An Epidemiological Approach to Emergency Vehicle Advanced Warning System Development: A Two-Phase Study

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Christopher José Drucker

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Dedication

I lovingly dedicate this dissertation to my wife who encouraged me to fulfill this blessing.

I also dedicate this work to my mom and dad who, because of their sacrifices, made it possible for me to pursue such a distinguishing honor.

Abstract

Motor vehicle crashes involving emergency vehicle (EV; police, fire trucks, ambulances, etc.) and non-EV drivers have been a known problem that contributes to fatal and nonfatal injuries; however, characteristics associated with non-EV drivers, involved in these crashes, have not been examined adequately. This two-phase study involved: Phase 1) data analysis, using The National Highway Traffic Safety Administration's Fatality Analysis Reporting System and the National Automotive Sampling System General Estimates System to identify driver, roadway, environmental, and crash factors, and consequences for non-EV drivers involved in fatal and nonfatal crashes with in-use and in-transport EVs; and Phase 2) design and analysis of the impact of two in-vehicle driver support systems that alert non-EV drivers to approaching EVs in a simulated urban environment, based on driving performance and usability measures under distracting and non-distracting conditions.

Phase 1 analysis identified potential factors associated with non-EV drivers by utilizing epidemiological methodologies and multivariate logistic regression modeling. Non-EV drivers were more often involved in nonfatal crashes with EVs when driving: distracted (vs. not distracted; OR = 1.9); with vision obstructed by external objects (vs. no obstruction; OR = 36.4 for obstruction due to buildings); at intersections of four-points or more (vs. no intersection; OR = 2.1); at night (vs. midday; OR = 2.8); and in opposite directions (vs. same directions; OR = 4.8) of the EVs. Fatal crashes were associated with driving on urban roads (vs. rural; OR = 2.2); straight through intersections (vs. same direction; OR = 3.4) of four-points or more (vs. no intersection;

OR = 4.9); and at night (vs. midday; OR = 1.6) although these types of crashes were less likely to occur on dark roads (vs. daylight; OR = 0.6). Consequences included increased risk for non-EV drivers to be fatally wounded (vs. no injury; OR = 2.1) among crashes involving at least one fatality.

Phase 2 consisted of eighty-five participants completing a driving simulator trial-based experiment in which they encountered EVs crossing four-way intersections. Overall, the analysis indicated improved responses and roadway safety among participants presented with the driver support systems compared to participants presented with no driver support system. Most notably, participants were at decreased risk of collisions with EVs when given a driver support system (vs. no driver support system; OR = 0.3). The presence of the driver support systems did not increase in-vehicle distractions or perceived mental workload of the driving tasks. In addition, drivers indicated a moderate level of trust and reported the systems to be somewhat useful and satisfying.

The findings of this two-phase study suggest drivers have difficulties in visually detecting EVs in different environments and that the use of technology may be beneficial as an intervention to mitigate roadway crashes between non-EV and EV drivers. Future research should continue to examine these interactions to identify methods to improve roadway safety.

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Organization

The organization of this dissertation provides initial chapters including an overall introduction, a comprehensive review of the literature, and a comprehensive presentation of the research designs and statistical methods. These initial chapters are followed by two major manuscripts (Chapters 4 and 5) that report the findings from this two-phase study. Chapters 4 and 5 are presented in a manner suitable for publication in peer-reviewed journals; therefore, there is some redundancy with the first three chapters. A final chapter provides an overall discussion of the study.

Chapter I: Introduction

The impact of motor vehicle crashes (MVCs) is a well-documented public health problem within the United States. From 2001 through 2010, MVCs ranked first among causes of unintentional injury deaths (Figure 1). More specifically, MVCs are the leading cause of unintentional injury deaths for persons one through 34 and 55 through 64 years of age (CDC, 2013). Figure 2 shows the trends for motor vehicle deaths, vehicle miles traveled, deaths per 100,000 populations, and deaths per 100,000,000 vehicle miles traveled from 1925 through 2010. Since 2005, deaths resulting from MVCs have decreased monotonically, resulting in an overall change of 21.7% from 2005 (n = 45,343) to 2010 (n = 35,500 [estimated]). The 2010 death rate of 1.18 per 100,000,000 vehicle miles traveled was the lowest recorded death rate since vehicle miles traveled has been available (CDC, 2013). The decrease in death rate is partially attributed to changes in laws and regulations, roadway infrastructure design, vehicle safety specifications and equipment, and education among motor vehicle operators. More recently, the use of in-vehicle driver support systems (DSS) and roadway-based technologies that alert drivers to potential critical situations have been shown to be beneficial in reducing MVCs and mitigating outcome severity (Kiefer & Hankey, 2008; Lenné, Triggs, Mulvihill, Reagen & Corben, 2008).

Motor vehicle crash types are predominantly those that involve drivers colliding into other motor vehicles (e.g., buses), followed by fixed objects (e.g., telephone poles), pedestrians, non-collisions (e.g., jackknife, rollover), pedalcyclists, and other sources (e.g., trains, animals; NSC, 2012; Figure 3). Although all types of crashes pose some level of health-related risks, MVCs between non-emergency vehicle (EV) and in-use (i.e., on an emergency call) and in-transport (i.e., in motion at time of crash) EV drivers (such as police, fire trucks, and ambulances) are a particular concern due to the high transportation fatality rate among emergency medical service (EMS) personnel (Maguire, Hunting, Smith, & Levick, 2002; Slattery & Silver, 2009); these involve an increased likelihood of non-EV drivers and occupants being fatally wounded as a consequence (Sanddal, Sanddal, Ward, & Stanley, 2010). In addition, such crashes require at least two additional EVs to enter into service – one to respond to the original emergency call and one to attend to the new crash (Custalow & Gravitz, 2004).

Previous research on collisions between non-EVs and EVs has predominantly focused on characteristics associated with the EV drivers (Kahn, Pirrallo, & Kuhn, 2001) and their health-related outcomes (Becker, Zaloshnja, Levick, Guohua, & Miller, 2003); however, characteristics associated with non-EV drivers have not been examined adequately. Collisions involving EVs can be described as the result of a multifaceted interaction of factors associated with the EV and non-EV drivers, and the environment (Custalow & Gravitz, 2004); therefore, it is essential to understand all components that make up these collisions. In addition, studies have suggested that EVs' lights and siren (L/S) are ineffective in providing essential time-dependent safety-related information to non-EV drivers on the roadway (De Lorenzo & Eilers, 1991; Withington, 1999). L/S are the primary source for alerting drivers on the roadway that an EV is approaching; however, the effectiveness of L/S are limited due to physical and environmental factors that obstruct detection (Robbins, 1995).

Among critical roadway situations, technology (e.g., driver support systems [DSS]) has been utilized as a method to augment the driving experience, i.e. to enhance driver abilities under various conditions and situations to detect imminent threats or assist in high workload situations. The use of technology has been demonstrated in both simulation and naturalistic driving environments to produce positive results that reduce MVCs and mitigate crash severity (Lee, McGehee, Brown, & Reyes, 2002). It is believed that the use of technology can overcome the ineffectiveness of L/S as demonstrated in previous simulator and real-world applications (Lenné, et al., 2008; Hanowski, Dingus, Gallagher, Kieliszewski, and Neal, 1999)

Based on the paucity of research examining non-EV driver characteristics and the ineffectiveness of L/S, the purpose of this two-phase study was to 1) identify driver, roadway, environmental, and crash factors, and consequences for non-EV drivers involved in fatal and nonfatal MVCs with in-use and in-transport EVs and 2) design and examine the impact of two in-vehicle DSSs that alert drivers to approaching EVs in an simulated urban environment, based on driving performance and usability measures under distracting and non-distracting conditions

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Figures

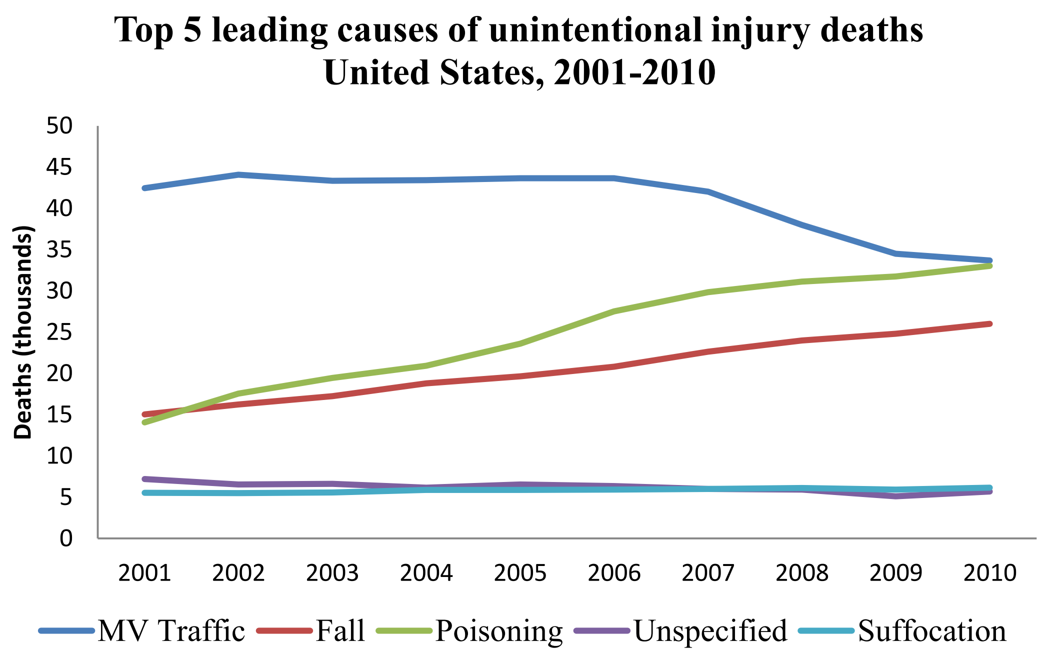

Figure 1: Top 5 leading causes of unintentional injury deaths in the United States, 2001-2010 (Data retrieved from CDC, WISQARS)

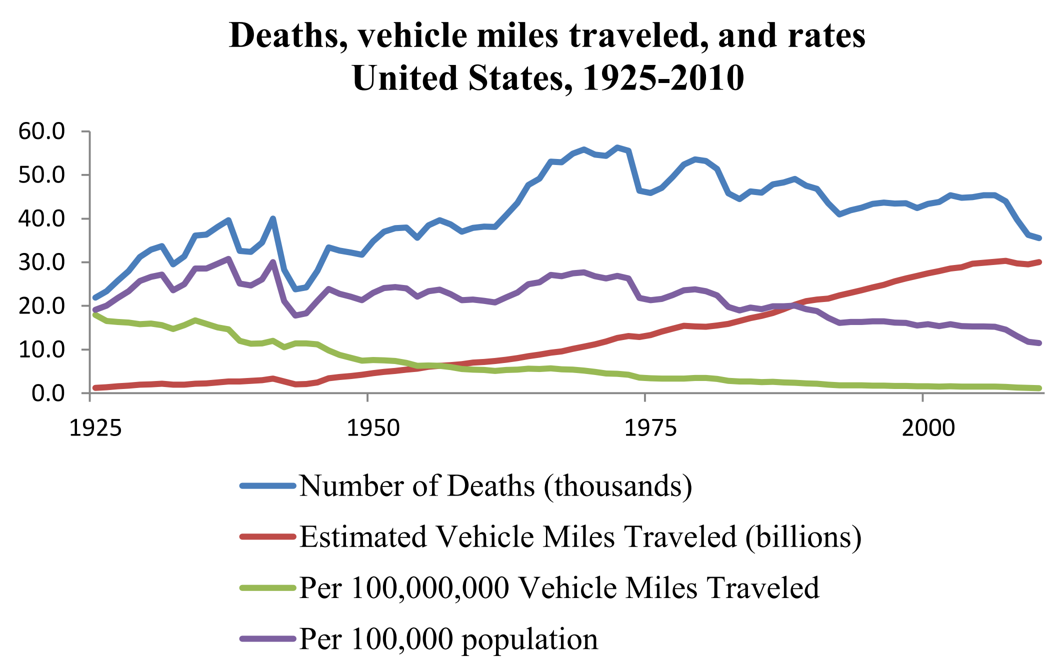

Figure 2: Deaths, vehicle miles traveled, and rates for United States, 1925-2010 (data extracted from NSC Injury Facts 2012 Edition page 128-129)

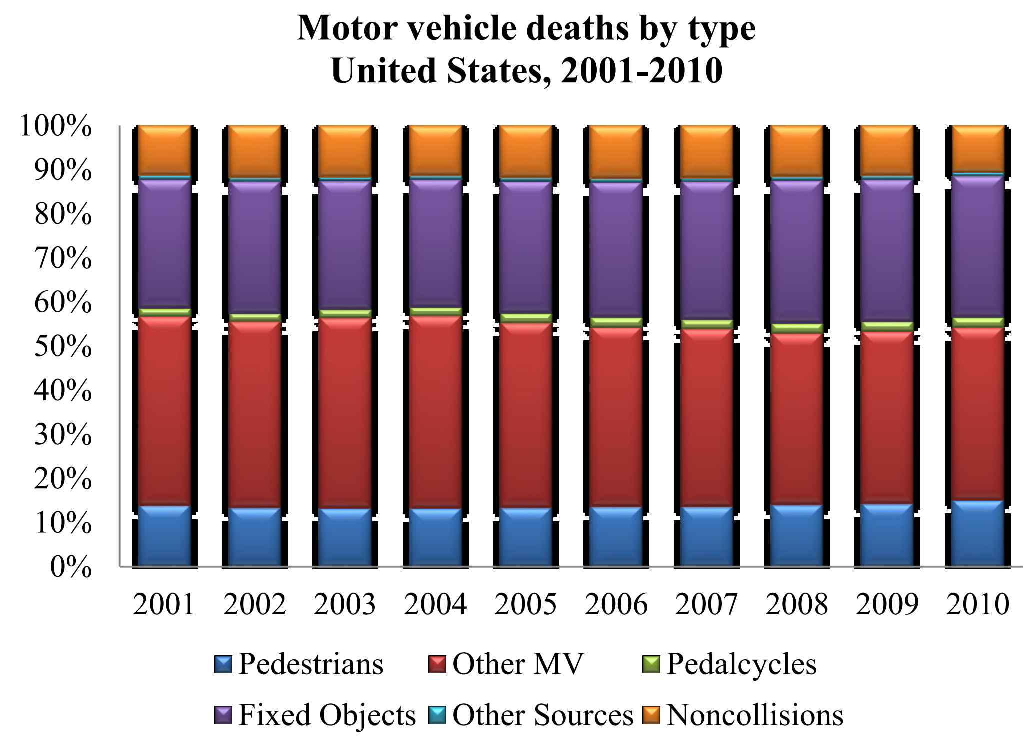

Figure 3: Motor vehicle deaths by type in United States, 2001-2010 (data extracted from NSC Injury Facts 2012 Edition page 130-131)

Chapter II: Literature Review

Phase 1

Magnitude of Problem

Emergency medical service (EMS) personnel are exposed to a myriad of occupationally-related hazards that can result in fatal and nonfatal injuries. It has been estimated that the EMS occupational fatality rate was 12.7 fatalities per 100,000 EMS workers, annually (between 1992 and 1997), more than double the national average (5.0/100,000) for all U.S. workers (Maguire, et al., 2002). The hazards associated with the highest risk for work-related fatalities among EMS personnel are motor vehicle crashes (MVCs). The transportation-specific fatality rates for ambulance, police, and firefighters were 9.6, 6.1, and 5.7 deaths per 100,000 workers, which exceeded the average transportation-related fatality rate (2.0/100,000) for all U.S. workers between 1992 and 1997 (Maguire, et al., 2002).

From 2001-2010, 368,946 emergency vehicles (EVs) were involved in single and multivehicle crashes (NHTSA, 2001-2010), which represents an increase of over 20 percent compared to the previous decade during which 302,969 crashes were reported (Ray & Kupas, 2005). As expressed previously, MVCs are predominantly characterized as two or more vehicles colliding into each other. Collisions involving EVs can be described as the result of a multifaceted interaction of factors associated with the EV driver, the non-EV driver, and the environment (Custalow & Gravitz, 2004). To date, most of the literature has been associated with EV drivers and the environment.

Potential Risk Factors (EV-related)

Lights and Sirens

The use of L/S by EVs has been debated for decades regarding time saved in transportation, warning effectiveness, and its impact on roadway safety. A number of studies have examined time-savings when transporting with L/S versus without L/S and found time savings ranging from one minute 46 seconds to three minutes 50 seconds (Ho & Lindquist, 2001; Brown, Whitney, Hunt, Addario, & Hague, 2000; Ho & Casey, 1998). In general, studies have consistently shown that travelling with L/S reduces travel times; however, it is believed that the time saved is only clinically relevant for very few life threatening cases (Brown, et al, 2000; O'Brien, Price, & Adams, 1999; Hunt, et al., 1995).

Older studies have suggested that EVs traveling with L/S are at increased risk for MVCs (Pirrallo & Swor, 1994; Saunders & Heye, 1994; Auerbach, Morris, & Phillips, 1987). This effect has been demonstrated more recently (Becker, et al., 2003; Kahn, et al., 2001). For example, a study by Custalow and Gravitz (2004) identified 91% of all collisions occurred when the EVs were traveling with L/S even though only 75% of all emergency responses were made with L/S.

The purpose of L/S is to assist EV drivers by presenting attention-grabbing cues to other roadway users in order for them to detect and make appropriate driving maneuvers; therefore, L/S are an essential safety component (Saunders & Gough, 2003). However, arguments have been made that the increased risk for MVCs while traveling with L/S derives from the ineffectiveness to provide essential time-dependent safety-related information (De Lorenzo & Eilers, 1991). The literature suggests two general areas which may impact the effectiveness of L/S: saliency i.e., noticeability of an EV's L/S (Robbins, 1995) and effective distance (Catchpole & McKeown, 2007; Withington, 1999; De Lorenzo & Eilers, 1991). Saliency can be influenced by physical and environmental factors that obstruct detection of the EVs' L/S or by other factors that may impede detection ability (e.g., driver distraction). The effective distance of L/S is influenced by various factors such as closed windows and increased sound proofing technology of current motor vehicles which may attenuate penetration of the siren sound (Robbins, 1995). External (e.g., roadway traffic) and internal noises (e.g., radio playing, conversing) can impact the relative effective distance the siren sound has to exceed to combat the sound levels of competing noises.

Driving Experience

The risk of MVCs has been associated with younger, less experienced EV drivers compared to older, more experienced drivers (Studnek & Fernandez, 2008; Custalow & Gravitz, 2004). In general, this effect is seen within society as crash rates indicate younger drivers are at highest risk than any other age group (Williams, 2003).

Collision History

In general, it is believed that prior driver history of MVCs is associated with increased likelihood of being involved in subsequent crashes, compared to drivers with no such prior history (Chandraratna, Stamatiadis, & Stromber, 2006). Other studies have also identified prior history of MVCs among EV drivers as a risk factor for future crashes (Custalow & Gravitz, 2004; Kahn, et al., 2001; Biggers Jr, Zachariah, & Pepe; 1996).

Potential Risk Factors (Non-EV driver-related)

Distracted Driving

The primary task of a driver is to operate a motor vehicle as safely as possible and any engagement outside of the primary task is considered to be a distraction; however, drivers often engage, either willingly or unwillingly, in activities that divert their attention away from the driving task (Young & Regan, 2009). All distractions endanger the lives of drivers, vehicle occupants, pedestrians, and persons within or near a roadway where motor vehicles are traveling. Distraction-related crashes accounted for more than 3,300 deaths and 387,000 injuries in 2011 (NHTSA, 2013a). The severity of the problem is demonstrated by a recent survey which indicated that, at any point during the day in the United States, approximately 660,000 drivers are manipulating electronic devices (e.g., cell phones) while driving (NHTSA, 2013b).

Driver distractions present in many forms that include eating, reading, and manipulating navigational units, radios, and temperature controls while driving. One of the most prevalent forms of distraction is cell phone usage and, as a result, research on cell phones and driving has provided interesting findings (Caird, Willness, Steel, & Scialfa, 2008). The first published study on cell phone usage and its impact on driving performance showed that, in general, driving performance was degraded when a driver is engaged in a secondary task (Brown, Tickner, & Simmonds, 1969). Redelmeier and Tibshirani (1997) conducted a case-crossover epidemiological study to determine whether using a cell phone while driving increases the risk for MVCs. Their major finding was that using a cell phone increased the risk for MVCs about four times higher compared with not using a cell phone. This finding is similar to the hazard associated with drinking and driving (Strayer, Drews, & Crouch, 2006). Another important finding from their study was that the use of hands-free devices showed no safety advantages (Redelmeier & Tibshirani, 1997), a finding which has been further established (Beede & Kass, 2006; Strayer & Drews, 2004). More recently, distracted driving resulting from texting has been identified as a major risk factor for MVCs. Similar to cell phone conversations, texting while driving has been associated with increased risk for MVCs (Alosco, et al., 2012; Wilson & Stimpson, 2010). According to the Insurance Institute for Highway Safety, as of 2013, 39 US states and the District of Columbia have laws banning drivers from texting while driving -- while only 11 states and the District of Columbia ban hand-held cell phone usage while driving.

Alcohol use

The impact of alcohol consumption is widely known to have detrimental effects on driving performance; however, alcohol-related crashes are still prevalent on our roadways and accounted for 31% (~11,000 per year) of all fatal crashes from 2001 through 2011(NHTSA, 2001-2011). A study by Weiler et al. (2000), examined reaction times of drivers who were, at separate intervals, given alcohol and other drugs. Alcohol resulted in the slowest reaction times to the critical events and poorest overall driving performance. Zador, Krawchuk, and Voas (2000) estimated age and gender-specific relative risk (RR) estimates based on a function of blood alcohol concentration (BAC) and found a monotonic increase in risk as BAC increased. Interesting findings were the relative risk estimates for male (RR = 6.13 [35+ years old] to 51.87 [16-20 years old]) and female (RR = 6.13 [35+ years old] to 14.91[16-20 years old]) drivers at the legal BAC of 0.08%, showing an excess in risk for MVCs.

Alcohol intoxication has been identified among non-EV drivers involved in MVCs with EVs. Custalow and Gravitz (2004) found that non-EV drivers were at increased risk (OR = 6.1 [1.1-33.9]) for an injury-causing MVC with an EV when intoxicated compared to the absence of alcohol intoxication.

Age

In general, older drivers have received increased attention as a result of their elevated crash rates per vehicle miles travelled (McGwin Jr & Brown, 1999) and due to the rising average age of the driving population. Age-related differences are well-documented among drivers (Horrey & Wickens, 2006; Spence & Ho, 2008; Strayer, et al., 2003). The literature provides evidence that many cognitive and perceptual processes, which are important to the driving tasks, decline with increasing age (Hakamies-Blomqvist, Mynttinen, Backman, & Mikkonen, 1999); however, it is debated that the experience of older drivers may offset some of these deficits (Becic, Manser, Drucker, & Donath, 2012; Kramer & Willis, 2003). This offsetting may explain why Custalow and Gravitz (2004) did not find an increase in odds for EV-involving MVCs based on drivers' age (OR = 1.0 [0.8-1.1]).

