app installed on your smartphone that records your driving behavior. Additionally, the app will provide you real-time audio and visual feedback for six of the twelve weeks. We will also be asking you to provide some basic information on your driving history, habits, and opinions. There will also be several visual and cognitive tests that we will administer prior to installing the app on your smartphone.

More detailed information about the study procedures can be found under “What happens if I say yes, I want to be in this research?”

Is there any way that being in this study could be bad for me?

The foreseeable risks to you is anticipated to be minimal. While you will be receiving visual feedback from the in-vehicle system, you will also be receiving audio feedback as well which allows you to receive feedback without needing to take your eyes off the road. Participants in previous controlled field tests that utilized the same in-vehicle warning system reported that using the system while driving required very little mental effort. Any potential distraction from the in-vehicle system will be no greater than the types of distractions you are already subject to during normal driving. The difference in this case is that you will be receiving feedback about your driving and the roadway that could create safer driving practices for you.

Will being in this study help me in any way?

We cannot promise any benefits to you or others from your taking part in this research. However, possible benefits include creating and increasing more awareness about your own driving habits and behaviors. Participants in previous controlled field tests that utilized the same in-vehicle system reported high satisfaction with the feedback they received regarding their driving habits and changes they felt they needed to make to improve their driving.

Detailed Information About This Research Study

The following is more detailed information about this study in addition to the information listed above.

How many people will be studied?

We expect about 15 people here will be in this research study out of 30 people in the entire study nationally.

What happens if I say “Yes, I want to be in this research”?

- As a participant, you will interact with researchers during your time in the study. We will be directing you through the study procedures at each step to ensure you are comfortable and progressing through the study in a timely manner. Additionally, researchers will give all of their contact information to you to answer any questions or concerns related to the study.
- Prior to the start of the study, the RoadCoach app will be downloaded onto your smartphone. Researchers will give you detailed instructions on how the app works and the meaning of all the warnings and notifications that you may potentially receive from the RoadCoach app. Researchers will also provide you with a phone mount, if you do not have one, a Bluetooth adapter, if your car does not have Bluetooth. The purpose of connecting your phone to a Bluetooth is so that each time you get in your vehicle, the RoadCoach app will connect to the Bluetooth in your vehicle and automatically begin recording your driving data.
- You will be asked to drive in your own for twelve weeks with your smartphone mounted

on the windshield of the vehicle and connected to Bluetooth. During the first three weeks of the study, the smartphone app, RoadCoach, will collect data regarding your driving behavior. After the first three weeks of the study, researchers will then remotely change the RoadCoach app so that it begins to give you both visual and auditory feedback in real-time about the roadway as well as your driving behavior. The app will continue to give you feedback for six weeks. After the ninth week of the study, researchers will again remotely change the RoadCoach app so that it goes back to collecting your driving data, but you will receive no feedback from the app for the final 3 weeks of the study.

- At the conclusion of each week, you will be sent an email with a brief survey that will take approximately five minutes to complete. Since this is a remote study, the survey serves as a way for researchers to stay in contact with you to ensure everything is working properly and what your interaction with the RoadCoach app has been like (this only applies to the six weeks in which you receive feedback from the app).
- At the conclusion of the study, researchers will complete an interview with you about your thoughts and feedback about using the RoadCoach app, and you will be paid \$120 in cash for your participation.
- The study will begin at the completion of the informed consent process, if you choose to participate.

What happens if I say “Yes”, but I change my mind later?

You can leave the research at any time and it will not be held against you. If you choose to end the study early the researchers may still use the data collected up to the point of your withdrawal.

You may choose to end the study for whatever reasons you would like, and no further data will be collected about your driving.

What are the risks of being in this study? Is there any way being in this study could be bad for me? (Detailed Risks)

This research may hurt you in the following ways: First, driving naturally has some level of risk that can result in serious injury or death. You are responsible for driving safely in this study. Second, you may experience high risk while driving due to the potential distraction of audio and visual information from the RoadCoach warning system. These risks are minimal, and this system has been tested extensively with both novice and experienced drivers who reported minimal levels of mental and demonstrated minimal visual distraction from the system. Third, you are at an increased risk of crash if you manually interact with your phone while driving. The RoadCoach app will launch automatically and does not require you to interact with it while driving. Be sure to place your phone safely in the provided mount while driving and do not interact with it for any purpose until you are fully stopped in a safe location. In addition to these risks, this research may hurt you in ways that are unknown. These might be minor or be severe as to cause death.