Potential Risk Factors (Environmental-related)

Intersections

It is well established that roadway intersections have the highest risk for MVCs involving non-EV and EV drivers. A Custalow and Gravitz (2004) review of EV collisions identified intersections as a significant predictor for collisions (OR = 4.3 [1.4-13.9]). Other studies have shown that 27-85% of EV-related MVCs occurred at intersections (Lenné, et al., 2008; Ray & Kupas, 2007; Ray & Kupas, 2005; Kahn, et al., 2001; Weiss, Ellis, Ernst, Land, & Garza, 2001).

Rural/Urban Environments

Rural and urban environments pose different risks for MVCs involving non-EV and EV drivers. In general, fatal crashes are consistently higher in rural compared to urban environments (Zwerling, et al., 2005); however, fatal crashes involving EVs have been shown to occur more frequently in urban environments (Sanddal et al., 2010; Ray & Kupas, 2005) while injury-causing crashes were twice as likely in rural environments (Weiss et al., 2001). Ambulances were more likely to be impacted from the rear (OR = 4.67 [1.5-19.2]; Weiss et al., 2001) and crash within an intersection (66.7% versus 25.7%; Ray & Kupas, 2005) when in an urban, compared to rural, environment.

A number of studies have shown that EV-related rural and urban crashes do not differentiate, based on day of week, time of day, and that most MVCs occur when the weather is favorable (Ray & Kupas, 2005; Weiss et al., 2001).

Phase 2

Crash Mitigating Technology

In-vehicle Devices

Among critical roadway situations, technology (e.g., driver support systems [DSS]) has been utilized as a method to augment the driving experience i.e., to enhance driver abilities under various conditions and situations to detect imminent threats. The use of technology has been demonstrated in: simulation, test track, and naturalistic driving environments to produce positive results for frontal-rear end collisions (Mohebbi, Gray, & Tan, 2009; Ho, Reed, & Spence, 2007; Ho, Spence, & Tan, 2005; Lee, et al., 2002); side blind zones encounters (Kiefer & Hankey, 2008; Kramer, Cassavaugh, Horrey, Becic, & Mayhugh, 2007); fast approaching following vehicles (Cummings, Kilgore, Wang, Tijerina, & Kochhar , 2007; Ho, et al., 2005); and inadvertent lane departures (Navarro, Mars, & Hoc, 2007; Kozak, et al., 2006; Stanley, 2006; Suzuki & Jansson, 2003).

The use of DSSs has also been utilized to provide safety-related information to non-EV drivers that EVs are approaching. A study by Lenné et al. (2008), examined driver responses to advanced warnings for approaching in-use EVs. Participants encountered EVs in three crash scenarios: 1) EVs driving straight through intersections on a red traffic light perpendicular to the participants' vehicle; 2) EVs turning in front of the participants' vehicles from the opposite direction; and 3) EVs approaching from the rear of the participants' vehicles. The first two crash scenarios represent the locations of roadways that pose the highest risk for MVCs between non-EV and EV drivers (Custalow and Gravitz, 2004). Participants were given up to eight seconds of advanced notification that an EV was approaching. In general, the presence of the warning system provided benefits to roadway safety. Compared to a no warning condition, participants changed lanes earlier when EVs were approaching from the rear, reduced their velocity earlier, and increased their scanning of the environment. Although the timing component of the warning system allowed for improved driver safety, in practical situations, alerts given too early may be ignored by its intended users if the threat that activated the warning cannot be perceived (Lee, et al., 2002).

In an earlier study, Hanowski et al. (1999), showed that, in a field test consisting of unexpected events, including an approaching EV from the rear, drivers who were presented with an advanced warning system, compared to no warning system, responded more quickly (1.05 seconds versus 2.98 seconds). Specifically for EV-related events, 18.2% resulted in negative responses i.e., drivers responded to the events after the warning was initiated and before the EV was visible. These negative responses have direct impact on roadway safety; however, they can be modified based on drivers' trust and warning system reliability. If a warning system produces many false alarm events, adherence would decrease and the benefit of the warning system will become negated. Although the application of using in-vehicle technology as a method to alert drivers to approaching EVs is novel, the studies by Lenné et al. (2008), and Hanowski et al. (1999), showed potential benefits consistent with other applications of DSSs.

Roadway-based Devices

A study by Savolainen, Datta, Ghosh, and Gates (2010), examined the impact of a dynamic traffic sign at urban signalized intersections that provided visual alerts to non-EV drivers of approaching EVs. The pre-post analysis revealed positive benefits of the roadway-based technology. The percentage of drivers who yielded the right-of-way to the EVs increased from 77.1% to 96.6% while the transportation time through the intersections decreased after installation of the dynamic traffic sign. The authors suspected the changes to be a function of drivers receiving notification of the approaching EVs earlier (Savolainen et al., 2010).

Another form of roadway-based technology to reduce MVCs involving non-EV and EV drivers is through emergency vehicle preemption systems (EVPS). These systems are typically integrated at urban signalized intersections where congestion increases the difficulties for EV drivers to operate safely and efficiently. The purpose of EVPS is to allow green lights for the EV while all opposing traffic receives red lights. The effects of EVPS are a reduction in conflict points that would decrease the risk for MVCs and increase transportation efficiency (Louisell, Collura, Teodorovic, & Tignor, 2004). These roadway-based technologies have demonstrated, albeit in limited settings, to improve safety between non-EV and EV drivers; however, they are inherently limited to signalized intersections. Although intersections pose the highest risk roadway junction for these types of events, fatal and nonfatal crashes can occur on any roadway segments.

Potential Risk Factors

Distraction

An unintended consequence of utilizing technology for mitigating MVCs, particularly for in-vehicle devices, is the potential to increase in-vehicle driver distraction (Becic, et al., 2013; Lee, Caven, Haake, & Brown, 2001). As expressed earlier, research has shown a negative impact for distraction on driver performance. A study by Lee et al. (2002), examined a rear-end collision warning system with and without drivers engaged in a visual distraction task. The percentage of collisions when driving with a warning system, were not different between distracted and non-distracted conditions; however, when driving without a warning system, distracted compared to non-distracted driving resulted in an increased percentage of collisions.

Donmez, Boyle, and Lee (2007) conducted a study assessing the impact of a visual-manual distraction task on a warning system that provided 1) accurate, 2) unnecessary, and 3) false alarms for multiple critical events. The analysis revealed the distraction task did not significantly interact with the three warning systems based on the study's outcome measures. Maltz and Shinar (2007) conducted a similar study on imperfect in-vehicle warning systems and showed that drivers increased their temporal headway under the less reliable system when distracted; however, under the most reliable system, distraction did not impact headway.

A study by Becic et al. (2013) assessed the impact of a cognitive distraction task on an in-vehicle device that provided noncritical information i.e., information regarding traffic flow at a rural stopped-control intersection, to drivers crossing from a minor road. The study revealed that the presence of the informational display did not increase in-vehicle distraction as the proportion of correct responses (secondary task consisted of hearing and adding numbers together) did not differ between when the display was turned on or off. Although in-vehicle distraction was not apparent across the studies by Lee, Donmez, and Becic, it is critical to assess all roadway safety devices and technologies that require allocation of cognitive resources away from the primary driving task.

Usability

Usability is an important component when assessing the overall potential benefits and costs of in-vehicle DSSs. Trust in a system is a well-known factor for system adherence (Abe & Richardson, 2006; Lees & Lee, 2007). If drivers distrust a DSS, the warnings may be ignored; therefore, the intent of the system can be negated. If drivers find an alert to be uninformative or not understandable, it may impact a driver's reliance (willingness to depend on alert to indicate threat) and compliance (willingness to respond to the warning) to the DSS (Lees & Lee, 2007; Bliss and Acton 2003).

A study by Suzuki and Jansson (2003), examined two auditory and two haptic warnings when drivers made unintended lane departures. The haptic warnings included vibrations to the steering wheel and pulse-like steering torque applied in the opposite direction in which the drivers were veering off course. Although the haptic warnings, compared to the auditory warnings, produced faster steering reaction times, results indicated a potential problem when a warning was not informative or understandable. Drivers who received the pulse-like steering torque warning executed two different types of steering behaviors – correct or incorrect responses. The correct response would be for drivers to continue engaging the steering wheel in the direction of the applied torque; however, many drivers executed incorrect responses. These drivers turned the steering wheel in the opposite direction of the applied torque which essentially increased the deviation of the unintended lane departure. This incorrect behavior was executed by drivers who were both aware and not aware of the meaning of the warning. This study provided an example of how usability issues can affect the potential benefits of a DSS.

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Tables

Table 1: Summary of literature – Matrix for Phase 1

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Alosco, Spitznagel, Fischer, Miller, Pillai, Hughes,	2012	To examine eating and drinking behaviors and texting on driving performance	186 undergraduates (Kent State University), Ohio, USA	Trial-based experiment, MANOVA	• Eating/texting associated with degraded driving performance
Beede & Kass	2006	To study the effects of cognitively distracting tasks on driving	36 undergraduate (University of West Florida), 20 to 53 years of age, in Florida, USA	Trial-based experiment (simulator), ANOVA	• Traffic violations, driving maintenance, attention lapses, and response time significantly impacted when using hands-free phone
Biggers Jr., Zachariah, & Pepe	1996	To define the incidence and severity of EV-related crashes	86 collision events among 180,000 emergency calls totaling 2,651,760 miles, in 1993, in Texas, USA	Retrospective study	• 85.1% of collisions occurred at non-intersection points • 33% of drivers had previous histories of MVCs

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Brown, Tickner, & Simmonds	1969	To determine if driving skills are impaired from telephone usage	24 men, 21to 57 years of age, in the United Kingdom	Trial-based experiment (test track), Wilcoxon matched-pairs signed-ranks test, Kendall's rank correlation coefficient	• Ability to judge gaps were degraded • Concurrent telephoning produced impairment of perception • Increased driving time when engaged in telephoning
Brown, Whitney, Hunt, Addario, & Hogue	2000	To determine time saved associated with lights and sirens in urban environments	32 emergency responses, in New York, USA	Prospective study, paired t-test	• L/S reduced response time by one minute 46 seconds
Catchpole & McKeown	2007	To examine siren parameters and propose vehicle siren design	240 emergency runs within a three-month period, in West Yorkshire, England	Trial-based experiment (in traffic), t-test	• Grill-mounted sirens with localizable cues were more advantageous
Chandraratna, Stamatiadis, & Stromber	2006	Develop a crash prediction model for future crash occurrence	Two databases used from 1995 to 2002 (Kentucky Driver License [1999 and 2002]), in Kentucky, USA	Retrospective analysis, logistic regression	• Strong association between previous at-fault crash involvement and subsequent crash

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Custalow & Gravitz	2004	To identify factors associated with non-EV and EV drivers involved in collisions	Data from Hospital on all EV-related collisions from 1989 to 1997, Colorado, USA	Descriptive analysis and multiple logistic regression	• EV drivers should visually clear intersection before entering • Higher proportion of crashes when lights and sirens engaged
De Lorenzo & Eilers	1991	To review safety literature on EV markings and warning techniques	Literature review	Literature review, qualitative	• Red flashing lights alone are not optimal visual signals • Risk of seizures from strobe lights unsubstantiated
Ho & Casey	1998	To determine if L/S saves travel time for EVs in urban environments	64 emergency runs from October 1995 through June 1996	Prospective study, descriptive statistics and ANOVA	• L/S reduced response time by three minutes and 2 seconds
Ho & Lindquist	2001	To determine if L/S saved transport time	67 emergency runs during 21-month period, Minnesota, USA	Prospective study, descriptive statistics, paired student t-tests, and ANOVA	• Significant time saving when traveling with L/S (3.63 minutes saved) • Shorter runs increased time-saving versus longer runs

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Kahn, Pirrallo, & Kuhn	2001	To describe fatal ambulance crash characteristics	FARS database from 1987 to 1997	Retrospective analysis, Multivariate ANOVA	• Most crashes occurred during emergency use and at intersections
Langford, Methorst, & Hakamies-Blomqvist	2006	To confirm Low Mileage Bias of older drivers	47,502 drivers, five age groups, in three mileage driven groups, in the Netherlands	Survey data, t-test	• Crash rate decreased as age increased for medium and high mileage drivers • Older drivers who drove less were at increased risk
Maguire, Hunting, Smith, & Levick	2002	To estimate the occupational fatality rate among EMS personnel	3 fatality databases (CFOI [1992 to 1997], NEMSMS [1992 to 1997], and FARS [1994-1997])	Descriptive epidemiology, rates	• Estimated 12.7 fatalities per 100,000 EMS workers per year • More than twice national average
O'Brien, Price, & Adams	1999	To determine if L/S reduces transport time to hospital	Convenience sample of 75 ambulances, in Kentucky, USA	Prospective study, paired t-test and Spearman correlation	• Difference between travel time with and without L/S was three minutes and 50 seconds.

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Ray & Kupas	2007	To describe characteristics of EV crashes in rural and urban areas	311 rural and 1,434 urban ambulance crashes from January 1, 1997 to December 31, 2001, in Pennsylvania, USA	Retrospective analysis, chi-square test and Fisher's exact test	• Urban crashes involved intersection and traffic signals • Crash severity similar between rural and urban environments • Rural crashes more often due to environmental factors
Ray & Kupas	2005	To describe characteristics associated with occupant injuries in MVCs with EVs	2,038 MVCs involving EVs and 23,155 MVCs involving similar-sized vehicles, from 1997 to 2001, in Pennsylvania, USA	Chi-square tests and Fisher's exact test	• EV crashes occurred most frequently at intersections and traffic signals
Redelmeier & Tibshirani	1997	To examine if using a cell phone increases the risk for MVCs	699 drivers, from July 1, 1994 through August 31, 1995, in Toronto, Canada	Case-cross over study, binomial tests and conditional logistic regression	• Relative risk four times higher for MVC when using a cell phone versus not using a cell phone • No safety advantages for hands-free devices

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Saunders & Gough	2003	To survey interactions between non-EV drivers and ambulances using L/S	Quota sample of 200 residents, 21 to 61 years of age, in Staffordshire, England	Survey data, Chi square tests of association	• One-third found interaction with EV stressful. • EV driver satisfied with handling of event and use of audible warning devices
Strayer & Drews	2004	To examine hands-free phone conversations on driving performance	40 participants (n = 20 older [65 to 74 years of age] and younger [18 to 25] years of age), in Utah, USA	Trial-based experiment (simulator), Multivariate ANOVA	• Two-fold increase of rear end collisions • Slower reaction times • Increased following distances • Equivalent effects for younger and older adults
Strayer, Drews, & Crouch	2006	To determine impairment associated with cell phone usage and driving	40 participants (n = 25 men), 22 to 34 years of age, social drinkers, in Utah, USA	Trial-based experiment (simulator), Multivariate ANOVA and planned contrasts	• Impairment from cell phone usage as profound as impairment from drinking and driving
Studnek & Fernandez	2008	To explore if demographic and work-related characteristics are associated with crashes	Cohort of nationally registered EMS professionals in 2004; 1,775/5,565 participated with 111 cases identified	Survey with descriptive statistics, logistic regression	• Odds of crash higher among younger compared to older EV drivers and drivers reporting sleep problems

Author(s)	Year	Purpose	Population	Methods	Findings
Weiler, Bloomfield, Woodworth, Grant, Layton, Brown, McKenzie, Baker, & Watson	2000	To compare the effects of drugs and alcohol on driving performance	40 participants with seasonal allergies (25-44 years of age), in Iowa, USA	Randomized, double-blind, double-dummy, four-treatment, four-period crossover trial (simulator), Mixed-general linear model, Box-Cox analysis	• Alcohol performance overall poorest • Lane-keeping impaired after alcohol
Weiss, Ellis, Ernst, Land, & Garza	2001	To compare urban and rural ambulance crashes	183 ambulance crashes from August 1993 to March 1997, in Tennessee, USA	Retrospective analysis, Chi-square test or Fisher's Exact test, OR and 95%CI	• Rural crashes resulted in more injuries • Citations more likely issued to urban drivers
Wilson & Stimpson	2010	To determine trends of driving fatalities resulting from texting and cell phone use	51,857 fatalities caused by distraction, FARS data from 1999 to 2008	Descriptive statistics and multivariate regression analysis	• Texting prevalence is increasing and contributes to rising deaths
Withington	1999	To determine sound characteristics to assist in locating approaching EVs	200 participants from 19 to 57 years of age,	Trial-based experiment (road)	• Varying noise patterns can draw attention within a complex system

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Zador, Krawchuk, & Voas	2000	To examine and refine alcohol-related RR for fatal crash by age and gender as a function of BAC	Data taken from FARS and NASS-CDS	Similar to proportionate morbidity study, logistic regression models	• Drivers with legal limit BACs are at highly elevated risk for fatal collisions

Table 2: Summary of literature – Matrix for Phase 2

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Becic, Manser, Drucker, & Donath	2013	To examine the impact of distraction on an in-vehicle informational device	24 younger (19 to 28 years of age) and older (60 to 69 years of age) participants, in Minnesota, USA	Trial-based experiment (simulator), repeated measures mixed design ANOVA	• Distraction did not adversely impact driving performance • Drivers more likely to stop at intersections when distracted • No difference in proportion of secondary task responses when system was on or off
Bliss & Action	2003	To document the effects of alarm unreliability	70 undergraduate students (from the University of Alabama), in Huntsville, Alabama	Trial-based experiment (simulator); ANOVA and Tukey-Kramer post-hoc comparisons	• Alarm and swerving reactions improved when alarms were more reliable
Cummings, Kilgore, Wang, Tijerina, & Kochhar	2007	To explore multiple warnings versus a single master alarm for fast approaching following vehicle situations	40 participants (18 to 40 years of age), in USA	Trial-based experiment (simulator); general linear repeated measures model, Chi-square test, Wilcoxon signed-rank test, Mann-Whitney U test	• No difference in reaction times and response accuracy between single and master alarms • Low alarm reliability can negatively influence driving performance

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Donmez, Boyle, and Lee	2007	To investigate real-time visual feedback on the interaction between warning system and driving performance	29 participants (18 to 55 years of age), in Iowa, USA	Trial-based experiment (simulator); repeated measures ANOVA and Tukey-Kramer test for post-hoc comparisons	• When given feedback on distracted state, drivers glanced at the in-vehicle display fewer times • Real-time feedback can provide positive results from distracted states
Hanowski, Dingus, Gallagher, Kieliszewski, & Neale	1999	To investigate the benefits and costs of an in-vehicle DSS for unexpected situations	10 younger (from 18 to 25 years of age) and older (from 65 to 75 years of age) participants, in Blacksburg, Virginia	Trial-based experiment (in traffic); ANOVA	• Mean response time to unexpected events decreased 1.93 seconds when drivers had the warning information
Ho, Reed, & Spence	2007	To determine utility of auditory, vibrotactile, and combined cues to alert drives to frontal-rear end collisions	15 male participants from 17 to 41 years of age, Oxford, England	Trial-based experiment (simulator), ANOVA, post-hoc comparisons with Bonferroni corrections	• Braking responses faster with multi-warning signal (audiotactile) compared to unimodal warning signal
Ho, Spence, & Tan	2005	To examine the impact of auditory, visual, and vibrotactile cues on frontal-rear end collisions	12 participants (22 to 29 years of age), in Oxford, England	Trial-based experiment (simulator), repeated measures ANOVA	• Faster responses for vibrotactile warnings compared to auditory or visual warnings

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Kiefer & Hankey	2008	To examine the effect of a side blind zone alert system on driver lane change behavior	16 middle-aged (40-50 years of age) and older (60-70 years of age) participants, in Blacksburg, Virginia, USA	Trial-based experiment (in-traffic), Chi-square tests and ANOVA	• Reduction in left and right lane change attempts without glancing over the shoulder when warning system was present
Kozak, Pohl, Birk, Greenberg, Artz, Blommer, Cathey, & Curry	2006	To address warning effectiveness and customer acceptance of a lane departure warning system	32 participants, in Michigan, USA	Trial-based experiment (simulator); ANOVA and post-hoc t-test	• For drowsy drivers, steering wheel vibration and torque was most effective in producing faster reaction times and shorter lane deviations
Kramer, Cassavaugh, Horrey, Becic, & Mayhugh	2007	To examine the utility of different uni- and multimodal warning systems on driving performance	20 younger (18 to 26 years of age) and older (61 to 82 years of age) participants, USA	Trial-based experiment (simulator); mixed design ANOVA	• Frontal and side collision performance was best for multimodal warning system • Older drivers benefited as much as younger drivers

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Lee, McGehee, Brown, & Reyes	2002	To examine 1) the effectiveness of a rear-end collision warning system in alerting distracted drivers and 2) the benefits of the system to non-distracted drivers	Experiment 1) 120 participants from 25 to 55 years of age, in Iowa, USA Experiment 2) 140 participants from 25-55 years of age	Experiment 1) Trial-based experiment (simulator); mixed linear model, cluster analysis, and chi-square test Experiment 2) Data analysis of collision events, mixed linear model	• Early warnings helped distracted drivers (compared to late or no warnings) to react more quickly to an imminent threat • The rear-end collision warning system showed benefits to non-distracted drivers as well
Lees & Lee	2007	To examine a DSS with three alarm types and distractions on driver performance	64 participants (20 to 35 years of age), in Iowa, USA	Trial-based experiment (simulator); mixed design ANOVA	• False and unnecessary alarms influenced trust and compliance • Response to critical events differentiated between systems prone to either false or unnecessary alarms
Lenné, Triggs, Mulvihill, Regan, & Corben	2008	To evaluate the impact of a advanced warning system on EV detection	22 participants (21 to 50 years of age), Victoria, Australia	Trial-based experiment (simulator), ANOVA	• Reduction in drivers' speed • Faster changing of lanes to allow EV to pass

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Mohebbi, Gray, & Tan	2009	To examine the effectiveness of rear-end collision warnings while engaged in cell phone usage	16 participants (19 to 49 years of age), USA	Trial-based experiment (simulator), repeated measures ANOVA	• Cell phone usage decreased reaction time to auditory warning system • No difference between cell phone usage (yes/no) and reaction time to tactile warning system
Navarro, Mars, and Hoc	2007	To determine if motor priming is a benefit compared to auditory or vibrotactile warning systems	20 participants (from 19 to 57 years of age), in Nantes, France	Trial-based experiment (simulator); repeated measures ANOVA, Newman-Keuls tests for post-hoc comparison	• All test devices improved drivers' steering performance with greatest impact found with the motor priming device
Savolainen, Datta, Ghosh, & Gates	2010	To examine the impact of a roadway base warning system for approaching EVs	Five signalized intersections; 103 and 85 EV runs before and after installation of device, respectively	Before and after evaluation methodology, two-sample Kolmogorov-Smirnov test, ANOVA, Kruskal-Wallis test, Mann-Whitney U test	• Warning device improved driver awareness of approaching EVs at urban signalized intersections • Increased percentage of drivers yielding right-of-way • Decreased clearance time for EVs

Author(s)	**Year**	**Purpose**	**Population**	**Methods**	**Findings**
Stanley	2006	To examine three sensory modalities on lane departures	15 participants (20 to 48 years of age), in Montana, USA	Trial-based experiment (simulator), general linear model and Friedman test	• Haptic warning produce faster reaction times, compared to auditory and combination modalities
Suzuki & Jansson	2003	To analyze a lane departure warning system	24 participants (from 25 to 57 years of age), in Linköping, Sweden	Trial-based experiment (simulator), means and standard deviations between groups	• In unpredicted conditions, steering vibration reduced steering reaction times • In predicted conditions, auditory cue reduced steering reaction time • Some participants turned steering wheel in opposite direction of warning torque which produced incorrect strategies

Chapter III: Research Design and Methods

Specific aims

Phase 1

The aim of Phase 1 was to identify characteristics associated with non-emergency vehicle (EV) drivers involved in crashes with in-use and in-transport EVs. In-use and in-transport EVs were defined as EVs on call and in motion at the time of the collisions. The aim was attained by:

1. Identifying observations, using the National Highway Traffic Safety Administrations' Fatality Analysis Reporting System (FARS) and National Automotive Sampling System – General Estimate System (NASS-GES) from 2002 through 2010 for non-EV drivers involved in:

a. Collisions with in-use and in-transport EVs
b. Collisions with non-EVs while in-transport

The FARS data are a census of all fatal motor vehicle crashes (MVCs) that occurred within the United States, District of Columbia, and Puerto Rico. For a crash to be eligible within the FARS dataset, the death of a motorist or non-motorist must have occurred within 30 days from the time of the crash. The NASS-GES data are a nationally representative probability sample of all police-reported MVCs. Both datasets contain information regarding the special use of vehicles (e.g., taxi, police, military) and whether the vehicles were listed as in-use for an emergency.

2. *Developing directed acyclic graphs for selected exposure-outcome relations.*

Directed acyclic graphs (DAGs) are graphical models used to show direct causal effects between exposure and outcome variables through directional arrows (Hernán, Hernández-Diaz, Werler, & Mitchell, 2002). Selection of confounders for each exposure-outcome relation was based on DAGs and followed the methods described by Maldonado and Greenland (2002) and the six-step process of Shrier and Platt (2008).

Shrier and Platt's six-step process towards unbiased estimates:

Step 1: Covariates chosen should not be descendants of the exposure (i.e., caused by the exposure).

Step 2: Remove all variables that are non-ancestors of the exposure, outcome, and covariates included for bias reduction (an ancestor is a variable that causes another variable directly or indirectly).

Step 3: Remove all pathways leading from the exposure.

Step 4: Connect any two parents who share a common child (parent variables are two variables that causes another variable).

Step 5: Remove all directional arrowheads.

Step 6: Remove all pathways between the covariates in the model and any other variables.

Each multivariate logistic regression model included variables beyond the exposure of interest and the outcome of fatal or nonfatal crash with an EV, as these variables represented a minimum sufficient set of confounders required to block all "backdoor pathways" between the exposure and outcome association (Gerberich, et. al, 2004).

The goals of Phase 1 were to 1) Identify factors (expressed as estimated odds ratios [OR] and 95% confidence intervals [CI]) that were likely associated with crashes between non-EV and EV drivers and 2) Use the factors identified to guide the design and testing of two in-vehicle driver support systems (DSSs).

Phase 2

The aim of Phase 2 was to investigate the degree to which in-vehicle DSSs that present concurrent and advanced information with regard to approaching in-use EVs impacts driver behavior under distracting and non-distracting conditions. The aim was attained by:

1. *Utilizing a driving simulator to replicate critical intersection events under highly controlled conditions.*

The HumanFIRST Program's portable driving environment simulator consisted of a driver seat, vehicle controls (pedals, steering, and transmission) and gauges mounted on a portable chassis. The simulator's visual display consisted of three 32-inch high-definition monitors that provided 88 degrees of forward field of view.

2. *Assigning human subjects into one of three experimental groups.*

Experimental Group 1

The first experimental group consisted of participants presented with traditional lights and sirens (L/S) and a DSS, entitled Improved Saliency System (ISS) that addressed the issue of saliency. Without the ISS, the EV siren became audible and lights became visible when the participant's time-to-contact (TTC) crossed a threshold of 2.5 and 2.0 seconds, respectively. These parameters represented conservative estimates of the effective distance for L/S identified by De Lorenzo & Eilers (1991). The sound levels of the siren increased from 75db (when first activated) to 85db (when the EV crossed the path of the participant's vehicle). The 85db value was chosen as the maximum siren sound level because a 10db increase over the road noise level is recommended for auditory warning signals (Sorkin, 1987).

The timing of the activation of the ISS was matched to the L/S of the EVs (i.e., TTC = 2.5s) as this allowed determination of whether differences in participants' responses were due or not due to the ISS timing differences. The ISS remained activated until the EVs crossed the intersections.

The ISS provided two levels of information -- an ecological auditory icon and a visual cue. The use of an ecological auditory icon served two purposes. First, ecological icons have been shown to engage the attention of drivers more effectively than using an arbitrary sound (Ho & Spence, 2005). Secondly, using an arbitrary alert can potentially confuse drivers if presented in a larger frame consisting of other DSSs, which are expected to be implemented in vehicles on a wide scale in the near future. The auditory warning was presented to participants at a constant sound level of 85db to reflect the recommended increase in sound level for auditory warnings above ambient road noises (Sorkin, 1987) and to effectively eliminate the Doppler Shift.

The siren alone provides insufficient information to orient a driver's gaze and, subsequently, driving maneuvers are often made after EVs are detected visually (Withington, 1999). To address driver issues related to advance warning systems for the detection of EVs (Lenné, et al., 2008), the ISS incorporated spatial cueing. The visual cue displayed USDOT standard vehicle traffic warning sign W11-8 (see Figure 11). Research has shown spatially predictive cues that direct the attention of drivers in relevant directions were associated with quicker response times than non-spatially predictive cues if given shortly beforehand (Ho & Spence, 2005). If an EV was approaching from the passenger side of the participant's vehicle, the cue would appear on the bottom right of the forward screen and vice-verse for driver side events. Connected-vehicles technology allows drivers to receive information, through other vehicles or the infrastructure within proximity of a potential threat even when the threat appears to be absent from the visual field. Participants with the ISS essentially would receive information as to the direction of an approaching EV even though the EV was not visible for another 500 milliseconds.

Experimental Group 2: The second experimental group consisted of participants presented with traditional L/S and a DSS, entitled Advanced Notification System (ANS) that addressed the issue of effective distance. The ANS was identical to the ISS except the effective distance of the L/S was increased from 12 meters (De Lorenzo & Eilers, 1991) to approximately 60 meters. This fivefold increase equates to an ANS activation threshold of 4.0 seconds (at 35 mph), essentially providing an additional 1.5 seconds to respond to the threats. The advanced notification is consistent with the capabilities of future connected-vehicles technology that can provide drivers with information from various vehicles and infrastructures within proximity, essentially allowing for an increase in the effective distance of the EV's L/S.

Experimental Group 3: The third experimental group served as a control in which participants were only presented with the EV's L/S. The control group replicated current real-world driving conditions and allowed examination of the impact of the DSSs. Although the use of a true baseline i.e., no L/S displayed, would also allow determination of the impact of the DSSs, the practicality of this comparison does not reflect real-world driving. It was assumed that EVs not engaged in L/S would not cross an intersection when presented with a red traffic light. Since the current study incorporated EVs crossing against traffic lights, all EVs had their L/S engaged.

3. *Examining five performance measures to assess the impact of the DSSs.*

Safety margin indicated the participant's distance (m) from the intersections when the EVs entered the intersections. If no action was taken by the participant, this would represent the remaining distance before a collision would have occurred. This measure represents a level of safety as a diminished margin of safety can be associated with an increased risk of a crash. *Response time* was defined as the time (s) between warning system activation and participant's first response (e.g., braking). The purpose of the DSSs was to increase saliency; therefore, this measure allowed determination of whether improving saliency affects participant behavior. The *85^{th} percentile maximum brake duration* represented the duration (s) in which a participant reached the 85^{th} percentile of their maximum brake pressure. This measure was used as a surrogate in determining response abruptness (e.g., slamming brake pedal) and indicated if presentation of information was interpreted differently between warning system and age groups. *Collisions* represented the number of events in which participants collided with an EV and reflect the overall goal of the DSSs. *Distraction task* was measured as the proportion of correctly answered questions divided by the total number of questions with which a participant was presented across the two drives. A proportion was selected because it allowed for a standardization of results across all participants since the total number of questions that a participant could have received was based on the time they took to complete the drives. Assessing participant responses to a distraction task enabled determination of costs (e.g., increased in-vehicle driver distraction) and benefits (e.g., increased response accuracy) associated with the DSSs.

The Adding 1-Back task was used to simulate distraction as it exerts a substantial load on the working memory. In this task, drivers were presented with two, two-digit numbers, and were instructed to provide two responses for each sequence of digits. The first response required drivers to add the ones column from the two-number sequence they heard. For example, if the driver heard "31, 74", they were required to say "5" (1 + 4 = 5) to answer correctly. For the second response, drivers needed to determine if the current response was greater or lesser than their previous response. Answers were recorded for later transcription. The adding portion of this task has been used previously (Becic, et al., 2013) and the 1-Back portion is a variant of the *n*-Back task (Kirchner, 1958) which has been used as a standard working memory measure in cognitive research (Kane, Conway, Miura, & Colflesh, 2007).

4. *Examining three usability measures to assess impact of the DSSs.*

Trust in a system is a well-known factor for system adherence (Abe & Richardson, 2006; Lees & Lee, 2007). If drivers distrust the DSSs, the warnings may be ignored; therefore, the purpose of the system is negated. Trust was obtained through a seven-item questionnaire regarding perceived trust of the DSSs on a five-point Likert scale, ranging from 1 = “Strongly Disagree” to 5 = “Strongly Agree” (Jian, et al., 2000; Wiese, 2007). A trust score was calculated by adding the responses of the seven questions and dividing by “7”. *Acceptance* is necessary when introducing novel in-vehicle technology as it impacts system use (Van Der Laan, et al., 1997). Acceptance was determined through a usability scale questionnaire which contained nine questions that make up two dimensions of perceived usefulness and satisfaction of the DDSs (Van Der Lann, et al., 1997). The results from these scales are averaged to obtain a score of perceived usefulness and satisfaction. The scale ranges from -2 to +2 with higher usefulness and satisfaction scores suggesting drivers thought the information presented was useful and enjoyable (Rakauskas, Graving, Manser, & Jenness, 2010). The questionnaire was administered to drivers prior to using the DSSs (after receiving verbal instructions and a visual demonstration of the system) and post study. *Mental workload* was examined since the DSSs may add to the mental workload of the driving task. An increase to the overall mental workload can negatively impact driver performance and perceived usability of the DSSs. Mental workload was assessed through the NASA-TLX questionnaire which provides a subjective estimate of mental workload through the use of six workload-related factors: mental demands; physical demands; temporal demands; own performance; effort; and frustration (Hart & Staveland, 1988). A total mental workload score was achieved by adding the six factors together and dividing by “6”. Collectively, these driving performance and usability measures allowed examination of the hypotheses of the current study.

The goals of Phase 2 were to determine if drivers would benefit from receiving concurrent or advanced information regarding approaching EVs based on:

1. Driving performance and usability measures.
2. Changes in in-vehicle distraction resulting from the presence of a DSS.

Target population

Phase 1

According to the National Safety Council, there were an estimated 211,900,000 licensed drivers in the United States during 2010 (National Safety Council, 2012); however, licensed drivers make up only half of the target population. The magnitude of unlicensed drivers in the United States is not well established; however, it has been estimated that approximately 5.0% of drivers involved in fatal crashes were unlicensed (AAA, 2011).

Study Population

The study population consisted of drivers who were at least 14 years of age, in-transport when involved in a fatal or nonfatal MVC with another in-transport vehicle, and were captured in the FARS or NASS-GES databases from 2002 through 2010. During this time period, there were 268,515 and 610,883 observations, respectively, for drivers involved in fatal and nonfatal collisions.

Phase 2

The target population in the current study consisted of:

1. Older drivers between 60 and 75 years of age who reported: at least twenty years of driving experience; possession of a valid driver's license; current residency

within Minnesota's Saint Paul and Minneapolis metropolitan area; no history of motion sickness; visual acuity of at least 20/40 (corrected or uncorrected) with no colorblindness; no underlying health conditions that affected their driving ability; and no deafness.

2. Younger drivers between 18 and 30 years of age who reported: at least one year of driving experience; possession of a valid driver's license; current residency within Minnesota's Saint Paul and Minneapolis metropolitan area; no history of motion sickness; visual acuity of at least 20/40 corrected or uncorrected and no colorblindness; no underlying health conditions that affected their driving ability; and no deafness.

Case and control selection

Phase 1

Cases (N = 1,025 and 527 for nonfatal and fatal collisions, respectively) were all members of the study population who were at least 16 years of age and were driving a non-EV (e.g., bus, taxi, private vehicle) in a non-emergency manner and involved in a MVC with an in-use and in-transport EV (i.e., ambulance, fire truck, or police vehicle). These included both licensed and unlicensed drivers.

Controls (N = 602,889 and 266,662 for nonfatal and fatal collisions, respectively) were all members of the study population who were at least 16 years of age and were driving a non-EV (e.g., bus, taxi, private vehicle) in a non-emergency manner and was involved in a collision with a non-EV (e.g. taxi). These included both licensed and unlicensed drivers.

Phase 2

The study design used in Phase 2 was experimental; therefore participants were allocated into one of the experimental groups. Descriptions of the three experimental groups was given previously within this chapter under the section Specific Aims for Phase 2.

Contact procedures

Phase 1

This study utilized existing datasets that were publicly available; therefore, contact procedures were not applicable.

Phase 2

Prior to initiation, approval of the study was received from the University of Minnesota Institutional Review Board to ensure protection of human subjects. Older and younger drivers were recruited from Saint Paul and Minneapolis, Minnesota, through online and print media. This method of recruitment may have introduced bias into the study; however, we address this issue in Chapter V Section 4.5. The original method for study recruitment was through the Minnesota's Driver's License Database; however, access to the database was not granted due to recent federal access changes. Before enrolling into the study, potential drivers were prescreened to identify individuals who were susceptible to motion sickness or had health-related issues that may have impacted their driving ability. Upon arrival to the driving simulator laboratory, drivers completed a consent form (Appendix A), driving history questionnaire (Appendix B), and were tested for color-blindness and visual acuity (minimum 20/40 corrected or uncorrected).

Sample size calculations

Phase 1

No sample size calculations were generated. All observations (cases and controls) were utilized for analysis.

Phase 2

A sample size calculation was necessary to determine the number of human subjects needed to run in the driving simulator in order to have adequate power. The software used to generate the sample size needed for the study was G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007). The parameters used to calculate sample size are found in Table 3.

The effect sizes selected represented Cohen's effect sizes for small and large effects for ANOVAs (Cohen, 1992), in addition to an effect size between Cohen's medium (0.25) and high effect sizes. The alpha (α) error probability, or Type I error, represents the probability of wrongfully rejecting a null hypothesis and was set at the 0.05 level. Power represents the ability for the study to reject the null hypothesis if it is false and was set at a 0.80 level. The number of groups was set at 6 and is the number of combinations of two age groups (older/younger) and three experimental groups (ISS, ANS, Control). Number of measurements reflected the repeated events per group which totaled 20 (4 drives with 5 events per drive). Figures 8, 9, and 10 graphically represented the power of the study as a function of total sample size with effect sizes of 0.1, 0.3, and 0.4, respectively.

The study incorporated a sample size of N = 84, which was generated using the effect size between medium and high to generate a more conservative sample size than the high effect size estimate (n = 48). Additionally, driving simulator studies are highly controllable and an effect is reasonably expected to be seen; therefore, the study did not utilize the low effect size sample size (n >100).

Data analysis

Phase 1

Descriptive statistics were used to indicate frequencies of driver, roadway, environmental, and crash factors, and consequences among non-EV drivers involved in fatal and nonfatal collisions with and without EVs. Multivariate logistic regression models for fatal and nonfatal crashes were used to identify potential factors associated with non-EV drivers involved in collisions with EVs compared to collisions with non-EVs (expressed as estimated odds ratios [OR] and 95% confidence intervals [CI]) while holding a priori selected covariates constant based on the exposure-outcome DAGs (Hernán, et al., 2002). The models enabled estimation of the odds that a non-EV driver in a crash will be more, or less likely, to have a specific characteristic (e.g., distracted) if they are involved in collisions with EVs compared with collisions involving non-EVs.

Directed Acyclic Graphs

<u>Distracted Driving</u> – The scientific literature is well documented with studies showing driving while distracted (e.g., texting) is detrimental to roadway safety (Strayer, Drews, & Johnston, 2003). Figure 4 shows the DAG for distracted driving and indicates the covariates included within the multivariate model. The final model included Age,

Gender, Location, Reported Alcohol and Drug Use, and Roadway Surface Condition as these covariates were determined to be potential confounders for the association between distracted driving and collisions with EVs, according to Shrier and Platt's (2008) six-step process.

Obscured Vision – If a threat cannot be visually detected, it is reasonable to believe that consequences, such as collisions, may occur. This factor was selected as drivers may have found it difficult to detect approaching EVs in conditions where physical barriers may impede visual detection. Additionally, increased distractors in the visual field may increase the difficulty to detect a specific object (Verghese & McKee, 2004). Figure 5 shows the DAG for obscured vision with the following covariates selected: Age, Distracted Driving, Gender, Location, Roadway Surface Condition, and Time of Day.

Location – Most fatalities resulting from collisions occur in rural environments even though a majority of the US population lives in urban environments (Zwerling, et. al., 2005); however, previous studies have found an increased risk for fatal crashes involving EVs in urban compared to rural environments (Custalow & Gravitz, 2004). Figure 6 shows the DAG for Location with the following covariates selected: Age, Gender, Light Condition, Number of Lanes, and Region.

Intersection Type – Previous research has identified intersections as the region of roadway with the highest frequency of collisions between non-EV and EV drivers (Kahn, et al., 2001; Ray & Kupas, 2005). Due to limited data (only for 2010), Figure 7 shows the

DAG for intersection type with the following covariates selected: Age, Gender, Location, and Region.

Phase 2

In this study, the exposure of interest is the experimental groups and the outcomes of interest are the five performance and three usability measures. Drivers were assigned into experimental groups, based on age and sex. Stratification of results based on these two characteristics removed all known “backdoor pathways” between the exposures and outcomes.

Driving performance measures were analyzed separately for driver and passenger side events (i.e., when the EV approached from the left and right sides of the participant’s vehicle, respectively) because of potential differences in visual obstructions. Mixed effects models were used to measure differences in the following continuous dependent measures among the three experimental groups: safety margin; response time; 85^{th} percentile maximum brake duration; distraction task; trust; and total mental workload. Random effects were used to account for individual differences in responses to the warning systems alerts. SAS® software, version 9.2 (SAS Institute Inc, 2010) mixed procedure was used to analyze the models. Driving performance measures (excluding distraction task) were submitted to a four-way mixed-model ANOVA with Experimental Group (ISS, ANS, and control), Age (younger, older) and Sex (male, female) as between-subject factors and Distraction (present, absent) as a within-subject factor. The distraction task measure was submitted to a three-way mixed-model ANOVA with Experimental Group, Age, and Sex as between-subject factors. Usability measures were submitted to a three-way mixed-model ANOVA with Experimental Group (excluding control), Age, and Sex as between subject factors. Tukey-Kramer analyses for differences in least-square means were performed for pair-wise comparisons of significant main and interaction effects of three levels or more (Kramer, 1956). T-statistics and associated p-values (critical alpha set at 0.05) are reported for each comparison.

The risk of collision was estimated with odds ratios (OR) using a general linear model and 95% confidence intervals were used to describe the precision of the estimates. The ORs were adjusted for within-person correlation using General Estimating Equations to account for multiple collisions by the same participant. All models were adjusted for Sex, and stratified by Age and Experimental Group.