Will it cost me anything to participate in this research study?

Taking part in this research study will not lead to any costs to you.

What happens to the information collected for the research?

Efforts will be made to limit the use and disclosure of your personal information, including research study and medical records, to people who have a need to review this information. We cannot promise complete confidentiality. Organizations that may inspect and copy your information include the Institutional Review Board (IRB), the committee that provides ethical and regulatory oversight of research, and other representatives of this institution, including those that have responsibilities for monitoring or ensuring compliance.

Will anyone besides the study team be at my consent meeting?

There will not be anyone else at the consent meeting besides you and the study team.

Whom do I contact if I have questions, concerns or feedback about my experience?

This research has been reviewed and approved by an IRB within the Human Research Protections Program (HRPP). To share feedback privately with the HRPP about your research experience, call the Research Participants' Advocate Line at [612-625-1650](tel:612-625-1650) or go to <https://research.umn.edu/units/hrpp/research-participants/questions-concerns>. You are encouraged to contact the HRPP if:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research participant.
- You want to get information or provide input about this research.

Will I have a chance to provide feedback after the study is over?

The HRPP may ask you to complete a survey that asks about your experience as a research participant. You do not have to complete the survey if you do not want to. If you do choose to complete the survey, your responses will be anonymous.

If you are not asked to complete a survey, but you would like to share feedback, please contact the study team or the HRPP. See the "Investigator Contact Information" of this form for study team contact information and "Whom do I contact if I have questions, concerns or feedback about my experience?" of this form for HRPP contact information.

Can I be removed from the research?

The person in charge of the research study or the sponsor can remove you from the research study without your approval. Possible reasons for removal include discovery that your eligibility criteria are insufficient (e.g. you are colorblind, you appear to have vision or hearing problems that affect your driving performance), or unsafe driving practices. Researchers reserve the right to withdraw participants from continuing the study without their willful consent for any reason that involves safety risks or safety concerns. An example of forced withdrawal would be a participant that is not allowing their phone to connect to the in-vehicle Bluetooth, refusing to run the RoadCoach app, or is in any other way preventing data collection from occurring in the specified manner. Researchers will respectfully inform the participant of their reason for withdrawal and will compensate their time appropriately.

We will tell you about any new information that may affect your health, welfare, or choice to stay in the research. This may include unforeseen events; such as issues with your smartphone properly running the RoadCoach app or other technical errors with the RoadCoach app itself. These events are unlikely. In the event such an issue occurs, the research team will do what they can to fix the problem so that you may remain in the study if you wish.

What happens if I am injured while participating in this research?

If you are injured during engagement in this research activity, please call 911 to seek emergency medical care. Care for such injuries will be billed in the ordinary manner, to you or your insurance company. If during this study and during the use of RoadCoach while drive you are involved in a vehicle crash with or without an injury, notify the research staff right away.

Will I be compensated for my participation?

If you agree to take part in this research study, we will pay you \$120 in cash for your time and effort upon study completion. If you choose to withdraw from the study, the prorated payment schedule is \$10 per week.

Optional Elements:

The following research activities are optional, meaning that you do not have to agree to them in order to participate in the research study. Please indicate your willingness to participate in these optional activities by placing your initials next to each activity.

**Yes,
I agree** **No,
I disagree**

The investigator may contact me in the future to see whether I am interested in participating in other research studies by Dr. Nichole Morris

If yes, provide the following contact information:

Email Address: _____

Phone Number: _____

Your signature documents your permission to take part in this research. You will be provided a copy of this signed document.

Signature of Participant

Date

Printed Name of Participant

Signature of Person Obtaining Consent

Date

Printed Name of Person Obtaining Consent

APPENDIX Q: POST-STUDY SEMI-STRUCTURED INTERVIEW QUESTIONS

POST-STUDY SEMI-STRUCTURED INTERVIEW QUESTIONS

1. Were there any ADVANTAGES to using RoadCoach?
2. Were there any DISADVANTAGES to using RoadCoach?
3. What did you like BEST about RoadCoach?
4. What did you like LEAST about RoadCoach?
5. In what scenarios do you feel RoadCoach would be MOST useful?
6. In what scenarios do you feel RoadCoach would be LEAST useful?
7. What, if anything, would you change about RoadCoach?
8. How did you feel about the wording of the audio recordings of RoadCoach?
9. Would you like it if you could customize the functions of RoadCoach? If so, how?
10. How would you like something similar to RoadCoach as a built-in technology that came with your vehicle?