Figures

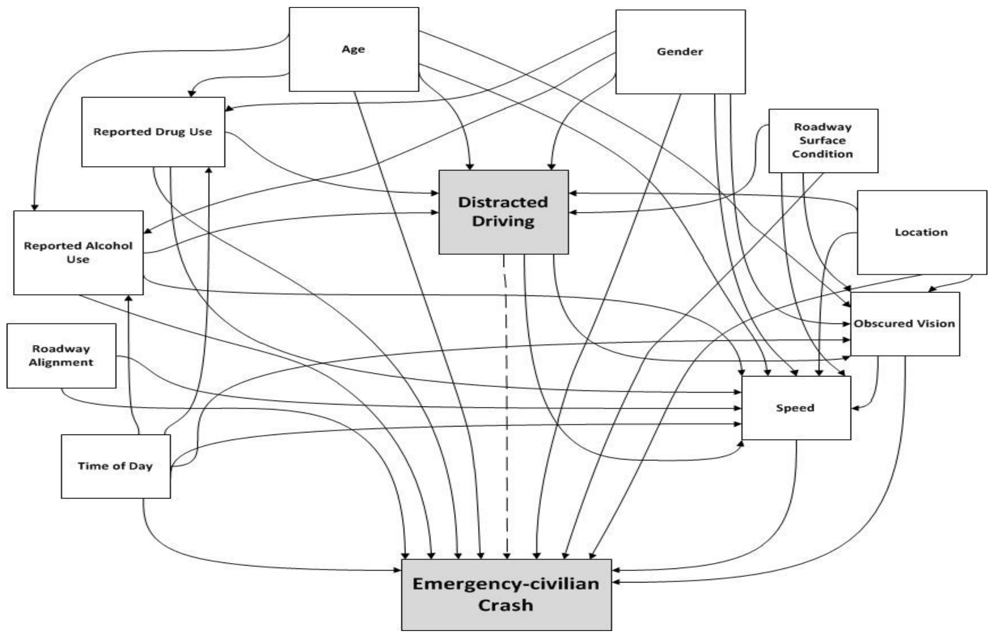

Figure 4: Directed acyclic graph showing potential confounders of the association between distracted driving and non-EV driver collisions with emergency vehicles

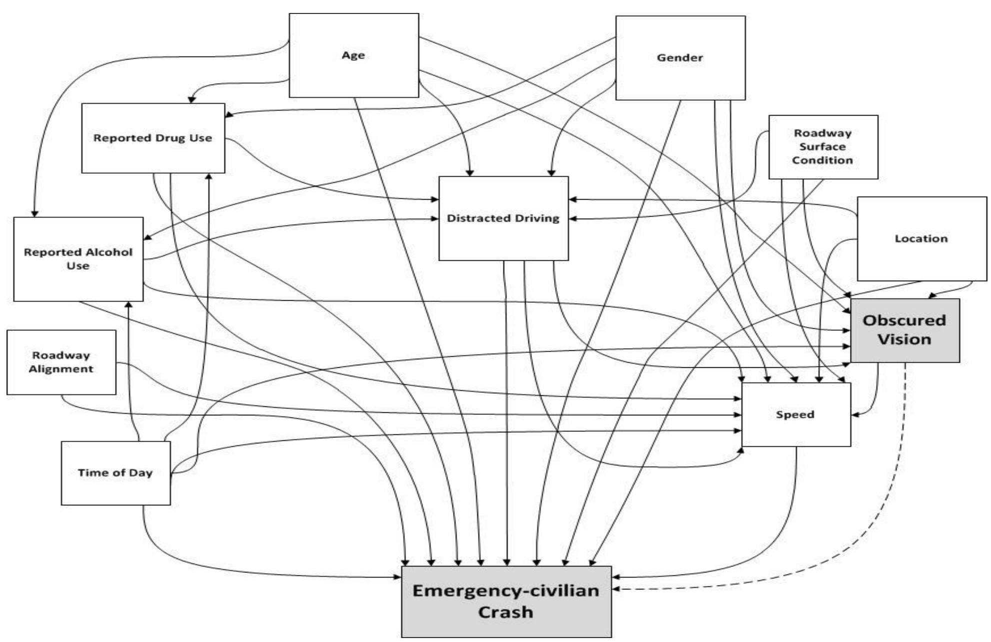

Figure 5: Directed acyclic graph showing potential confounders of the association between obscured vision and non-EV driver collisions with emergency vehicles

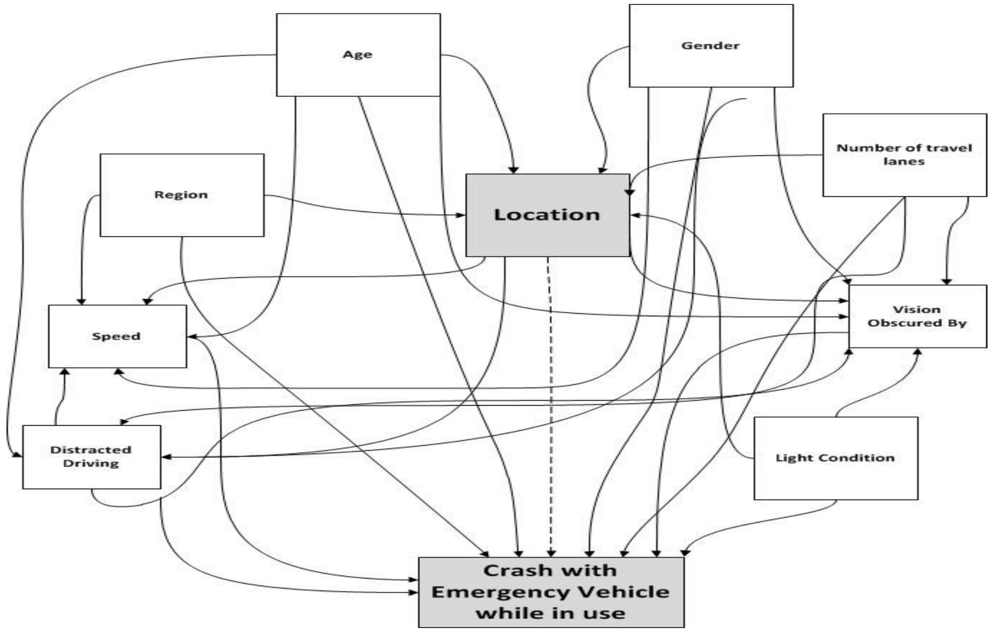

Figure 6: Directed acyclic graph showing potential confounders of the association between location and non-EV driver collisions with emergency vehicles

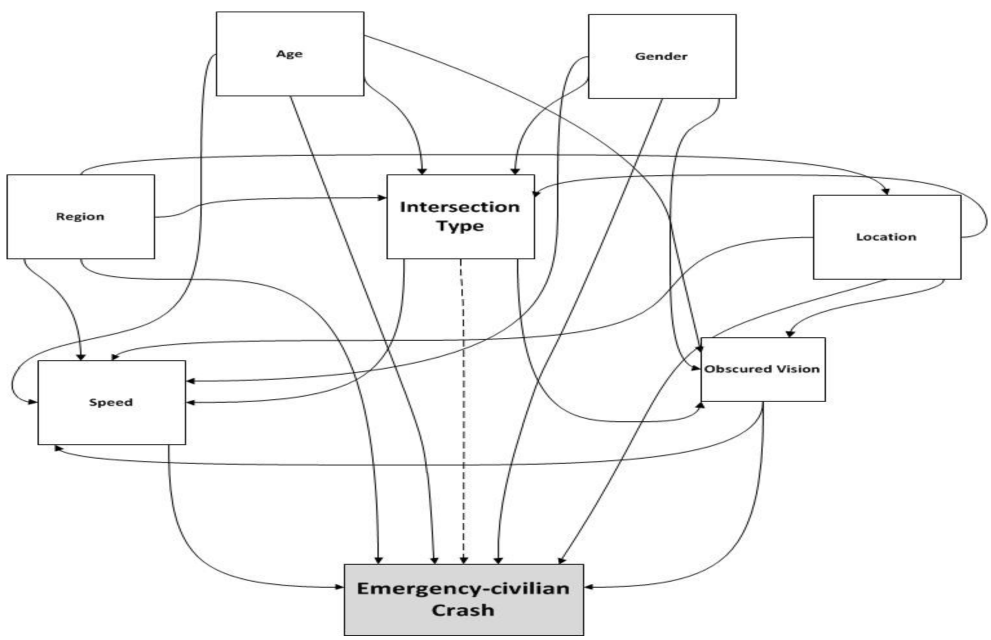

Figure 7: Directed acyclic graph showing potential confounders of the association between intersection type and non-EV driver collisions with emergency vehicles

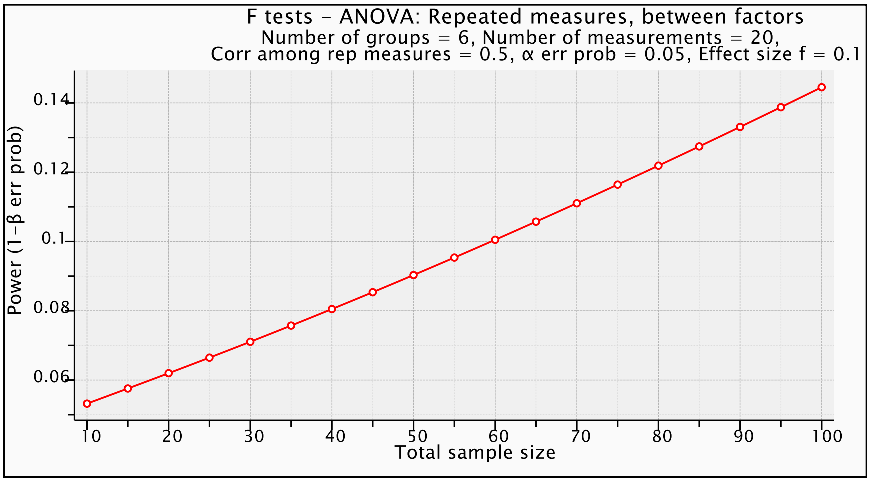

Figure 8: Sample size calculation with effect size = 0.1 for Phase 2

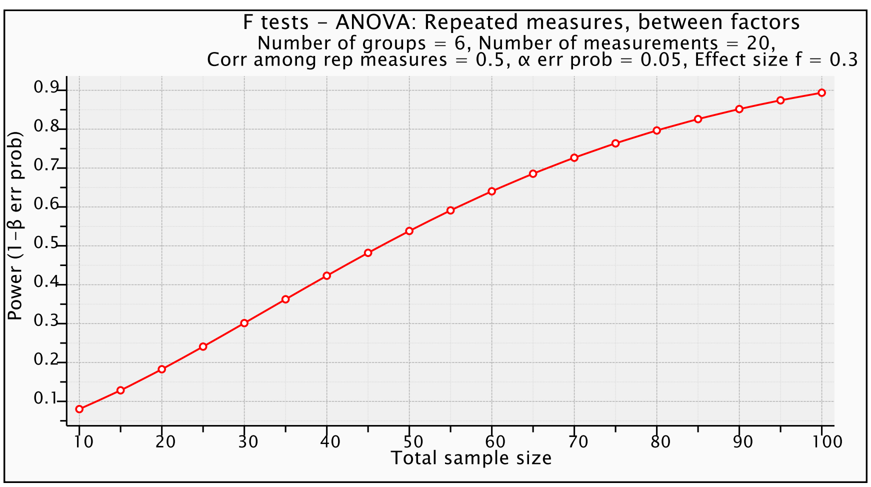

Figure 9: Sample size calculation with effect size = 0.3 for Phase 2

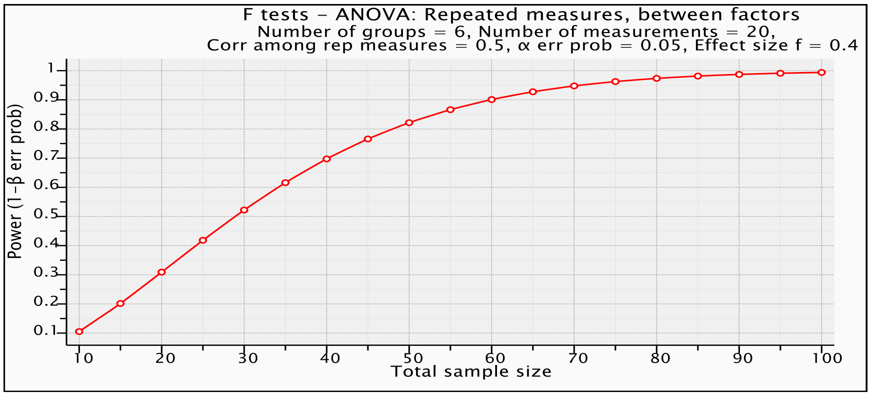

Figure 10: Sample size calculation with effect size = 0.4 for Phase 2

Tables

Table 3: Sample size parameters for Phase 2

Input Parameters	Cohen's Low Effect Size	Cohen's High Effect Size	Arbitrary Effect Size
Effect size f(V)	0.1	0.4	0.3
α error probability	0.05	0.05	0.05
Power (1-β error probability)	0.80	0.80	0.80
Number of groups†	6	6	6
Number of measurements‡	20	20	20
Sample Size Calculated	*675*	*47*	*84*

†, Combinations of 2 age groups (older, younger) and 3 EGs (ISS, ANS, and control)
‡, Participants drove 4 routes with 5 events per route

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Chapter IV: *Phase 1 Manuscript*

Title: Factors Associated with Non-Emergency Vehicle Drivers Involved in Crashes with Emergency Vehicles

Motor vehicle crashes involving emergency vehicle (EV) and non-EV drivers have been a known problem that contributes to fatal and nonfatal injuries; however, characteristics associated with non-EV drivers have not been examined adequately. This study used data from The National Highway Traffic Safety Administration's Fatality Analysis Reporting System and the National Automotive Sampling System General Estimates System to identify driver, roadway, environmental, and crash factors, and consequences for non-EV drivers involved in fatal and nonfatal crashes with in-use and in-transport EVs. In general, non-EV drivers involved in crashes with EVs were more often driving: straight through intersections (vs. same direction) of four-points or more (vs. not at intersection); where traffic signals were present (vs. no traffic control device); and at night (vs. midday). For nonfatal crashes, drivers were more often driving: distracted (vs. not distracted); with vision obstructed by external objects (vs. no obstruction); on dark but lighted roads (vs. daylight); and in opposite directions (vs. same directions) of the EVs. Consequences included increased risk of injury (vs. no injury) and receiving traffic violations (vs. no violation). Fatal crashes were associated with driving on urban roads (vs. rural), although these types of crashes were less likely to occur on dark roads (vs. daylight). The findings of this study suggest drivers may have difficulties in visually detecting EVs in different environments.

1. Introduction

Motor vehicle crashes between emergency vehicle (EV; such as police, fire trucks, and ambulances) and non-EV drivers are a known concern due to high risk of fatal and nonfatal roadway injuries (Custalow & Gravitz, 2004). The National Highway Traffic Safety Administration (NHTSA; 2001-2010) reported that 368,946 EVs were involved in crashes from 2001 to 2010. This number represents an increase of over 20 percent, compared to the previous decade during which 302,969 crashes were reported (Ray & Kupas, 2005). According to the National Emergency Medical Services Advisory Council (2009), identifying the rate of EV crashes is difficult because of the inadequacies of data collections systems to acquire common denominator data, such as vehicle miles traveled.

Research pertaining to emergency-civilian crashes (ECCs, crashes involving non-EV and EV drivers) have predominantly focused on factors associated with EV drivers (Kahn, et al., 2001), the environment (Kahn et al., 2001; Ray & Kupas, 2007), and health-related outcomes (Becker, et al., 2003), in part, due to the high transportation fatality rate among emergency medical service personnel (Maguire, et al., 2002; Slattery & Silver, 2009). Ambulance drivers have received particular attention (Studnek & Fernandez, 2008; Weiss, et al., 2001) since they are at a higher risk for crashes compared to law enforcement officers and fire fighters (Sanddal, Albert, Hansen, & Kupas, 2008). Other crash characteristics, such as the use of lights and sirens, have received dual consideration, examining their impact on emergency response time (Ho & Lindquist, 2001; Petzäll, Petzäll, Jansson, & Nordström, 2011) as well as a connection with crash frequency (Custalow & Gravitz, 2004; Pirrallo & Swor, 1994).

It is important to note that an ECC combines various factors, including those that relate to the non-EV driver (Custalow & Gravitz, 2004); however, such factors for non-EV drivers have not been examined adequately. Identifying these factors is essential since occupants of non-EVs are more likely to be fatally wounded as a consequence of these crashes (Sanddal et al., 2010).

In light of the paucity of research examining ECCs, the purpose of this study was to identify driver, roadway, environmental, and crash factors, and consequences for non-EV drivers involved in fatal and nonfatal motor vehicle crashes with in-use and in-transport EVs.

2. Methods

2.1. Study design

To identify the characteristics of non-EV drivers involved in crashes with EVs, ECCs were compared to non-ECCs (non-EV drivers involved in crashes not containing EVs) for both fatal and nonfatal crashes. This analysis is similar to proportionate morbidity or mortality analyses in which the characteristics of ill or deceased people are compared. While this study design cannot identify causal factors, because of inability to characterize all motor vehicle drivers at risk of being involved in a crash with an EV, it is useful for generating hypotheses about causal factors that contribute to these types of crashes.

Publicly available data from the NHTSA's Fatality Analysis Reporting System (FARS) and National Automotive Sampling System General Estimates System (NASS-GES), from 2002 through 2010, were used. The FARS data are a census of all fatal motor vehicle crashes that occurred within the United States, District of Columbia, and Puerto Rico. For a crash to be eligible within the FARS dataset, the death of a motorist or a non-motorist must have occurred within 30 days from the time of the crash. The NASS-GES data are a nationally-representative probability sample of all police-reported motor vehicle crashes. General eligibility requirements for the FARS and NASS-GES datasets can be found in the Analytical Users' Manuals (US Department of Transportation, 2010, 2011). Both datasets contain information regarding the special use of vehicles (e.g., taxi, police, military) and whether the vehicles were listed as in-use for emergencies. In-use and in-transport EVs were defined as EVs on emergency calls and in motion at the time of the crash. All fatal observations within the NASS-GES dataset were removed to form a nonfatal-only dataset.

The ECC and non-ECC type datasets contained observations only for in transport non-EV drivers who were involved in fatal or nonfatal crashes with another in-transport motor vehicle, that is, an EV or non-EV. Crashes involving EVs, exclusively, and single vehicle crashes, were removed from the datasets. One nonfatal crash observation was removed due to the vehicle being listed as in-use for an emergency but as a non-EV.

2.2. Statistical Analysis

Descriptive statistics were used to report frequencies of driver, roadway, environmental, and crash factors, and consequences between the two crash types.

Multivariate logistic regression models for fatal and nonfatal crashes were used to identify potential factors associated with ECCs compared to non-ECCs (expressed as estimated odds ratios [OR] and 95% confidence intervals [CI]) while holding a priori selected covariates constant, based on directed acyclic graphs (DAGs, Hernán, et al, 2002). The DAGs enable identification of parsimonious models and exclude covariates that should not be entered into the regression lest they introduce bias. The resulting models estimate the odds that an individual in a crash will be more, or less likely to have a specific characteristic (e.g., age or distraction) if they are involved in an ECC rather than a non-ECC. The analyses for this study were generated using SAS® software, Version 9.2 (SAS Institute Inc., 2010).

3. Results

3.1. Vehicle Crash Characteristics

Examination of the two datasets revealed that ECCs represented a small proportion of all of fatal and nonfatal crashes, 0.20% and 0.17%, respectively (Table 4). Sex and age distributions of ECCs and non-ECCs were similar within fatal and nonfatal crashes (Table 4). Among nonfatal crashes, higher proportions of ECCs, compared with non-ECCs involved: distracted drivers; obscured vision; traffic controlling devices; and crashes at angles. The two most reported sources of distractions for drivers were "inattentive or lost in thought" and "looked but did not see", which accounted for 37% and 17%, respectively (results not shown in table). Nonfatal ECCs also occurred at intersections, at night on dark but lighted roads, and resulted in some level of bodily injury, vehicle damage, and drivers receiving traffic violations.

Among fatal crashes, ECCs compared to non-ECCs, more frequently: indicated no source of distraction; occurred on urban roads, at intersections and at night on dark but lighted roads; involved traffic controlling devices and crashes at angles. Non-EV drivers were more likely to be fatally wounded when involved in a fatal crash with an EV compared to a fatal crash with a non-EV.

3.2 Multivariate Analyses

Table 5 presents results of multivariate modeling of driver, roadway, environmental, and crash factors, and consequences for non-EV drivers involved in fatal and nonfatal crashes with in-use and in-transport EVs. Factors of interest were adjusted for potential confounders (see footnote in Table 5), based on DAGs.

3.2.1 Nonfatal Crashes

Driver factor analyses indicated differences between crash types for age and distraction (Table 5). Teenage drivers in crashes were less likely to be involved in ECCs (OR=0.7), compared to drivers aged 20-29. Overall, drivers were more likely to be distracted (OR= 1.9). Gender was not shown to be a differentiating factor.

Analyses of roadway factors showed that physical objects obstructing drivers' vision, location within a road, and presence of traffic control devices were associated with crash types (Table 5). Emergency-civilian crashes were more likely to have driver's vision obstructed by objects on the road: buildings, billboards, and other structures (OR=36.4); parked vehicles (OR=3.4); trees, crops and vegetation (OR=4.5); and other in-transport motor vehicles (OR=2.2). Emergency-civilian crashes occurred more frequently at intersections, specifically intersections that contained four-points or more

(OR=2.1), compared to not being located at intersections. The presence of automatic traffic lights (OR=2.4) and traffic controlling persons (OR=6.7), compared to no controlling devices was associated with ECCs. However, the association between automatic traffic lights and ECCs may be confounded by the location within the roadway, i.e., intersection or non-intersection, given the limited data available for this variable.

Environmental factors identified for ECCs included time of day and lighting characteristics at the time of the crash (Table 5). Driving at night (9 pm-5 am), compared to driving during midday (11 am-4 pm), was three times more likely in ECCs (OR=2.8). Similarly, ECCs were more likely to occur when driving on dark but lighted roads (OR=1.6), compared to driving in daylight.

Emergency-civilian crashes were associated with: angles (OR=4.3); head-on collisions (OR=1.9); or sideswipes in opposite (OR=3.0) and same (OR=2.5) directions, compared to rear-end collisions (Table 5). Similarly, ECCs were more likely to occur when non-EV and EV drivers were heading in opposite directions (OR=4.8) and when they were crossing straight through intersections (OR=3.1), compared to crashes in the same direction.

Consequences for drivers included increased risks for bodily injury, receiving traffic violations, and incurring disabling damage to their vehicles, as a result of ECCs versus non-ECCs (Table 5). Risks were increased for all injury outcomes (excluding fatal) when crashes involved an EV. Similarly, the vehicles among the non-EV drivers were more likely to become disabled (OR=2.7), compared to no vehicle damage, and drivers were more likely to receive a “failed to yield the right-of-way” violation

(OR=3.0), compared to receiving no violations, when an EV was involved in the crash. However, drivers were less likely to receive a speed-related violation (OR=0.4) when involved in a nonfatal ECC.

3.2.2 Fatal Crashes

Analyses of driver factors for fatal crashes were limited due to high proportions of fatalities among non-EV drivers (Table 4). However, roadway factors were associated with differences between the two crash types (Table 5). Fatal ECCs were more than two times greater on urban compared to rural roads, and more likely to occur at T-intersections (OR=5.6) and intersections of four-points or more (OR=4.9), compared to crashes not occurring at intersections. Similar to nonfatal ECCs, the presence of automatic traffic lights was associated with fatal ECCs (OR=2.6).

Environmental factors were similar between crash types. Fatal and nonfatal ECCs were more likely at night (OR=2.8 and 1.6, respectively), versus the afternoon. However, driving on dark roads at the time of the crash was less likely than driving in daylight (OR=0.6) for fatal ECCs, and driving on dark but lighted roads, versus in daylight, was associated with nonfatal ECCs only.

Crash factors indicated head-on versus rear-end collisions were less likely for fatal ECCs (OR=0.4). Similar to nonfatal ECCs, fatal ECCs were associated with crashes that occurred as non-EV drivers drove straight through intersections (OR=3.4).

Consequences identified increased risk of fatal injury (OR=2.1) among non-EV drivers who were involved in crashes with EVs, compared to those involved in crashes with non-EVs. Other crash consequences (moving violations and vehicle damaged) indicated no significant differences.

4. Discussion

This study analysis of two national datasets identified several driver, roadway, environmental, and crash-level factors, and consequences for non-EV drivers involved in fatal and nonfatal crashes with in-use and in-transport EVs. Identifying the factors more common in ECCs, compared to other crashes, can help focus research and prevention efforts for non-EV driver crashes with EVs.

4.1 Driver Factors

Non-EV drivers' failure to notice EVs has been previously identified as a primary factor associated with ECCs (Clarke, Ward, Bartle, & Truman, 2009); however, this is a rather broad explanatory factor. The current study enabled investigation of factors that contribute to this broad concept of failing to notice EVs. For example, older adults experience numerous perceptual and cognitive declines (Salthouse, Hancock, Meinz, & Hambrick, 1996), including those in visual acuity (Klein, Klein, Linton, & De Mets, 1991) and inattentional blindness (Graham & Burke, 2011); yet, no difference was identified for older (60+) or middle aged (30-59), compared to young (20-29) drivers involved in ECCs. In fact, teenage (14-19), compared to drivers between the ages of 20 and 29, were less likely to be involved in a nonfatal ECC, a finding that may be associated with drivers' license restrictions. Teenage drivers may be required to drive during daylight hours and, as a result, would not be exposed to nighttime driving, which was shown to increase the likelihood for collisions with EVs.

Internal distractions among drivers are well known risks for motor vehicle crashes with potential serious costs (Strayer, et al., 2006). In this study, drivers who indicated a source of distraction were more likely to be involved in nonfatal ECCs. Cognitive distractions, such as being inattentive or lost in thought, which was the highest reported type of distraction, has been shown to negatively affect visual detection for changes in traffic scenes (McCarley, et al., 2004). Drivers that are taxed with a secondary cognitive task spend more time looking forward of their vehicle and are less likely to detect a target in the periphery of their vision (Harbluk, Noy, Trbovich, & Eizenman, 2007). This may provide insight into nonfatal ECCs that occurred at angles and non-EV drivers driving straight through intersections as visual scanning in the periphery declines.

4.2 Roadway Factors

In this study, it was identified that general age-related changes may not contribute to drivers' failure to notice EVs but, rather, how roadway characteristics, such as visual obstructions due to external objects may contribute. The analyses showed that buildings, billboards, parked vehicles, trees, crops, vegetation, and other in-transport motor vehicles were more likely to be associated with nonfatal ECCs. The purpose of lights on an EV is to provide a visual stimulus to alert motorists of an approaching EV; however, if a driver's vision is obstructed, an EV that is not following standard roadway rules (e.g., driving through red lights at intersections) may go undetected.

Intersections in general, more specifically T- and four-points or more intersections, may be a contributing factor to drivers failing to notice. When drivers approach an intersection, they typically scan for relevant objects (e.g., traffic signals) in an attempt to decipher how these objects impact their ability to cross a junction safely. However, as the number of distractors (e.g., pedestrians, traffic routes) increase, visually searching for a specific target among the clutter becomes more difficult (Verghese & McKee, 2004). When the target is dissimilar to the distractors, the "pop-out effect" may be responsible for immediate detection of the target (Becker, 2010). For example, an EV's warning lights acts as a pop-out when the vehicle is traveling down a street full of parked cars; however, when the EV is at a busy urban intersection, the EV's warning lights would not act like a pop-out. This example can be illustrated by the second most frequent type of distraction that may have influenced driver performance -- looked but did not see -- suggesting that drivers might have attempted to identify the target but failed to identify or discriminate it from other vehicles on the road. Visual perception of relevant information may be disrupted among these types of looked, but did not see, crashes (Koustanai, Boloix, Elslande, & Bastien, 2008).

The FARS data analyzed in this study showed that majority of fatal non-ECCs (55%) occurred on rural roads; however, among fatal ECCs, the majority occurred on urban roads (68%). Urban roads present more visual clutter (e.g., pedal cyclist, pedestrians, traffic congestion) compared to rural roads, which can mask impending critical events (Underwood, 2007). Consequently, visually detecting an EV may become more difficult on urban roads.

4.3 Environmental Factors

The ability of a driver to visually detect objects in the environment is affected by the amount of light present; a driver's visual performance declines in reduced lighting conditions (Plainis, Murray, & Charman, 2005). As a result, driving in such conditions decreases the visibility of objects in the environment and may contribute to fatal and nonfatal ECCs at night. Surprisingly, fatal ECCs were less likely to occur on dark roads while driving on dark but lighted roads was more likely for nonfatal ECCs. Since emergency lights have greater contrast in darker environments, it is possible that the non-EV drivers' ability to detect an approaching EV increases (Hsieh, Colas, & Kanwisher, 2011). When dark environments become lighted, objects become more visible and the EV's warning lights lose contrast; thus, they become less effective in orienting a driver's attention. This concept may explain the association between nonfatal ECCs and driving on roads in environments that are dark but lighted. The implication of this finding is contrary to the recommendation of increased roadway lighting as a method to reduce motor vehicle crashes. Although roadway lighting is associated with decreases in pedestrian-motor vehicle crashes (Retting, Ferguson, McCartt, 2003; Sullivan & Flannagan, 2002), at rural stop-controlled intersections (Donnell, Porter, & Shankar, 2010), and in other possible crash scenarios, roadway lighting may be detrimental to the safe interaction between non-EV and EV drivers. In addition, roadways that are lighted have been shown to be associated with faster driving speeds (Assum, Bjørnskau, Fosser, & Sagberg, 1999), which may also contribute to the underlying factors associated with these types of crashes; however, limitations within the datasets did not allow for analyses to include such factors.

4.4 Crash Factors

Describing harmful events between non-EVs and EVs provided an understanding into the sequence of events that led to the ECCs. Such analyses have been conducted previously by recreating crash events and identifying which mechanisms failed along the function event sequence (Malaterre, 1990). By including such sequences, it allows for identification of potential failures that may have contributed to issues related to visibility.

The manner of collision represents the nature of impact between non-EVs and EVs while crash type takes into account the crash category (e.g., vehicle turning) for the first harmful event specific to the non-EV driver. The first harmful events suggest visual detection of the EVs may not have been completed or drivers may not have had enough time to detect and react to the situation as EVs were more likely approaching in different directions (e.g., opposite, perpendicular) of the non-EV drivers. The available time to detect an EV decreases when the vehicles are moving towards each other compared to moving in the same direction.

4.5 Consequences

Post-crash factors can provide important information to help understand the consequences of ECCs. Failing to yield the right-of-way, found to be the most common violation among non-EV drivers involved in EV crashes in this study, suggests that non-EV drivers are unable to visually detect oncoming EVs and, as a result, execute inappropriate driving maneuvers that contribute to the crashes.

The current study enabled a better understanding of how driver, roadway, environmental, and crash factor characteristics and consequences are associated with fatal and nonfatal ECCs. Furthermore, the results enabled explication on a widely accepted concept – i.e., that non-EV drivers fail to notice EVs – and ascertainment of how specific endogenous (e.g., internal distractions) and exogenous (e.g., roadway locations) factors contribute to this overarching failure in recognition.

These results, although not causal, can identify potential avenues for future research and prevention efforts. Recommendations for changes to roadway infrastructures, such as improved roadway lighting, can decrease the risk for certain types of motor vehicle crashes (Donnell et al., 2010; Retting et al., 2003) but may also increase the risk for ECCs. Traffic safety engineers could utilize the data to design and integrate infrastructure-based solutions (e.g., emergency vehicle preemption systems) in high-risk areas, such as urban intersections.

Advancements in technologies have made in-vehicle devices commonplace for providing information to drivers of potential critical situations and assisting in navigation of difficult driving environments (Becic, et al., 2013). The use of collision warning systems to alert drivers to a myriad of potential collision events, including approaching in-use and in-transport EVs (Lenné, et al., 2008), have shown promising results. The integration of technology within and between vehicles on the road is the future of driving. Connected-vehicle safety systems (i.e., vehicle-to-vehicle and vehicle-to-infrastructure) communicate relevant information that may create the necessary components for a collision event (e.g., roadway conditions, obstacles, approaching EVs). We believe this study can open pathways to scientific questions and research aimed at reengineering roadways and integrating in-vehicle technologies to further improve roadway safety for non-EV and EV drivers.

4.6 Limitations

The present study is not without limitations. Emergency vehicles' operating lights and sirens have been associated with increased risk for crashes (Custalow & Gravitz, 2004); however, the FARS and NASS-GES datasets only indicate if the EV was in-use, that is, on an emergency call. It is not known whether or not all EVs' lights and sirens were activated at the time of the crashes. For study purposes, the assumption was made that an EV on an emergency call consisted of using lights and sirens.

The FARS dataset is inherently limited in its ability to identify driver factors if the person fatally injured was the driver. The inability to collect driver data among the deceased can introduce subjectivity by the crash scene investigator into the crash reports and, subsequently, bias the results. In addition, drivers not fatally injured at the time of data acquisition may provide inappropriate information to law enforcement and crash scene investigators, particularly in the context of distracted driving, in order to avoid potential fault or penalty. As a result, some driver information within the NASS-GES and FARS dataset may be misleading.

Factors observed within the NASS-GES and FARS datasets may have been limited by the amount of data that were collected and as a result, the observed outcome may have been affected. Finally, as described previously, the analyzed data included only crash events; therefore, it is not possible to directly estimate risk of an ECC for any given factor. However, by comparing to other crashes, potential patterns of risk associated with ECCs have been identified.

5. Conclusions

Results of this study suggested that drivers may have difficulties in visually detecting EVs that are approaching in different driving conditions. An EV warning system may not be as effective in conditions where: a driver's vision is obstructed (e.g., by buildings, parked vehicles) or limited (e.g., nighttime); drivers are distracted; and within roadway locations that may be cluttered (e.g., intersections, urban environments). One method to augment drivers' abilities in detecting approaching in-use EVs is the use of technology in the forms of roadway-based preemption systems and in-vehicle driver support systems. These systems have shown to benefit non-EV drivers in detecting EVs and reducing the incidence of ECCs. Future research should continue to evaluate these types of systems under situations in which drivers' visibility is impacted.

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Tables

Table 4: Driver, Roadway, Environmental, and Crash-level Characteristics, and Consequences among Non-Emergency Vehicle Drivers Involved in Nonfatal and Fatal Emergency-Civilian Crashes (ECC)

Variables	Nonfatal Crashes*				Fatal Crashes**			
	ECC		Non-ECC		ECC		Non-ECC	
	N = 1,025†	%‡	N = 602,889†	%‡	N = 527†	%‡	N = 266,662†	%‡
Driver-level								
Gender								
Female	394	38.4	248,239	41.2	171	32.4	75,344	28.3
Male	623	60.8	351,757	58.3	356	67.6	190,667	71.5
Missing	8	0.8	2,893	0.5	0	0.0	651	0.2
Age								
14-19	81	7.9	64,246	10.7	43	8.2	22,941	8.6
20-29	275	26.8	145,565	24.1	117	22.2	57,987	21.7
30-39	197	19.2	117,923	19.6	94	17.8	48,251	18.1
40-49	209	20.4	113,163	18.8	86	16.3	49,403	18.5
50-59	134	13.1	81,077	13.4	77	14.6	38,479	14.4
60-69	57	5.6	40,998	6.8	43	8.2	22,216	8.3
70+	57	5.6	32,460	5.4	67	12.7	27,385	10.3
Missing	15	1.5	7,457	1.2	0	0.0	0	0.0
Distracted [a]								
No	519	50.6	357,107	59.2	45	88.2	20,180	81.4
Yes	199	19.4	74,600	12.4	1	2.0	1,664	6.7
Missing	307	30.0	171,182	28.4	5	9.8	2,958	11.9
Roadway-level								
Vision Obscured by [b]								
No Obstruction	753	73.5	461,709	76.6	84	15.9	46,600	96.0
Building,	10	1.0	184	0.0	0	0.0	0	0.0

Variables	Nonfatal Crashes*				Fatal Crashes**			
	ECC		Non-ECC		ECC		Non-ECC	
	N = 1,025†	%‡	N = 602,889†	%‡	N = 527†	%‡	N = 266,662†	%‡
Billboard or Other Structure								
Parked Vehicle	22	2.1	4,798	0.8	0	0.0	44	0.1
Trees, Crops, and Vegetation	4	0.4	683	0.1	0	0.0	102	0.2
In-transport Motor Vehicle	19	1.9	4,745	0.8	1	0.2	226	0.5
Other	17	1.7	8,099	1.3	31	5.9	1,147	2.4
Missing	200	19.5	122,671	20.3	411	78.0	422	0.9
Location								
Rural	121	11.8	102,242	17.0	169	32.1	146,422	54.9
Urban	477	46.5	281,044	46.6	357	67.7	119,055	44.6
Other	316	30.8	164,798	27.3				
Missing	111	10.8	54,805	9.1	1	0.2	1,185	0.4
Intersection Type [c]								
Not an Intersection	32	35.2	25,992	45.8	12	23.5	14,877	60.2
Y-Intersection	1	1.1	256	0.5	0	0.0	218	0.9
T-Intersection	3	3.3	6,395	11.3	12	23.5	2,849	11.5
Four-points or More	42	46.2	17,073	30.1	27	52.9	6,716	27.2
Roundabout	0	0.0	81	0.1	0	0.0	4	0.0
Missing	13	14.3	6,972	12.3	0	0.0	58	0.2

Variables	Nonfatal Crashes*				Fatal Crashes**			
	ECC		Non-ECC		ECC		Non-ECC	
	N = 1,025†	%‡	N = 602,889†	%‡	N = 527†	%‡	N = 266,662†	%‡
Traffic Control Devices								
No Controls	337	32.9	330,465	54.8	261	49.5	169,789	63.7
Yield Sign	3	0.3	7,351	1.2	3	0.6	1,596	0.6
Warning Sign	10	1.0	7,765	1.3	2	0.4	3,875	1.5
Traffic Signal (Lights)	490	47.8	174,693	29.0	167	31.7	35,020	13.1
Stop Sign	56	5.5	46,689	7.7	74	14.0	44,860	16.8
Person	10	1.0	1,278	0.2	1	0.2	423	0.2
Other	104	10.1	13,155	2.2	15	2.8	10,321	3.9
Missing	15	1.5	21,493	3.6	4	0.8	778	0.3
Environmental-level								
Time of Day								
11am-4pm (Midday)	365	35.6	267,786	44.4	165	31.3	99,014	37.1
5pm-8pm (Evening)	213	20.8	132,814	22.0	117	22.2	56,835	21.3
9pm-5am (Night)	232	22.6	62,461	10.4	147	27.9	57,770	21.7
6am-10am (Morning)	213	20.8	137,820	22.9	97	18.4	52,758	19.8
Missing	2	0.2	2,008	0.3	1	0.2	285	0.1
Light Condition								
Daylight	662	64.6	463,712	76.9	316	60.0	171,241	63.5
Dark	45	4.4	30,228	5.0	79	15.0	49,055	18.2
Dark but	284	27.7	87,029	14.4	117	22.2	34,397	12.8

Variables	Nonfatal Crashes*				Fatal Crashes**			
	ECC		Non-ECC		ECC		Non-ECC	
	N = 1,025†	%‡	N = 602,889†	%‡	N = 527†	%‡	N = 266,662†	%‡
Lighted								
Dawn	7	0.7	6,764	1.1	1	0.2	5,055	1.9
Dusk	20	2.0	12,791	2.1	14	2.7	9,278	3.4
Missing	7	0.7	2,365	0.4	0	0.0	630	0.2
Crash-level								
Manner of Collision								
Rear-end	164	16.0	256,858	42.6	88	16.7	43,606	16.4
Angle	740	72.2	258,373	42.9	360	68.3	135,623	50.9
Head-on	35	3.4	29,382	4.9	48	9.1	67,067	25.1
Sideswipe Opposite Dir.	11	1.1	8,054	1.3	9	1.7	8,688	3.3
Sideswipe Same Dir.	74	7.2	49,983	8.3	18	3.4	9,311	3.5
Other	1	0.1	239	0.0	2	0.4	1,570	0.6
Missing	0	0.0	0	0.0	2	0.4	802	0.3
Crash Type [d]								
Same Dir.	214	20.9	268,694	44.6	5	9.8	4,618	18.7
Opposite Dir.	36	3.5	23,178	3.8	6	11.8	8,339	33.7
Vehicle Turning	276	26.9	161,333	26.8	11	21.6	4,687	19.0
Intersection – Straight Path	309	30.1	71,439	11.8	17	33.3	4,328	17.5
Other	0	0.0	0	0.0	12	23.5	2,681	10.8
Missing	190	18.5	78,245	13.0	0	0.0	69	0.3
Consequences								
Injury								

Variables	Nonfatal Crashes*				Fatal Crashes**			
	ECC		Non-ECC		ECC		Non-ECC	
	N = 1,025†	**%‡**	**N = 602,889†**	**%‡**	**N = 527†**	**%‡**	**N = 266,662†**	**%‡**
No Injury	348	34.0	277,260	46.0	101	19.2	63,807	24.9
Possible	245	23.9	129,027	21.4	46	8.7	27,826	10.8
Non-incapacitating	232	22.6	109,547	18.2	58	11.0	28,196	11.0
Incapacitating	197	19.2	82,070	13.6	55	10.4	33,639	13.1
Fatal	-	-	-	-	265	50.3	101,694	39.6
Missing	3	0.3	4,985	0.8	2	0.4	1,500	0.6
<u>Moving Violation</u>								
None	624	60.9	406,054	67.4	468	88.8	232,767	87.3
Failed Traffic Signal	9	0.9	13,621	2.3	7	1.3	2,842	1.1
Failed to Yield The Right-of-way	156	15.2	34,543	5.7	11	2.1	3,721	1.4
Reckless Driving	11	1.1	6,741	1.1	18	3.4	10,777	4.0
Speed-related	11	1.1	18,031	3.0	1	0.2	1,501	0.6
Other	214	20.9	123,899	20.6	12	2.3	10,202	3.8
Missing	0	0.0	0	0.0	10	1.9	4,852	1.8
<u>Vehicle Damage</u>								
None	13	1.3	11,269	1.9	1	0.2	1,877	0.7
Minor	123	12.0	122,332	20.3	31	5.9	16,333	6.1
Functional	153	14.9	102,186	16.9	56	10.6	36,588	13.7
Disabling	437	42.6	190,736	31.6	436	82.7	208,710	78.3
Missing	299	29.2	176,366	29.3	3	0.6	3,154	1.2

* Data from the National Automotive Sampling System General Estimates System (2002-2010)
** Data from the Fatality Analysis Reporting System (2002-2010)
† Total may differ by factor depending on data collection for each year
‡ Percentages may not add up to 100 due to rounding
a FARS data only available for 2010 (N=24,853)
b FARS data only available for 2009 and 2010 (N=48,677)
c GES and FARS data only available for 2010, N=57,372 and N=24,773, respectively
d FARS data only available for 2010 (N=24,773)

Table 5: Multivariate Logistic Regression Analyses of Driver, Roadway, Environmental, and Crash-level Characteristics, and Consequences among Non-Emergency Vehicle Drivers Involved in Nonfatal and Fatal Emergency-Civilian Crashes (ECC)

Variables	Nonfatal ECC*		Fatal ECC**	
	Adjusted		Adjusted	
	OR	95%CI	OR	95%CI
Driver-level				
Gender				
Female	1.0	--	1.0	--
Male	1.1	1.0-1.3	0.8	0.7-1.0
Age				
14-19	0.7	0.5-0.9	0.9	0.7-1.3
20-29	1.0	--	1.0	--
30-39	0.9	0.7-1.1	1.0	0.7-1.3
40-49	1.0	0.8-1.2	0.9	0.7-1.1
50-59	0.9	0.7-1.1	1.0	0.7-1.3
60-69	0.7	0.6-1.0	1.0	0.7-1.4
70+	0.9	0.7-1.2	1.2	0.9-1.6
Distracted [a]				
No	1.0	--	1.0	--
Yes	1.9	1.6-2.3	0.8	0.1-5.9
Roadway-level				
Vision Obscured by [b]				
No Obstruction	1.0	--	1.0	--
Building, Billboard or Other Structure	36.4	18.4-71.9	--	--
Parked Vehicle	3.4	2.2-5.2	--	--
Trees, Crops, and Vegetation	4.5	1.7-12.0	--	--
In-transport Motor Vehicle	2.2	1.3-3.9	2.7	0.4-19.8
Location [c]				
Rural	1.0	--	1.0	--
Urban	1.3	1.0-1.6	2.2	1.8-2.7
Intersection Type [d]				
Not an Intersection	1.0	--	1.0	--
Y-Intersection	3.0	0.4-22.2	--	--
T-Intersection	0.4	0.1-1.3	5.6	2.4-12.7
Four-points or More	2.1	1.3-3.4	4.9	2.4-10.0
Traffic Control Devices [e]				
No Controls	1.0	--	1.0	--
Yield Sign	0.6	0.2-2.1	1.2	0.4-3.9
Warning Sign	1.2	0.7-2.3	0.4	0.1-1.5
Traffic Signal (Lights)	2.5	2.1-2.9	2.6	2.1-3.2

Variables	Nonfatal ECC[*]		Fatal ECC**	
	Adjusted		Adjusted	
	OR	95%CI	OR	95%CI
Stop Sign	1.2	0.9-1.7	1.1	0.8-1.4
Officer, Guard, etc.	6.7	3.1-14.2	1.6	0.2-11.8
Other	5.8	4.4-7.5	1.0	0.6-1.8
Environmental-level				
Time of Day [f]				
11am-4pm (Midday)	1.0	--	1.0	--
5pm-8pm (Evening)	1.2	1.0-1.4	1.3	1.0-1.6
9pm-5am (Night)	2.8	2.3-3.3	1.6	1.3-2.1
6am-10am (Morning)	1.2	1.0-1.4	1.1	0.9-1.4
Light Condition [g]				
Daylight	1.0	--	1.0	--
Dark	0.7	0.5-1.1	0.6	0.4-0.9
Dark but Lighted	1.6	1.1-2.1	0.9	0.6-1.2
Dawn	0.3	0.1-1.0	--	--
Dusk	1.3	0.8-2.3	1.0	0.6-1.7
Crash-level				
Manner of Collision [h]				
Rear-end	1.0	--	1.0	--
Angle	4.3	3.4-5.5	1.2	0.9-1.6
Head-on	1.9	1.1-3.2	0.4	0.3-0.6
Sideswipe Opposite Direction	3.0	1.4-6.6	0.5	0.3-1.1
Sideswipe Same Direction	2.5	1.7-3.7	1.1	0.6-1.8
Crash Type [i]				
Same Direction	1.0	--	1.0	--
Opposite Direction	4.8	1.5-14.6	0.8	0.2-2.5
Vehicle Turning	0.8	0.3-2.1	2.1	0.7-6.2
Intersection - Straight Path	3.1	1.3-7.0	3.4	1.2-9.4
Consequences				
Injury [j]				
No Injury	1.0	--	1.0	--
Possible	2.3	1.6-3.2	1.3	0.8-2.0
Non-Incapacitating	1.8	1.3-2.5	1.3	0.9-1.9
Incapacitating	2.1	1.4-2.9	1.2	0.8-1.8
Fatal	--	--	2.1	1.5-2.9
Moving Violation [k]				
None	1.0	--	1.0	--
Failed Traffic Signal	0.4	0.2-0.8	1.4	0.7-3.1
Failed to Yield the	3.0	2.5-3.6	1.7	0.9-3.1

Variables	Nonfatal ECC*		Fatal ECC**	
	Adjusted		Adjusted	
	OR	95%CI	OR	95%CI
Right-of-Way				
Reckless Driving	0.8	0.4-1.6	1.0	0.6-1.6
Speed-related	0.4	0.2-0.7	0.4	0.1-2.9
Other	1.0	0.8-1.2	0.7	0.4-1.3
Vehicle Damage [m]				
Minor	1.0	--	1.0	--
Functional	1.2	0.8-1.8	1.2	0.6-2.2
Disabling	2.7	1.9-3.8	1.4	0.8-2.4

* Data from the National Automotive Sampling System General Estimates System (2002-2010)
** Data from the Fatality Analysis Reporting System (2002-2010)
a Adjusted for age, location, reported alcohol, reported drugs, roadway surface condition, sex (Fatal crash data only for 2010)
b Adjusted for age, body type, location, roadway surface condition, sex, time of day (Fatal crash data only for 2010)
c Adjusted for age, light condition, number of lanes, region, sex
d Adjusted for age, location, region, sex; Data only available for 2010
e Adjusted for age, day of week, number of lanes, region, sex, traffic flow, weather
f Adjusted for age, location, season, sex
g Adjusted for age, location, number of lanes, time of day, season, sex, weather
h Adjusted for age, distracted (only for injury), roadway alignment, roadway surface condition, sex, vision obscured (only for injury)
i Adjusted for age, location, number of lanes, roadway surface condition, sex (Fatal crash data only for 2010)
j Adjusted for age, body type, crash avoidance maneuver, location, sex
k Adjusted for age, injury severity, time of day, sex
m Adjusted for age, body type, crash avoidance maneuver, roadway surface condition, sex

Chapter V: *Phase 2 Manuscript*

Title: Detecting in-use and in-transport emergency vehicles: a study on saliency and an application of connected-vehicles technology using a driving simulator

Emergency vehicle drivers typically respond to urgent situations with lights and sirens engaged; however, lights and sirens have limited effectiveness in providing critical time-dependent safety-related information to roadway users. By alerting drivers to imminent critical situations, connected-vehicle technologies and driver support systems have proven useful in mitigating collision severity and preventing collisions from occurring. The current study examined the impact of two driver support systems on driving performance and usability measures under distracting and non-distracting conditions. Eighty-five participants, dichotomized into two age groups (younger/older) participated in a driving simulator trial-based experiment in which they encountered emergency vehicles crossing intersections. Overall, the driver support systems improved participant responses to emergency vehicles. Most notably, participants were at decreased risk of collisions with emergency vehicles when given a driver support system and the systems did not increase in-vehicle distractions. The presence of the driver support systems did not increase perceived mental workload of the driving task. These results support the concept of driver support systems integrated with connected-vehicle technology as a method to overcome limitations of standard warnings by lights and sirens. Future research should continue to examine technology as a method to mitigate roadway collisions between non-emergency vehicle and emergency vehicle drivers – an approach that is integral to comprehensive roadway safety.

1. Introduction

Emergency vehicles (EV), such as police cars, fire trucks, and ambulances, typically respond to urgent situations by traveling with lights and sirens (L/S) engaged. However, L/S are limited in their effectiveness in providing essential time-dependent safety-related information to drivers on the roadway (De Lorenzo & Eilers, 1991; Withington, 1999). The apparent ineffectiveness of L/S may have contributed to the more than 368,000 crashes involving EVs from 2001-2010 (National Highway Traffic Safety Administration, 2001-2010), an increase of over twenty percent from the previous decade (Ray & Kupas, 2005). In addition, research has shown negative consequences such as wake-effect collisions, which occur when drivers maneuver into other vehicles while attempting to give the right-of-way to EVs (Petzäll, et al., 2011). These occurrences are often greater and can result in both nonfatal and fatal injuries (Clawson, Martin, Cady, & Maio, 1997).

Among critical roadway situations, technology has been utilized as a method to augment the driving experience, i.e., to enhance driver abilities under various conditions and situations to detect imminent threats. Driver support systems (DSS), analogous to collision avoidance systems, can alert drivers to a variety of potentially critical events (e.g., rear-end collisions) and have been shown to produce positive results in reaction time and collision avoidance (Kiefer & Hankey, 2008; Lee, et al., 2002). Such DSSs would have application in alerting drivers to imminent threats with EVs; thus, understanding the root issues of ineffective L/S can aide in developing a DSS that is theoretically driven with the practical goal of mitigating these types of crashes and ameliorating the interaction between drivers and EVs. Additionally, a DSS may be beneficial by impacting EV travel time and frequency of wake-effect collisions.

The literature suggests two general areas which may influence the effectiveness of L/S: saliency i.e., noticeability of an EV's L/S (Drucker, et al., 2013; Robbins, 1995) and effective distance i.e., distance at which a siren is noticeable (Catchpole & McKeown, 2007; De Lorenzo & Eilers, 1991; Withington, 1999). Roadway and environmental factors may influence drivers' responses to L/S. (Drucker, et al., 2013). Physical barriers (e.g., buildings and parked motor vehicles) can obstruct drivers' visual fields and impede their ability to detect approaching EVs. Roadway intersections, specifically four-point or more and urban environments, in general, are more cluttered and provide additional distractions (e.g., signage and pedestrians). As the number of distractors increase, the ability of a driver to detect a specific target becomes more difficult (Verghese & McKee, 2004). Additionally, distracted driving can render L/S to be ineffective, which is contrary to the primary goal of L/S to attract attention. Drivers who were involved in crashes with EVs were twice as likely to be distracted, compared to those in crashes with non-EVs (Drucker, et al., 2013). It is well established that driving while distracted (e.g., texting) is detrimental to safety and negatively affects driving performance (Stavrinos, et al., 2013; Strayer, et al., 2003).

Various factors influence the effective distance of L/S (Robbins, 1995). For example, closed windows and increased sound proofing in current motor vehicles may attenuate penetration of the siren sound. External (e.g., roadway traffic) and internal noises (e.g., radio playing, conversing) can impact the relative effective distance the siren has to exceed to overcome sound levels of competing noises. Simply increasing the sound level output of an EV siren to increase penetration poses new health-related risks, particularly to the EV drivers and pedestrians.

The effect of these factors may influence drivers' abilities to detect EVs from L/S alone. The purpose of the current study was to determine the effectiveness of integration of in-vehicle DSSs on various driving performance and usability measures when encountering EVs. Four general hypotheses guided this study. First, drivers who are given additional information through a DSS will respond differently when an EV approaches. Second, effect of DSS on performance measures will be different for older and younger drivers. Third, incorporating DSSs may, as an unintended consequence, increase the potential for in-vehicle driver distraction (Becic, et al., 2013); therefore, performance when distracted will be different among drivers with and without the DSSs. Fourth, usability of the DSSs will differ between older and younger drivers.

2. Methods

2.1. Participants

The study was reviewed and approved by the University of Minnesota Institutional Review Board to ensure protection of human subjects. Eighty-five participants, recruited within Saint Paul and Minneapolis, Minnesota through online and print media, were dichotomized into two age groups: older participants ranging from 60 to 73 years of age (21 male, 22 female; M_{age} = 65.8 years; sd = 3.95) and younger participants ranging from 18 to 30 years of age (21 male, 21 female; M_{age} = 24.6 years; sd = 3.59). All participants possessed a valid driver's license, had normal or corrected-to-normal vision (visual acuity minimum of 20/40 and normal color vision), and indicated no history of motion sickness. Participants were compensated US $50 for their participation.

Before enrolling into the study, potential participants were prescreened to identify individuals who were susceptible to motion sickness or had health-related issues that may impact their driving ability or ability to withstand the simulator. Participants completed a consent form, driving history questionnaire, and were tested for color-vision using the Ishihara Test for Color Blindness (Ishihara, 1993). Participants also underwent examination of their visual acuity (minimum 20/40 corrected or uncorrected) using the standard Snellen Visual Acuity eye chart (Silber, et al., 2005). The tests for colorblindness and visual acuity ruled out potential confounding effects of participants' reduced ability in distinguishing flashing red lights or detecting EVs from a distance, respectively. Participants were assigned into one of three experimental groups based on age to ensure no age-related differences existed across groups. Each participant received instructions regarding the driving environment and warning system they would encounter while driving; they received the following instructions from the Minnesota's Department of Public Safety Driver's License Manual – "*When an emergency vehicle, such as an ambulance, fire truck, or police car, displaying flashing red lights and sounding a siren or bell approaches your vehicle on a two-way road, you must pull to the right and stop.*" Providing these instructions removed potential confounding based on participants' knowledge of how to interact appropriately with EVs.

Participants first completed a practice drive to familiarize themselves with the simulator and warning system and then practiced the distraction task. Each participant drove a specified route where they would encounter trials of intersection collision events with EVs. To avoid potential confounding from variations in EVs (e.g., smaller police cars and larger fire trucks may be obscured differently), participants encountered only ambulances. Each participant completed 5 trials for each combination of EV approach direction (left/right) and distraction (present/absent) totaling twenty trials that increased the power of the study. A Latin square design was used to counterbalance the order of distraction and the order in which the driving environments were presented.

2.2. Materials and apparatus

2.2.1. Driving Simulator

The study was conducted using the HumanFIRST Program's portable driving simulator with SimCreator® software (Realtime Technologies, Inc., Royal Oak, MI). The simulator consisted of a driver seat, vehicle controls (pedals, steering, and transmission) and gauges mounted on a portable chassis. The simulator's visual display consisted of three 32-inch high-definition monitors that provided 88 degrees of forward field of view. The use of a driving simulator was advantageous for this *type* of study as it allowed for the testing of the DSSs under highly controllable and safe conditions that could be replicated.

2.2.2. Driving Environment

The simulated driving environment consisted of a typically cluttered urban arterial 7-km road with physical obstructions (e.g., buildings) and intersections every 200 meters.

These parameters were identified previously as high risks that impeded the safe interaction between drivers and EVs (Drucker, et al., 2013); therefore, including such parameters enabled the method in which to best examine the impact of the DSSs. The arterial road consisted of two lanes of traffic heading in each direction with cross traffic having one lane of travel in each direction. Drives lasted approximately 10 minutes and participants were asked to maintain a velocity of 35 mph. The road noise level was set at 75dB which represents a typical noisy urban daytime environment (Ko, Change, Kim, Holt, & Seong, 2011; Tsai, Lin, & Chen, 2009).

2.2.3. Experimental Groups

Experimental Group 1:

The first experimental group consisted of participants presented with traditional L/S and a DSS, entitled Improved Saliency System (ISS) that addressed the issue of saliency. Without the ISS, the EV siren became audible and lights became visible when the participant's time-to-contact (TTC) crossed a threshold of 2.5 and 2.0 seconds, respectively. These parameters represented conservative estimates of the effective distance for L/S discussed by De Lorenzo & Eilers (1991). The sound levels of the siren increased from 75db (when first activated) to 85db (when the EV crossed the path of the participant's vehicle). The 85db value was chosen as the maximum siren sound level because a 10db increase over the road noise level is recommended for auditory warning signals (Sorkin, 1987).

The timing of the activation of the ISS was matched to the L/S of the EVs (i.e., TTC = 2.5s) as this allowed us to determine if differences in participants' responses were due to the ISS and not due to timing differences. The ISS remained activated until the EVs crossed the intersections.

The ISS provided two levels of information -- an ecological auditory icon and a visual cue. The use of an ecological auditory icon served two purposes. First, ecological icons have been shown to engage the attention of drivers more effectively than using an arbitrary sound (Ho & Spence, 2005). Secondly, using an arbitrary alert can potentially confuse drivers if presented in a larger frame consisting of other DSSs, which are expected to be implemented in vehicles on a wider scale in the near future. The auditory warning was presented to participants at a constant sound level of 85db to reflect the recommended increase in sound level for auditory warnings above ambient road noises (Sorkin, 1987) and to effectively eliminate the Doppler Shift.

The siren alone provides insufficient information to orient a driver's gaze and, subsequently, driving maneuvers are often made after the EV is detected visually (Withington, 1999). To address driver issues related to advance warning systems for the detection of EVs (Lenné, et al., 2008), the ISS incorporated spatial cueing. The visual cue displayed a USDOT standard vehicle traffic warning sign W11-8 (see Figure 11). Research has shown spatially predictive cues that direct the attention of drivers in relevant directions were associated with quicker response times than non-spatially predictive cues if given shortly beforehand (Ho & Spence, 2005). If an EV was approaching from the passenger side of the participant's vehicle, the cue would appear on the bottom right of the forward screen and vice-verse for driver side events. Connected-vehicles technology allows drivers to receive information, through other vehicles or the infrastructure within proximity of a potential threat even when the threat appears to be absent from the visual field. Participants with the ISS essentially would receive information as to the direction of an approaching EV even though the EV was not visible for another 500 milliseconds.

Experimental Group 2:

The second experimental group consisted of participants presented with traditional L/S and a DSS, entitled Advanced Notification System (ANS) that addressed the issue of effective distance. The ANS was identical to the ISS except the effective distance of the L/S was increased from 12 meters (De Lorenzo & Eilers, 1991) to approximately 60 meters. This fivefold increase equates to an ANS activation threshold of 4.0 seconds (at 35 mph), essentially providing an additional 1.5 seconds to respond to the threats. The advanced notification is consistent with the capabilities of future connected-vehicles technology that can provide drivers with information from various vehicles and infrastructures within proximity, essentially allowing for an increase in the effective distance of the EV's L/S.

Experimental Group 3:

The third experimental group served as a control in which participants were only presented with the EV's L/S. The control group replicated current real-world driving conditions and enabled examination of the impact of the DSSs. Although the use of a true baseline i.e., no L/S displayed, would also enable determination of the impact of the DSSs, the practicality of this comparison does not reflect real-world driving. It was assumed that EVs not engaged in L/S would not cross an intersection when presented with a stop-light. Since the current study incorporated EVs crossing against traffic lights, all EVs had their L/S engaged.

2.3. Secondary Task

To assess driver performance under distracting conditions, the Adding 1-Back task was included as it exerts a substantial load on the working memory and mimics distracted driving. Participants were presented with two, two-digit numbers, and were instructed to add the ones column from the two-number sequence they heard. For example, if the participant heard "31, 74", they should respond with "5" (1 + 4 = 5). Participants also needed to indicate if the current response was greater or lesser than their previous response. The adding portion of this task has been used previously (Becic, et al., 2013) and the 1-Back portion is a variant of the *n*-Back task (Kirchner, 1958) which has been used as a standard working memory measure in cognitive research (Kane, et al., 2007).

2.4. Performance Measures

Driving performance was assessed through *five* dependent measures: *Safety margin* indicated the participant's distance (m) from the intersections when the EVs entered the intersections. If no action was taken by the participant, this would represent the remaining distance before a collision would have occurred. This measure represents a level of safety as a diminished margin of safety can be associated with an increased risk of a crash. *Response time* was defined as the time (s) between warning system activation and participant's first response (e.g., braking). The purpose of the DSSs was to increase saliency; therefore, this measure determined if improving saliency affects participant behavior. The *85^{th} percentile maximum brake duration* represented the duration (s) in which a participant reached the 85^{th} percentile of their maximum brake pressure. This measure was used as a surrogate in determining response abruptness (e.g., slamming brake pedal) and indicated if presentation of information was interpreted differently between warning system and age groups. *Collisions* represented the number of events in which participants collided with an EV and reflected the overall goal of the DSSs. *Distraction task* was measured as the proportion of correctly answered questions divided by the total number of questions with which a participant was presented across the two drives. A proportion was selected because it allowed for a standardization of results across all participants since the total number of questions that a participant could have received was based on the time they took to complete the drives. Assessing participant responses to a distraction task enabled determination of costs (e.g., increased in-vehicle driver distraction) and benefits (e.g., increased response accuracy) associated with the DSSs.

Usability of the DSSs was assessed through three dependent measures. *Trust* in a system is a well -known factor for system adherence (Abe & Richardson, 2006; Lees & Lee, 2007). If drivers distrust the DSSs, the warnings may be ignored; therefore, the purpose of the system is negated. Trust was obtained through a seven-item questionnaire regarding perceived trust of the DSSs on a five-point Likert scale, ranging from 1 = "Strongly Disagree" to 5 = "Strongly Agree" (Jian, et al., 2000; Wiese, 2007). A trust score was calculated by adding the responses of the seven questions and dividing by "7". *Acceptance* is necessary when introducing novel in-vehicle technology as it impacts system use (Van Der Laan, et al., 1997). Acceptance was determined through a usability scale questionnaire which contained nine questions that make up two dimensions of perceived usefulness and satisfaction of the DDSs (Van Der Lann, et al., 1997). The results from these scales are averaged to obtain a score of perceived usefulness and satisfaction. The scale ranges from -2 to +2, with higher usefulness and satisfaction scores suggesting drivers thought the information presented was useful and enjoyable (Rakauskas, Graving, Manser, & Jenness, 2010). The questionnaire was administered to drivers prior to using the DSSs (after receiving verbal instructions and a visual demonstration of the system) and post study. *Mental workload* was examined since the DSSs may add to the mental workload of the driving task. An increase to the overall mental workload can negatively impact driver performance and perceived usability of the DSSs. Mental workload was assessed through the NASA-TLX questionnaire which provides a subjective estimate of mental workload through the use of six workload-related factors: mental demands; physical demands; temporal demands; own performance; effort; and frustration (Hart & Staveland, 1988). A total mental workload score was achieved by adding the six factors together and dividing by “6”. Collectively, these driving performance and usability measures enabled examination of the hypotheses of the current study.

2.5. Statistical Modeling and Analysis

Driving performance measures were analyzed separately for driver and passenger side events (i.e., when the EV approached from the left and right sides of the participant’s vehicle, respectively) because of potential differences in visual obstructions. Mixed effects models were used to measure differences in the following continuous dependent measures among the three experimental groups: safety margin; response time; 85th percentile maximum brake duration; distraction task; trust; and total mental workload. Random effects were used to account for individual differences in responses to the warning systems alerts. SAS® software, version 9.2 (SAS Institute Inc, 2010) mixed procedure was used to analyze the models. Driving performance measures (excluding distraction task) were submitted to a four-way mixed-model ANOVA with Experimental Group (ISS, ANS, and control), Age (younger, older) and Sex (male, female) as between-subject factors and Distraction (present, absent) as a within-subject factor. The distraction task measure was submitted to a three-way mixed-model ANOVA with Experimental Group, Age, and Sex as between-subject factors. Usability measures were submitted to a three-way mixed-model ANOVA with Experimental Group (excluding control), Age, and Sex as between subject factors. Tukey-Kramer analyses for differences in least-square means were performed for pair-wise comparisons of significant main and interaction effects of three levels or more (Kramer, 1956). T-statistics and associated p-values (critical alpha set at 0.05) are reported for each comparison.

The risk of collision was estimated with odds ratios (OR) using a general linear model and 95% confidence intervals were used to identify the precision of the estimates. The ORs were adjusted for within-person correlation using General Estimating Equations to account for multiple collisions by the same participant. All models were adjusted for Sex, and stratified by Age and Experimental Group.

3. Results

Each experimental group consisted of n = 7 older and younger male and female participants; however, the ANS group consisted of n = 8 older females, totaling a study size of N = 85 participants. Although observed effects differed depending upon sidedness, these findings were not the intent of the study.

3.1. Driving Performance

Overall, among the 1,700 possible intersection events, 1,419 (83.5%) were avoided, 271 (15.9%) resulted in collisions, and 10 (0.6%) were missing due to error. Of the events that were avoided, participants executed a first response driving maneuver of braking (98.7%), accelerating (0.7%), or steering (0.6%). Events that resulted in collisions were excluded from analyses as the frequencies of collision events did not yield large enough samples for analysis within older and younger participants in the ISS (n = 61 and 17, respectively) and ANS (n = 14 and 6, respectively) groups. Performance measures represent mean values observed from events in which participants successfully avoided EVs.

3.1.1. Safety Margin

Passenger Side. The analysis revealed differences in safety margins among participants across all three Experimental Group (Table 6). Post-hoc comparisons for the main effect of Experimental Group revealed participants in the control group were closer to the intersections compared to participants in the ISS and ANS groups (Table 6). Differences were also seen between DSS groups. The same analysis also revealed a significant two-way interaction between Age and Experimental Group ($F(2,77) = 7.35$, p

< 0.05). As Figure 12 illustrates, safety margins increased when additional information beyond the EV's L/S was provided; however, older participants' safety margins were greater in the ANS group compared to younger participants. Expected decreases in safety margins were found when participants were distracted compared to not being distracted (Table 6). Safety margins were not influenced by Sex (Table 6).

Driver Side. Similar to passenger side events, differences were seen in safety margins by Experimental Group (Table 6). The analysis also revealed a significant two-way interaction between Age and Experimental Group ($F(2,76) = 5.24$, $p < 0.05$). Older participants were further away from the intersections compared to younger participants in the ANS group; however, there were no differences between older and younger participants within the ISS ($p = 0.22$) and control ($p = 0.16$) groups. The same effect of distraction was seen among driver side events with participants closer to the intersection when engaged in the distraction task (Table 6). Sex did not influence safety margins (Table 6).

3.1.2. Response Time

The response time analysis represented braking maneuvers as the percentage of steering and accelerating responses did not yield adequate samples for analysis.

Passenger Side. Differences were found between experimental groups for response times (Table 6). Post-hoc comparisons showed response times were faster among the ISS and ANS groups compared to the control group (Table 6). Older participants responded more slowly compared to younger participants (Table 6). An interaction in response time was seen (see Figure 13) between Age and Experimental

Group ($F(2,72) = 3.68$, $p < 0.05$). In general, participants responded more quickly when presented with the DSSs; however, a difference between DSSs was seen (see Figure 13) among younger participants ($t = -3.15$, $df = 72$, $p < 0.05$). Response times among older participants were not affected by the type of DSS ($p = 0.51$). In general, participants when distracted responded slower compared to when not distracted (Table 6). Response times across males and females were not different (Table 6).

Driver Side. The analysis revealed significant differences by experimental group; again indicating participants presented with only L/S responded more than twice as slow compared to participants in the ISS and ANS groups (Table 6). Similar to passenger side events older participants, compared to younger participants, responded more slowly (Table 6). The analysis also revealed a significant effect of the distraction task, again showing participants responded slower when distracted versus not distracted (Table 6).

3.1.3. 85th Percentile Maximum Brake Duration

Passenger Side. The analysis identified differences in response abruptness among participants in the three experimental groups. Participants in the ANS group engaged the brake pedal more gradually when reaching the 85th percentile of maximum brake pressure compared to participants in the ISS and control groups (Table 6). In general, older participants braked more abruptly compared to younger participants (Table 6). The analysis also revealed a significant two-way interaction between Age and Experimental Group (F(2,72= 8.27, $p < 0.05$). As shown in Figure 14, older participants in the ANS group responded more quickly compared to younger participants in the same group (t = -6.13, $df = 72$, $p < 0.05$); however, there was no difference between the ISS and control groups within and across younger and older participants. Younger participants in the ANS group reached the 85th percentile a full second slower compared to younger participants in the ISS ($t = -8.39$, $df = 72$, $p < 0.05$) and control ($t = -8.65$, $df = 72$, $p < 0.05$) groups (Figure 14). Similarly, older participants in the ANS group reached the 85th percentile approximately 400 milliseconds slower compared to participants in the ISS ($t = -3.53$, $df = 72$, $p < 0.05$) and control ($t = -3.75$, $df = 72$, $p < 0.05$) groups (Figure 14). Sex and Distraction did not influence response abruptness (Table 6).

Driver Side. Similar effects were seen with experimental group and age differences as with passenger side events. A significant interaction of Age and Experimental Group ($F(2,71) = 7.84$, $p < 0.05$) revealed older, compared to younger participants, in the ANS group responded more abruptly ($t = -5.82$, $df = 71$, $p < 0.05$); however, no differences between the ISS and control groups within and across younger and older participants was seen. Brake response was found to be different across males and females with female participants responding more gradually compared to male participants (Table 6). Distraction did not influence braking abruptness (Table 6).

3.1.4. Collisions

Passenger Side. Participants were involved in 102 (12.1%) collisions out of 844 possible intersection events (Table 7). Among collision events, participants failed to respond with a driving maneuver (n = 16, 15.7%), or execute sufficient braking (n = 68, 66.7%), steering (n = 8, 7.8%), or combinations (n = 10, 9.8%) of maneuvers. There were differences in risks of crashes, based on experimental group stratified by age. Table 7 shows older participants in the ANS group were less likely to be involved in collisions with EVs compared to older participants in the control group. There was no difference between older participants in the ISS and control groups ($p = 0.59$). Older participants in the ANS group, compared to the ISS group, were less likely (OR = 0.1) to be involved in collisions with EVs. Compared to the control group, younger participants were less likely to be in collisions with EVs when driving with a DSS (Table 7). There was no difference between DSS groups among younger participants.

Driver Side. Participants were involved in 169 (19.9%) out of 846 possible collision events (Table 7). Collisions resulted from participants failing to respond with a driving maneuver (n = 48, 28.4%), or executing insufficient braking (n =77, 45.6%), steering (n =19, 11.2%), or combinations (n = 25, 14.8%) of driving maneuvers. Similar to passenger side events (Table 7), older and younger participants were less likely to be involved in collisions with EVs in the ANS group compared to the control group. Older participants (OR = 0.2) were less likely to be in collisions in the ANS compared to the ISS group. Additionally, younger participants in the ISS group were at decreased risk of collisions with EVs compared to younger participants in the control group. There was no difference between DSSs among younger participants.

3.1.5. Distraction Task Performance

The analysis revealed a significant main effect of Age ($F(1,70) = 20.18$, $p < 0.05$) showing an expected age-related reduction in accuracy among older ($M = 76.7\%$) compared to younger ($M = 90.1\%$) participants. The impact of the DSSs was positive for both older and younger participants, indicated by increased proportions of correct responses (see Figure 15); however, these findings were not significant (p = 0.85 and 0.09, respectively).

3.2. Usability Performance

3.2.1. Trust

The degree of perceived trust in the DSSs was not different across Experimental Groups (p = 0.80); however, Age was found to be influential ($F(1, 50) = 6.14$, $p < 0.05$). Overall, older drivers (M = 4.1) reported higher perceived trust in the DSSs compared to younger drivers (M = 3.8). Sex was not an influential factor regarding trust (p = 0.39).

3.2.2. Acceptance

In general, older and younger drivers perceived the DSSs to be somewhat useful and satisfying, indicated by mean scores marked in the top right quadrant of Figure 16. Older drivers reported increased satisfaction while younger drivers reported decreased satisfaction and increased usefulness of the DSSs post study; however, these differences were not statistically significant (p = 0.52, 0.22, and 1.00, respectively).

3.2.3. Mental Workload

There was no difference in perceived total mental workload between Experimental Groups when distractions were absent (p = 0.61); however, a main effect of Age ($F(1,70) = 8.95$, $p < 0.05$) was found indicating older drivers (M = 8.7) perceived increased total mental workload compared to younger drivers (M = 6.3).

When distracted, younger drivers in the DSS groups reported lower total mental workload scores (M = 11.7 and 11.1 for the ISS and ANS groups, respectively) compared to the control group (M = 12.9); however, these differences were not significant (p =

0.38). This same effect was seen in older drivers with those in the DSS groups reporting lower total mental workload scores compared to the control group when distracted; however, the effect also was not significant ($p = 0.94$).

4. Discussion

The current study examined the impact of two DSSs on various driving performance and usability measures across age groups and distraction. Unsafe interactions between non-EV and EV drivers are, in part, due to urbanized intersections where EVs may be occluded from a driver's line of sight (Drucker, et al., 2013) and where L/S has been found to be ineffective in alerting drivers (De Lorenzo & Eilers, 1991; Withington, 1999). Consequences consist of collisions that may occur as a result of inadequate safe distances between non-EV drivers and EVs or insufficient time to respond. Examination of the current results suggests the DSSs improved safe interactions compared to participants who received only traditional L/S. This finding is represented by variations in participant responses and may be explained, at least partially, by the differences in types of information presented.

4.1. ISS

The main finding of this study is that older and younger participants increased their safety margins 1.9 and 2.5 times, respectively, when in the ISS group compared to the control group. Several measures help to explain the observed difference. First, the increases in safety margins are important because they directly impact safe interactions and the risk for collisions with EVs. Younger and older participants were involved in fewer collisions with EVs in the ISS group. Second, the increased safety margins were not a function of participants' braking response. Compared to gradual braking, braking abruptly would decelerate a vehicle more quickly and would have accounted, in part, for the increased safety margins; however, there was no difference in braking responses among older and younger participants between groups. Third, it is well known that distracted driving negatively impacts reaction time; however, the presence of the ISS did not increase in-vehicle distraction as the distracting task performance was similar between groups.

The difference in safety margins between the ISS and control groups is likely due to participants' response times to the information presented. Older and younger participants' responded 33 and 45 percent faster, respectively, in the ISS group compared to the control group. Since activation of the warning systems was identical, the differences in response times were assumed to be attributed to the differences in information presented and not through some unmeasured factor. Participants in the ISS group may have responded more quickly since the auditory icon was initiated more loudly (10db above simulated road noises) compared to the control group where the EV siren was initiated at the same sound level as the road noise (Lee, Hoffman, & Hayes, 2004). The time lost from the siren having to increase sound in the control group may have contributed to the decreased safety margins. This effect is similar to having the siren penetrate sound proofing technology or overcome internal and external noises in order to alert drivers.

4.2. ANS

Increased safety margins among older and younger participants in the ANS group, compared to the control group, were expected. Previous research has shown positive findings when drivers were given additional time to react to EVs when presented with an advanced warning system (Lenné, et al., 2008). However, a finding worth examining among the ANS group was the differences in safety margins between older and younger participants. It is well known that older drivers tend to respond more slowly compared to younger drivers when an alert is given (A. F. Kramer, Larish, & Strayer, 1995); however, participants' response times within the ANS group were not different. In general, there was no evidence of increased in-vehicle distraction resulting from the presence of the ANS; however, younger participants did perform with increased accuracy compared to older participants in the ANS group. Though we can interpret this as older participants experiencing a greater effect of the distracting task, it was demonstrated that older and younger participants' response times were not different. Therefore, the decreased accuracy may be a function of cognitive abilities and may not have contributed to the differences in safety margins.

It is believed that the difference in safety margins between older and younger participants in the ANS group was attributed to the degree to which participants engaged their brake pedal. Older participants reached the 85^{th} percentile of maximum brake pressure approximately 0.4 seconds later than the control; however, with an overall time of 0.6 seconds, this was considered a fairly abrupt style of braking. Younger participants, compared with the control group, reached the 85^{th} percentile of maximum brake pressure approximately 1.0 second later, with an overall time of 1.3 seconds. This suggests the type of advanced warnings presented may be perceived differently across participants, thus, resulting in variations in participant behavior. It is possible that older participants did not differentiate the auditory cues or did not understand the intent of the advanced warning; therefore, upon activation of the ANS, they braked more abruptly compared to younger participants but less urgently compared to older participants in the other groups. Additionally, older participants may have been more likely to brake more firmly to stop at the intersections and yield the right-of-way compared to younger participants (Caird, Chisholm, & Lockhart, 2008). The implication of this finding questions the method in which advanced information regarding approaching EVs should be presented. Connected-vehicles technologies alert drivers to potential threats; however, if the study's results were to be extrapolated, a major consequence could arise. For example, if older drivers with connected-vehicle technology are alerted to approaching EVs, they may brake abruptly which could be unexpected to drivers following and unaware of the approaching EVs. Thus, while collisions with EVs may decrease, wake-effect collisions could potentially increase.

4.3. ISS versus ANS

Participants were given an additional 1.5 seconds in the ANS group compared to the ISS group that simulated an application of connected-vehicle technology. Examination of the current study results suggests potential benefits for such an application in alerting drivers to approaching EVs to improve roadway safety. The first main finding, comparing the two DSSs, was that increasing the effective distance of the warning 60 percent (from 2.5 to 4.0 seconds) decreased the risks for collisions up to ten times among older participants. This has multiple implications to roadway safety as occupants within non-EV vehicles are more likely to be fatally wounded as a consequence of collisions with EVs (Sanddal, et al., 2010). Additionally, older participants are more likely to be involved in collisions with multiple vehicles at intersections (Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998) and have the highest death rates per collisions (Li, Braver, & Chen, 2003).

The second main finding was the difference in behaviors between older and younger participants after the DSSs were initiated. Although participants' response times and levels of distraction were similar across DSS groups, older and younger participants' style of braking was different between groups. The differences in braking are believed to be attributed to the differences in warning activation, whereby the ISS group was presented with the information in a more urgent situation, thus, warranting a more abrupt style of braking.

4.4. Usability

Trust scores were moderate and did not differ between DSS groups; however, older drivers' perceived trust was greater than younger drivers. This finding is important because, through trust, adherence between drivers and technology can be established (Lees & Lee, 2007), and trust among older drivers generally requires more time to develop (Shinar, Dewar, Summala, & Zakowska, 2003). As a result, it would appear that driving responses were not a function of distrust in the DSSs. If drivers indicated distrust, this could have led to drivers not using the DSSs, which would essentially replicate the control group and all potential benefits could be negated.

In general, older and younger drivers perceived the DSSs to be useful and satisfying. Though the lower satisfying scores may be a result of the auditory icon and visual cue used in this study, the higher scores of usefulness provides insight that a DSS may be beneficial to drivers in alerting them to approaching EVs.

Total mental workload scores under non-distracting conditions were similar across experimental groups, indicating that the DSSs did not change perceived workload of the driving task. However, under distracting conditions, older and younger drivers in the DSS groups reported lower total mental workload scores, indicating a positive effect of the DSSs, albeit the effect was not significant. The implication of this finding is that if the DSSs increased the mental workload of the task, drivers may select to ignore the DSSs and therefore, any potential benefit would be removed.

4.5. Limitations

The results of this study should be interpreted with the following limitations in mind. The allocation of participants into warning systems groups was not random. As a result, there may have been underlying systematic differences among participants between groups. To the extent possible, the potential effects of these differences were adjusted in the statistical models by obtaining driving-related information and examining if differences existed across groups. Analysis of self-reported factors of driving experience, frequency of driving, miles driven in the previous year, education attainment, traffic violations and minor/major crashes in the previous three years found no differences across experimental groups.

The study utilized visual cues with the intent of directing the gaze of the participant in the direction from which the EVs were approaching. However, the study did not incorporate eye tracking software or facial capturing equipment; therefore, the contributions of the visual cue could not be quantified by this study.

The method of recruiting participants may have introduced bias (in the form of limited generalizability) into the study. The original method for study recruitment was through the Minnesota's Driver's License Database; however, access to the database was not granted due to recent federal access changes. As a result, older and younger participants were recruited through online and print advertisements. Participants who were recruited through this approach may be different than drivers who do not view these types of advertisements and, subsequently, may not have enrolled in the study.

5. Conclusions

The current study examined the impact of two DSSs on driving performance and usability measures when encountering EVs at urban intersections among older and younger participants under distracting and non-distracting conditions. Participants with a DSS demonstrated increased safety margins and responded more quickly to the warning systems than participants with only traditional L/S. Presence of the DSSs did not increase in-vehicle driver distraction and it decreased the risks for collisions with EVs. Drivers indicated a moderate level of trust and reported the DSSs to be somewhat useful and satisfying. Reported mental workload scores were lower for drivers in the DSS groups compared to the control.

This study demonstrated the potential importance of connected-vehicle technology as a method to improve safe interactions between non-EV and EV drivers. The purpose of motor vehicle safety research is to mitigate roadway collisions and eliminate consequences such as injuries and fatalities. With advancements in in-vehicle technologies, there is an opportunity to reduce the more than 368,000 fatal and nonfatal crashes involving EVs. Roadway-based technologies, such as EV preemption systems, have been shown to reduce these types of collisions; however, they have been instituted only at signalized intersections (Nelson & Bullock, 2000) and, therefore, are unable to capture all areas in which drivers are at increased risk for collisions with EVs.

Future research must continue to examine the effect of technology and connected-vehicle systems as a way to reduce crashes involving EVs. One particular area requiring further understanding is driver behaviors, particularly behaviors of older drivers as demonstrated by this study. Finally, research should consider other types of collisions, such as head-on collisions, as drivers have been identified with increased risks for collisions with EVs in this manner compared to collisions with non-EVs (Drucker, et al., 2013).

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Tables

Table 6: Least square means, F- and t-test statistics with associated p-values for the performance measures safety margin, response time, and 85th percentile maximum brake by passenger side and driver side events

Independent Variable	LS Means*	Statistic (df)	Value	P-value	LS Means*	Statistic (df)	Value	P-value
		Passenger Side				**Driver Side**		
				Safety Margin				
Experimental Group		F(2,72)	280.04	<0.001		F(2,71)	379.85	<0.001
Control	5.52m				4.58m			
ISS	11.65m				11.54m			
ANS	28.65m				29.67m			
ISS vs. Control†		t(72)	-6.11	<0.001		t(71)	-7.16	<0.001
ANS vs. Control†		t(72)	-23.38	<0.001		t(71)	-26.37	<0.001
ANS vs. ISS†		t(72)	-17.36	<0.001		t(71)	-19.40	<0.001
Age		F(1,72)	3.62	0.061		F(1,71)	0.02	0.897
Younger	16.07m				15.32m			
Older	14.47m				15.21m			
Distraction		F(1,67)	9.86	0.003		F(1,66)	10.52	0.002
Absent	15.81m				15.75m			
Present	14.74m				14.78m			
Sex		F(1,72)	0.57	0.453		F(1,71)	1.40	0.240
Female	14.96m				14.80m			
Male	15.59m				15.73m			
				Response Time				

Independent Variable	LS Means*	Statistic (df)	Value	P-value	LS Means*	Statistic (df)	Value	P-value
		Passenger Side				**Driver Side**		
Experimental Group		F(2,72)	86.39	<0.001		F(2,71)	22.74	<0.001
Control	1.15s				1.46s			
ISS	0.69s				0.67s			
ANS	0.75s				0.74s			
ISS vs. Control†		t(72)	12.14	<0.001		t(71)	6.05	<0.001
ANS vs. Control†		t(72)	10.69	<0.001		t(71)	5.67	<0.001
ANS vs. ISS†		t(72)	-1.75	0.084		t(71)	-0.50	0.62
Age		t(72)	12.14	<0.001		t(71)	6.05	<0.001
Younger	0.83s				0.85s			
Older	0.89s				1.07s			
Distraction		F(1,66)	47.43	<0.001		F(1,64)	24.43	<0.001
Absent	0.81s				0.92s			
Present	0.91s				1.00s			
Sex		F(1,72)	0.34	0.563		F(1,71)	0.92	0.341
Female	0.87s				0.91s			
Male	0.85s				1.01s			
			85th Percentile Maximum Brake Duration					
Experimental Group		F(2,67)	51.09	<0.001		F(2,66)	37.83	<0.001
Control	0.20s				0.23s			
ISS	0.25s				0.27s			
ANS	0.94s				0.88s			

Independent Variable	LS Means*	Statistic (df)	Value	P-value	LS Means*	Statistic (df)	Value	P-value
		Passenger Side				**Driver Side**		
ISS vs. Control†		t(67)	-0.52	0.603		t(66)	-0.38	0.706
ANS vs. Control†		t(67)	-8.74	<0.001		t(66)	-7.27	<0.001
ANS vs. ISS†		t(67)	-8.46	<0.001		t(66)	-7.44	<0.001
Age		F(1,67)	18.27	<0.001		F(1,66)	13.94	<0.001
Younger	0.61s				0.59s			
Older	0.32s				0.33s			
Distraction		F(1,60)	0.06	0.811		F(1,58)	1.27	0.265
Absent	0.47s				0.48s			
Present	0.46s				0.45s			
Sex		F(1,67)	2.59	0.112		F(1,66)	5.48	0.022
Female	0.52s				0.54s			
Male	0.41s				0.38s			

Post hoc comparisons are shown for variables with three levels only
*, Least-square Means
†, Post-hoc comparison (Tukey-Kramer test)

Table 7: Unadjusted and adjusted odds ratios (OR) and 95% confidence intervals (CI) for collision events

Collisions Events	**Collisions**	**%**	**Total Events**	**Odds Ratio**	**95% CI**
Unadjusted					
Experimental Group					
Control	173	31.2	555	-	-
ISS†	78	14.1	555	0.4	0.2-0.8
ANS‡	20	3.5	580	0.1	0.0-0.2
Age					
Younger*	112	18.5	830	-	-
Older**	159	13.5	860	1.4	0.7-2.9
Sidedness					
Passenger Side	102	12.1	742	-	-
Driver Side	169	19.9	677	1.8	1.5-2.3
Passenger Side – Adjusted					
AGE [a]					
Younger	45	10.9	414	-	-
Older	57	13.3	430	1.2	0.5-2.9
Experimental Group (Older)[b]					
Control	31	22.1	140	-	-
ISS†	23	16.4	140	0.7	0.2-2.6
ANS‡	3	2.0	150	0.1	0.0-0.2
Experimental Group (Younger)[b]					
Control	37	27.0	137	-	-
ISS†	6	4.4	137	0.1	0.0-0.6
ANS‡	2	1.4	140	0.04	0.0-0.2
Driver Side – Adjusted					
Age [a]					
Younger	67	16.1	416	-	-
Older	102	23.7	430	1.6	0.8-3.1
Experimental Group (Older)[b]					
Control	53	37.9	140	-	-
ISS†	38	27.1	140	0.6	0.3-1.5
ANS‡	11	7.3	150	0.1	0.1-0.3
Experimental Group (Younger)[b]					
Control	52	37.7	138	-	-
ISS†	11	7.9	138	0.1	0.0-0.4
ANS‡	4	2.9	140	0.04	0.0-0.2

†, Increased Saliency System
‡, Advanced Notification System
a, Adjusted for sex
b, Adjusted for age and sex

Figures

Figure 11: USDOT standard vehicle traffic warning sign W11-8

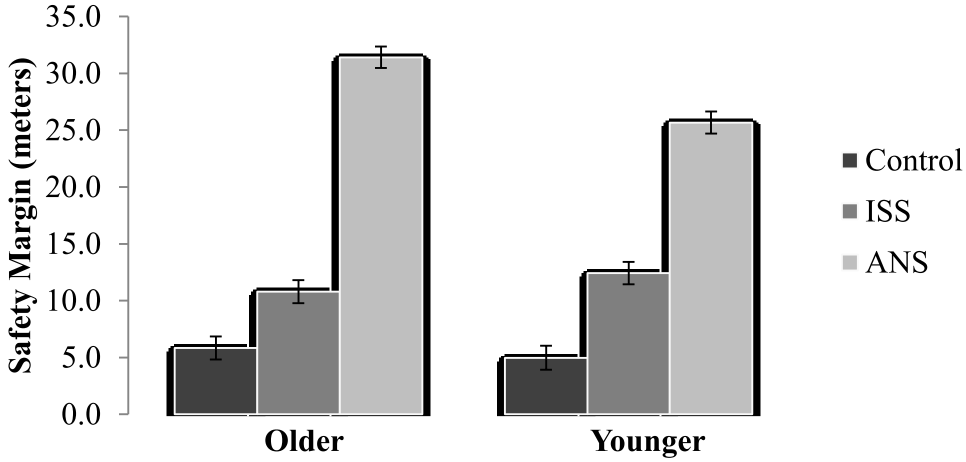

Figure 12: Safety Margin as a function of Age and Group with least square means and standard error bars for passenger side events

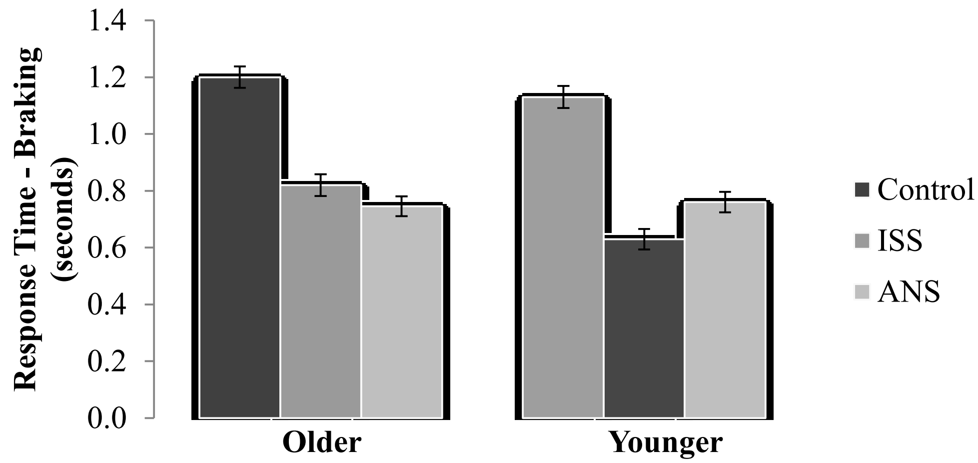

Figure 13: Response time as a function of Age and Group with least square means and standard error bars for passenger side events

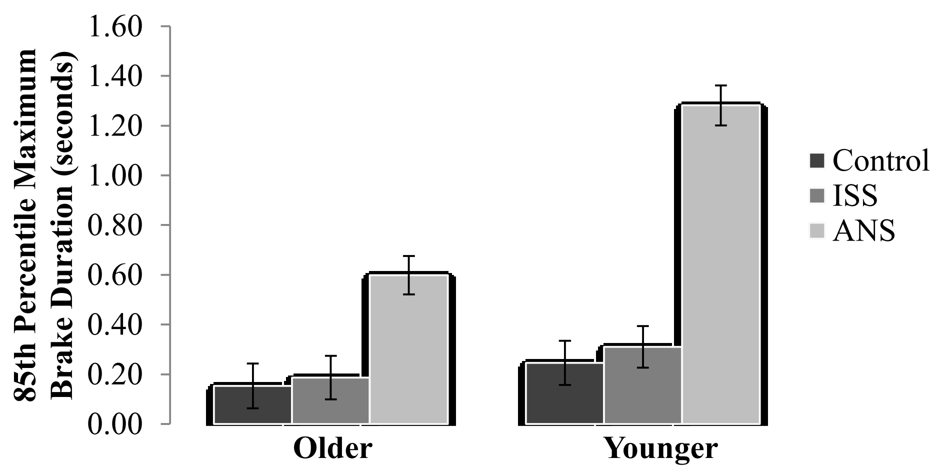

Figure 14: 85th percentile maximum brake as a function of Age and Group with least square means and standard error bars for passenger side events

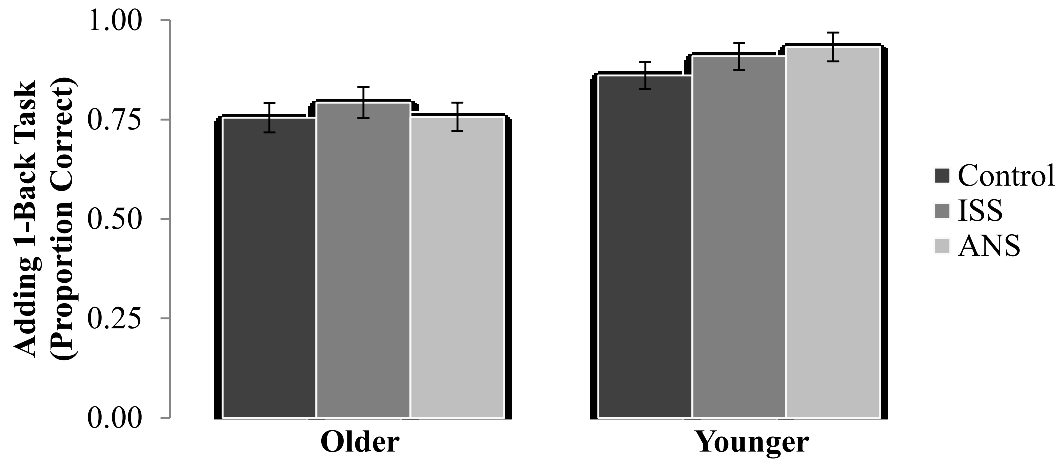

Figure 15: Percent correct for responses to the Adding 1-Back Task as a function of Age and Group with least square means and standard error bars

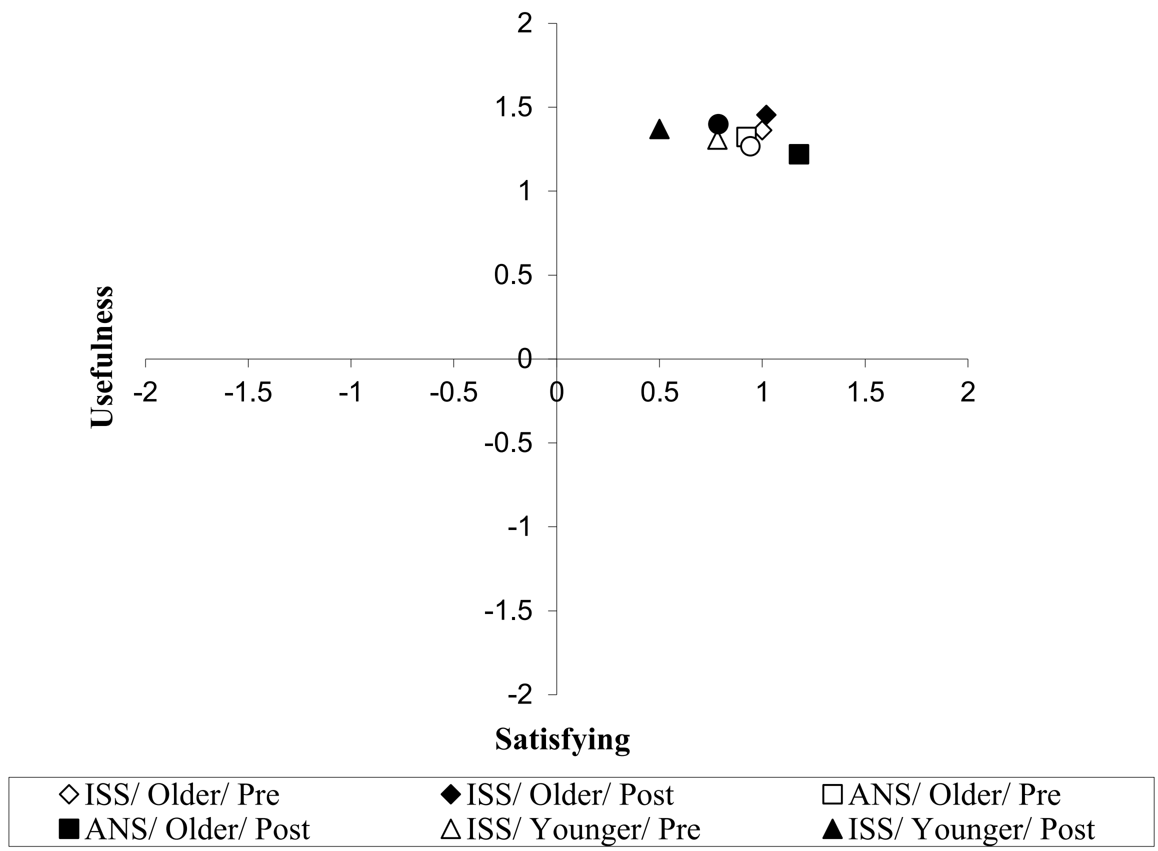

Figure 16: Pre and post usefulness and satisfaction mean scores for younger and older drivers within the ISS and ANS groups

Chapter VI: General Discussion

This two-phase study was unique and among the first to incorporate epidemiological principles to examine factors that were likely associated with non-emergency vehicle (EV) drivers involved in fatal and nonfatal crashes with EVs. Further, it enabled use of the information identified in phase one to assist in the phase two development and subsequent testing, through simulation, of two in-vehicle driver support systems (DSSs) with a goal to mitigate motor vehicle crashes (MVCs) between non-EV and EV drivers. Most studies have focused on factors associated with EV drivers (Kahn, et al., 2001) and their health-related outcomes (Becker, et al, 2003) as a result of the high transportation fatality rate among emergency medical service personnel (Maguire, et al., 2002; Slattery & Silver, 2009); however, characteristics associated with non-EV drivers had not been examined adequately to this time. Thus, it was imperative to understand the various factors of these crashes since non-EV drivers and their occupants are more likely to be fatally wounded when involved in collisions with EVs (Sanddal, et al., 2010). In addition, studies of in-vehicle DSSs traditionally do not emphasize the theoretical components that comprise the design and testing of these support systems.

As presented in earlier chapters, this research effort is important because MVCs are the leading cause of unintentional injury deaths across all age groups, and are the leading cause of unintentional injury death among persons one through 34 and 55 through 64 years of age (CDC, 2013) in the United States. Motor vehicle crash types are predominantly caused by drivers colliding into other motor vehicles and, as a result, the majority of studies have focused on multivehicle crashes; however, the interaction between two non-EVs is inherently different compared to a collisions involving EVs. In-use and in-transport EVs often drive in excess of posted speed limits and typically involve risky driving behaviors which, in general, increases the risk of crashes (Petzäll, et al., 2011; Becker, et al., 2003; Kahn, et al., 2001). Additionally, the use of lights and sirens (L/S) as a method to alert other roadway users has been demonstrated to be ineffective in providing essential time-dependent safety-related information (De Lorenzo & Eilers, 1991; Withington, 1999).

Phase 1

Non-EV drivers' failure to notice EVs has been previously identified as a primary factor for MVCs with EVs (Clarke, et al., 2009); however, this description is rather broad. Phase 1 enabled investigation of driver, roadway, environmental, and crash factors that contributed to the broad concept of failing to notice EVs. Identification of consequences also provided insight into understanding the difficulties of detecting approaching EVs.

Driver Factors. Failure to notice EVs may have resulted from non-EV drivers being distracted. Non-EV drivers were two-times more likely to have been distracted prior to nonfatal collisions with EVs compared to collisions with non-EVs. The extent of distracted driving and its influence on driving has been documented previously (Strayer, et al., 2006; McCarley, et al., 2004).

Roadway Factors. Drivers were at increased odds of MVCs involving EVs when: 1) their vision was obscured by external objects (e.g., buildings, parked vehicles); 2) at intersections of four points or more and; 3) on urban roads. Failure to notice EVs was probable if the EVs were not in the line of sight of the driver or if there were obstacles to overcome visually. Intersections typically require drivers to scan for relevant objects (e.g., traffic signals) in an attempt to decipher how those objects impact their ability to cross a junction safely. However, as the number of distractors (e.g., pedestrians, traffic routes) increases, visually searching for a specific target among the clutter becomes more difficult (Verghese & McKee, 2004). Urban roads present more visual clutter (e.g., pedal cyclist, pedestrians, traffic congestion) compared to rural roads, which can mask impending critical events (Underwood, 2007). Consequently, visually detecting EVs may become more difficult on urban roads.

Environmental Factors. It is known that a driver's visual performance declines in reduced lighting conditions (Plainis, et al., 2005) which may explain the increased risk of nonfatal collisions occurring at night (between 9pm and 5am). This finding is among the first to identify time of day as a potential risk factor for MVCs involving non-EV and EV drivers.

Crash Factors. Failure to notice may have resulted from drivers having inadequate time to detect approaching EVs. Drivers were at increased risk when the EVs approached from different directions (e.g., head-on, perpendicular) in which the non-EV drivers were heading. The available time to detect an EV decreases when the vehicles are moving toward each other compared to moving in the same direction.

Consequences. Non-EV drivers received violations for failing to yield the right-of-way which suggested that drivers were unable to visually detect oncoming EVs and, as a result, executed inappropriate driving maneuvers that may have contributed to the crashes.

Phase 1 enabled expansion on a widely accepted concept – that of non-EV drivers failing to notice EVs – and to ascertain how specific endogenous (e.g., internal distractions) and exogenous (e.g., roadway locations) factors contributed to this overarching failure in recognition. The factors identified were used in Phase 2 to develop and test two in-vehicle DSSs with a goal to mitigate MVCs involving non-EV drivers and EVs.

Strengths and Limitations

Phase 1 was not without limitations. EVs operating L/S have been associated with increased risk for crashes (Custalow & Gravitz, 2004); however, the FARS and NASS-GES datasets only indicate if the EV was in-use, that is, on an emergency call. It is not known whether or not EVs' had their L/S activated prior to the crashes. For study purposes, the assumption was made that an EV on an emergency call consisted of using L/S.

Factors observed within the NASS-GES and FARS datasets may have been limited by the amount of data that were collected and, as a result, the observed outcome may have been affected. Finally, as described previously, the analyzed data included only crash events; therefore it is not possible to directly estimate risk for any given factor.

Despite the limitations of Phase 1, the current study findings contributed to a gap of knowledge involving non-EV drivers; by using a comparison group of crashes involving non-EVs, potential patterns of risk associated with non-EV drivers involved in MVCs with EVs have been identified.

Study Validity

Information Bias

Information bias can result from errors in measuring exposure or outcome data in varying degrees of quality between comparison groups. The FARS dataset is inherently limited in its ability to identify driver factors (e.g., distraction) if the person fatally injured in the MVC is the driver; therefore, it is suspected that there was some level of measurement error in the reporting of exposure data. To ensure the accuracy of the data, "FARS Analysts" are trained state employees responsible for the gathering, translating, and transmitting of their state's data to the National Center for Statistics and Analysis in a standard format. Data are obtained from various states' documents including police accident reports, death certificates, state vehicle registration files, coroner/medical examiner reports, vital statistics, and other state records.

Sampling Bias

Sampling bias is an error due to systematic differences between those observations included and those not included in a study. Inclusion into the NASS-GES database is through probability sampling of police-reported crashes. Therefore, if a driver is involved in a crash that does not involve a police report, that crash event will not be sampled. Although it is assumed that MVCs involving EVs would potentially be captured, MVCs of a lesser extent not involving EVs may go unreported. As a result, the comparison group may not represent an appropriate probability sample of all non-EV-related MVCs. By restricting attention to police-reported crashes, the NASS-GES database represents crashes of increased severity and/or property damage. The FARS database includes crashes where at least one person was killed (vehicle occupant or non-vehicle occupant) within 30 days of the fatal crash. This cutoff does not allow for inclusion of crashes in which a person died more than 30 days after the crash; as a result, the magnitude of these types of MVCs is underestimated.

Confounding

The association for a specific causal contrast is confounded if there is imperfect substitution of the counterfactual (Maldonado & Greenland, 2002) or, in other words, the two comparison groups differ beyond the exposure of interest. A factor is traditionally considered a confounder if it possesses the following properties: 1) a risk factor for the outcome; 2) associated with the exposure of interest in the source population; and 3) not an intermediate step in the causal pathway between the exposure and outcome (Rothman, Greenland, & Lash, 2008). Confounding is similar to bias as it distorts the relation between the exposure and outcome.

For Phase 1, individual DAGS were generated for each hypothesized exposure-outcome association. Multivariate logistic regression models included variables beyond the exposure and outcome of interest as these variables represented a minimum sufficient set of confounders required to block all "backdoor pathways" between the exposure and outcome association (Gerberich, et. al, 2004). It is possible for uncontrolled confounders to affect the estimate; however, selection of confounders was limited to the variables that were assessed in the FARS and NASS-GES datasets.

Phase 2

Failure to recognize approaching EVs by non-EV drivers has been identified as a potentially causal factor that leads to MVCs (Clarke, et al., 2009) and was supported by the efforts of Phase 1. As presented in earlier chapters, DSSs have been utilized as a means to enhance driver abilities under various conditions and situations to detect imminent threats. The purpose of Phase 2 was to design and test (based on driving performance and usability measures) the efficacy of two in-vehicle DSSs that provided concurrent and advanced alerts of approaching EVs to drivers under distracting and non-distracting conditions. The factors identified in Phase 1 were used to facilitate this effort.

Driving Performance. Phase 2 indicated improved driver responses and roadway safety among drivers presented with a DSS compared to drivers presented with only traditional L/S. In general, drivers were at decreased risk of collisions with EVs when given a DSS; however, differences in driving performance existed across age and experimental groups. The main finding of the ISS group was that older and younger drivers increased their safety margins 1.9 and 2.5 times, respectively, compared to the control group. The increases in safety margins are important because they directly impact safe interactions with EVs. It is believed that the difference in safety margins between the ISS and control groups was attributed to drivers' response times as a result of the information presented and not a function of brake response duration or distraction (braking response duration and distraction were not different between the ISS and control groups). Older and younger drivers' responded 33 and 45 percent faster, respectively, in the ISS group compared to the control group. Since activation of the warning systems was identical, the differences in response times were assumed to be attributed to the differences in information presented and not through some unmeasured factor. Drivers in the ISS group may have responded more quickly since the auditory icon was initiated more loudly (10db above simulated road noises) compared to the control group where the EV siren was initiated at the same sound level as the road noise (Lee, et al., 2004)

It was expected that drivers, overall, would increase their safety margins compared to the control group (Lenné, et al., 2008); however, the main finding of the ANS group was the differences in safety margins between older and younger drivers. It is believed that the difference was attributed to the degree to which drivers engaged their brake pedal (85^{th} percentile maximum brake duration) and not due to response time or distraction (response time and distraction were not different between older and younger drivers within the ANS group). Younger drivers braked more slowly compared to older drivers once an alert was given. This is an interesting finding suggesting the type of advanced warnings presented may be perceived differently across drivers, thus, resulting in variations in driver behavior.

Usability. Overall usability of the DSSs was favorable. Trust scores were moderate and did not differ between DSSs; however, older drivers' perceived trust was greater than younger drivers. This finding is important because through trust, adherence between drivers and technology can be established (Lees & Lee, 2007). In general, older and younger drivers perceived the DSSs to be useful and satisfying. Though the lower satisfying scores may be a result of the auditory icon and visual cue used in this study, the higher scores of usefulness provide insight that a DSS may be beneficial to drivers in alerting them to approaching EVs. Total mental workload scores under non-distracting conditions were similar across experimental groups, indicating that the DSSs did not change perceived workload of the driving task. However, under distracting conditions, older and younger drivers in the DSS groups reported lower total mental workload scores, indicating a positive effect of the DSSs, albeit the effect was not important.

Strengths and Limitations

This study supported previous findings and generated new and important insights into the use of technology as a method to overcome ineffective L/S; however, the study is not without limitations. The allocation of drivers into warning systems groups was not random. As a result, there may have been underlying differences among drivers between groups that were not accounted for and may have confounded the results. This limitation was addressed by obtaining driving-related information and examining if differences existed across groups.

The study utilized visual cues with the intent of directing the gaze of the driver towards the direction from which the EVs were approaching; however, the contributions of the visual cue could not be quantified by this study.

Study Validity

Information Bias

As a result of Phase 2 being an experiment and not an observational study, it is assumed that there was no information bias among the exposures (experimental groups) and outcomes (performance and usability measures) of interest. It is important to note that all participants received information regarding the study's purpose of assessing an in-vehicle DSS; however, a third of the participants were selected as controls and thus, did not receive the DSS. This may have introduced bias as the participants' expectations were not met; therefore potentially influencing driver behavior.

Sampling Bias

The method of recruiting participants may have introduced bias into the study. The original method for study recruitment was through the Minnesota's Driver's License Database; however, access to the database was not granted due to recent federal access changes. As a result, older and younger drivers were recruited through online and print advertisements. Drivers recruited through this type of approach may be different than drivers who do not view these types of advertisements, thus, resulting in bias.

Interviewer Bias

Interviewer bias is a systematic error resulting from an interviewer's subconscious or conscious collection of data or influencing of responses by participants. To address this potential error, in part, Phase 2 utilized one interviewer for all subjects and a script to read to ensure information was disseminated the same across all subjects. In addition, interviewer was not blinded to participant exposure status i.e., the interview knew the DSS group each participant was allocated into. This may have introduced unintentional variation in information presented to participants.

Confounding

To ensure experimental groups were similar across older and younger drivers, a priori selected characteristics of driving experience, frequency of driving, miles driven in the previous year, education attainment, traffic violations and minor/major crashes in the previous three years were ascertained. No differences were found among older and younger drivers across the three experimental groups.

Conclusions

Overall, this two-phase study identified potential patterns of risk for non-EV drivers involved in collisions with EVs and designed and tested an intervention to mitigate these MVCs. Results of Phase 1 suggested that drivers may have difficulties in visually detecting EVs that are approaching in different driving conditions. EV's L/S may not be as effective in conditions where: a driver's vision is obstructed (e.g., buildings, parked vehicles) or limited (e.g., nighttime); drivers are distracted; and within roadway locations that may be cluttered (e.g., intersections, urban environments).

Results of Phase 2 demonstrated that drivers with a DSS were at decreased risk of collisions with EVs and the presence of the DSS did not increase in-vehicle distractions. Future research should continue to examine risk factors for MVCs and assess technology as a method to mitigate roadway collisions between non-EVs and EV drivers – an approach that is integral to comprehensive roadway safety.

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Appendix A – Phase 2 Consent Form

Advanced Vehicle-Based Driver Support System for Emergency Vehicle Detection

You are invited to participate in a research study to examine the effectiveness and understandability of a new system designed for use when emergency vehicles operating under lights and sirens are approaching your vehicle. You were selected as a possible participant because you responded to our ads or recruitment inquiries and were found to be a suitable participant for this study. We ask that you read this form carefully and ask any questions you may have before agreeing to participate in the study.

This study is being conducted by Christopher Drucker, who is a doctoral candidate at the University of Minnesota and Michael Manser who is the Director of the HumanFIRST Program at the University of Minnesota.

Background Information:
The purpose of this study is to investigate driver responses when an emergency vehicle that is under lights and sirens is approaching in different driving environments and to understand the impact distraction and, for some participants, how an advance vehicle-based driver support system impacts your driving behavior.

Procedures:
If you agree to be in this study, we will ask you to do the following things: (1) Answer a demographic and driving history questionnaire; (2) be trained in our driving simulator; (3) perform several drives in which you will drive in populated environments and cross intersections and drive on straight roads; and (4) answer a system trust, usability, mental workload, and usability scale questionnaire. The study will last for about 1.5 hours.

Risks and Benefits of Being in the Study:
There are no direct benefits to you for participating in this study. A small percentage of individuals may experience motion sickness while driving in the simulator. If you begin to experience this, notify us and we will stop the study. *Note: you are free to withdraw from the study at any time if you do not wish to continue.*

You will receive a payment of $50 for your participation. If you terminate the study early, you will receive full payment for your participation.

Confidentiality:
The records of this study will be kept private. You name will not be associated with any of the data collected today. In any sort of report we might publish, we will not include any information that will make it possible to identify you or other participants. Research records are stored securely in locked offices and only researchers on this study will have access to the data collected.

Voluntary Nature of the Study:

Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions:
You may ask any questions you have now. If you have questions later, **you are encouraged** to contact Christopher Drucker by mail at School of Public Health MMC 807 400 Delaware Street SE, Minneapolis, Minnesota, 55455, by phone at 612-626-4801, or by email at druck029@umn.edu.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), **you are encouraged** to contact the University of Minnesota's Research Subjects' Advocate Line, D528 Mayo, 420 Delaware Street SE, Minneapolis, Minnesota 55455; (612) 625-1650.

You will be offered a copy of this information to keep for your records.

Statement of Consent: I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature: ____ Date: __________________

Signature of Investigator: ___________________________ Date: __________________

Appendix B – Phase 2 Driving History Questionnaire

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

1. Your age: ____________ years

2. Your sex:
☐ Male
☐ Female

3. What is your highest educational level completed?
☐ High School / Vocational School / GED
☐ Associates Degree
☐ Bachelor's Degree
☐ Master's Degree
☐ Doctorate

4. Please state the **year** when you obtained your full driving license: ___________

5. About how often do you drive?

☐	☐	☐	☐	☐
Never	Hardly Ever	Sometimes	Most Days	Every Day

6. Estimate roughly how many miles you have driven in the past year:
☐ Less than 5000 miles
☐ 5001-10,000 miles
☐ 10,001-15,000 miles
☐ 15,001-20,000 miles
☐ Over 20,001 miles

7. About how often do you drive to and from your place of work?

☐	☐	☐	☐	☐
Never	Hardly Ever	Sometimes	Most Days	Every Day

Do you drive frequently on…	Yes	No
8. Highways?	☐	☐
9. Main Roads other than Highways?	☐	☐
10. Urban Roads?	☐	☐
11. Country Roads?	☐	☐

12. During the last three years, how many <u>minor</u> road crashes have you been involved in where you were at fault? A minor accident is one in which no-one required medical treatment, AND costs of damage to vehicles and property were less than $4000.

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

13. During the last three years, how many <u>major</u> road crashes have you been involved in where you were at fault? A major accident is one in which EITHER someone required medical treatment, OR costs of damage to vehicles and property were greater than $4000, or both.

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

14. During the last three years, have you ever been convicted for:

	Yes	No
a. Speeding	☐	☐
b. Careless or dangerous driving	☐	☐
c. Driving under the influence of alcohol/drugs	☐	☐

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

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

Appendix C – Phase 2 System Trust Questionnaire.

Please indicate how strongly you agree or disagree with the following statements. Answer these questions in relation to the **driver support system** you just used while driving in the simulator.

1. **The performance of the driver support system enhanced my driving safety.**

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

2. **I am familiar with the operation of the driver support system.**

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3. **I trust the driver support system.**

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

4. **The driver support system is reliable.**

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

5. **The driver support system is dependable.**

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

6. **The driver support system has integrity.**

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7. **The driver support system provides security.**

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Appendix D – Phase 2 Acceptance Questionnaire

Answer the following questions in relation to the driver support system. Fill in a box along the 5-scale box to indicate your response.

Example: If you think the driver support system will be difficult to use and requires a lot of effort to understand you might respond as follows:

Easy	☐ ☐ ☐ ☐ ■	Difficult
Simple	☐ ☐ ☐ ■ ☐	Confusing
Useful	☐ ☐ ☐ ☐ ☐	Useless
Pleasant	☐ ☐ ☐ ☐ ☐	Unpleasant
Bad	☐ ☐ ☐ ☐ ☐	Good
Nice	☐ ☐ ☐ ☐ ☐	Annoying
Effective	☐ ☐ ☐ ☐ ☐	Superfluous
Irritating	☐ ☐ ☐ ☐ ☐	Likeable
Assisting	☐ ☐ ☐ ☐ ☐	Worthless
Undesirable	☐ ☐ ☐ ☐ ☐	Desirable
Raising Alertness	☐ ☐ ☐ ☐ ☐	Sleep-inducing

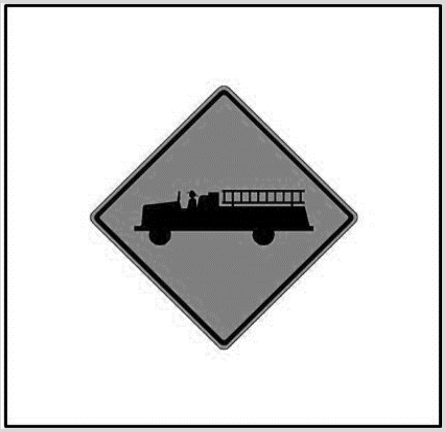

Image flashes in the direction of the approaching emergency vehicle.

Appendix E – Phase 2 NASA TLX Questionnaire

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High