Human Factors of Vehicle-Based Lane Departure Warning Systems

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Alice Ton, Principal Investigator
Department of Mechanical Engineering
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June 2015

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Final Report 2015-35

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Technical Report Documentation Page

1. Report No. MN/RC 2015-35	2.	3. Recipients Accession No.
4. Title and Subtitle Human Factors of Vehicle-Based Lane Departure Warning Systems		5. Report Date June 2015
		6.
7. Author(s) Christopher Edwards, Jennifer Cooper, Alice Ton		8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Mechanical Engineering HumanFIRST Program University of Minnesota 111 Church Street SE Minneapolis, MN 55455		10. Project/Task/Work Unit No. CTS # 2013073
		11. Contract (C) or Grant (G) No. (c) 99008 (wo) 110
12. Sponsoring Organization Name and Address Local Road Research Board Minnesota Department of Transportation Research Services & Library 395 John Ireland Boulevard, MS 330 St. Paul, Minnesota 55155-1899		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes http://www.lrrb.org/pdf/201535.pdf		

16. Abstract (Limit: 250 words)

Run-off-road (ROR) crashes are a concern for two-lane rural and urban roadways throughout Minnesota due to the frequency by which they contribute to fatal crashes (Minnesota Crash Facts, 2013). Mitigating the severity of the ROR events is an on-going research goal in order to help reduce the number of ROR crashes. Examining countermeasures that may reduce ROR crashes is important to determine the most efficient and effective method of warning.

Behavioral responses were examined through the use of an in-vehicle haptic-based lane departure warning system (LDWS) using a driving simulator. The study incorporated systematic variation to both the reliability of the warning and sequence of treatment conditions. An additional analysis examined the presence of *behavioral adaptation* after repeated exposure to the system. Severity of a ROR event was measured as the total time out of lane (TTL) and maximum lane deviation (MLD). Covariates (e.g. road shape) were examined to determine the influence they may have on the severity of a ROR.

The results reveal overall LDWS efficacy. TTL was significantly longer when no system was active compared to when it was active. LDWS led to shorter duration of ROR events. Greater velocity was found to be highly predictive of longer TTL. MLD was also greater for baseline drives compared to treatment drives. No behavioral adaptation or system overreliance was detected, suggesting long term benefits of the LDWS. Drivers who actively engaged in a distraction task were at far greater risk of traveling greater and more dangerous distances out of lane.

17. Document Analysis/Descriptors		18. Availability Statement	
Ran off road crashes, Two lane highways, Warning systems, Reliability, Trust (Psychology), Workload		No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 58	22. Price

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Prepared by:

Christopher Edwards
Jennifer Cooper
Alice Ton
Department of Mechanical Engineering
HumanFIRST Program
University of Minnesota

June 2015

Published by:

Minnesota Department of Transportation
Research Services & Library
395 John Ireland Boulevard, MS 330
St. Paul, Minnesota 55155-1899

Acknowledgments

The authors wish to acknowledge the following members of the HumanFIRST Program for their contributions: Peter Easterlund for programming the driving environment simulator, Oxana Kramarevsky for her assistance during protocol set-up, and Nichole Morris for her guidance and support throughout the project. The authors would also like to acknowledge Felipe Acosta at the University of Minnesota's statistic consultation clinic for his assistance with data analysis. Additionally, the authors would like to acknowledge members of the Technical Advisory Panel: Victor Lund for his assistance in developing driving scenarios and his input across various stages of the project, Alan Rindels and Kenneth Johnson for their feedback throughout the process, and Shirley Sherkow for her project management and oversight. Finally, the authors would like to acknowledge LRRB for funding the project and MnDOT for running the project.

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Executive Summary

Run-off-road (ROR) crashes contribute to more than half of the vehicular fatalities nationwide (Fatality Analysis Reporting, 2013). ROR crashes are of particular concern for two-lane rural roadways throughout Minnesota because of their overrepresentation within fatal crashes (Minnesota Crash Facts, 2013). Minimizing the propensity of lane departure events is an ongoing national research goal. Currently, in-vehicle warning systems that alert drivers to an impending ROR event are in the early stages of development and have little consistency in the driver–vehicle interfaces they employ. Understanding how the modality of such systems (i.e., visual, auditory, and haptic) impact driver behavior will aid in developing appropriate and timely warning systems. Furthermore, assessing driver trust and reliance on such systems will allow us to better understand the driver–computer interaction involved and refine the systems to present the most efficient and effective alerts. Examining driver responses in controlled experimental settings offers invaluable insight to guide the future development of these systems.

In the current study, behavioral responses were examined through the use of an in-vehicle haptic-based lane departure warning system (LDWS) in a driving simulator. The study incorporated systematic variation in both the reliability of the system (i.e., the likelihood—100%, 90%, or 70%—that the system was activated for an ROR event) and the sequence of treatment conditions (i.e., the order of inactive system exposure (baseline) and active system exposures (LDWS exposure drives 1 and 2)). The study investigated driver responses to the system in terms of overall system efficacy and the efficacy of the three reliability levels. An additional analysis examined the presence of behavioral adaptation after repeated exposure to the system. Behavioral adaptation is a common secondary effect that occurs when drivers become overreliant on a safety device (Rudin-Brown and Jamson, 2013).

The severity of an ROR event was measured by the total time out of lane (TTL) and maximum lane deviation (MLD). These measures offer the best-simulated representation of the severity of a lane departure event and demonstrate the efficacy of an LDWS to help drivers safely return to their lane. Additional covariates such as road shape (e.g., curved vs. straight), speed, brake pressure, and age were examined to determine the influence they may have on the severity of an ROR event when it occurs.

The overall results of the study reveal the effectiveness of the LDWS. TTL was significantly longer when no system was active (baseline) compared to when it was active (LDWS exposure drives 1 and 2). LDWS led to a shorter duration of lane departure events. Numerous covariates acted as predictors to TTL and most were associated with greater velocity, suggesting that if drivers lower their speed, they can return to their lane more quickly when they unexpectedly exit the lane. MLD was also greater for baseline drives compared to LDWS exposure drives. Finally, when participants drove without the LDWS (e.g., baseline) after repeated exposures to it, they maintained significantly reduced deviation measures (i.e., TTL and MLD), suggesting long-term benefits of the LDWS. The covariate of *overlapping secondary tasks* was found to be a significant predictor for MLD and provided insight into the relationship between distraction and severity of lane departure. Drivers who actively engaged in a distraction task were more likely to travel greater distances when they unexpectedly leave their lane, which can possibly put them at a greater risk of striking a bicyclist, highway worker, or roadside infrastructure (e.g., signage) on

the road. Future on-road studies are needed to examine low-cost solutions to in-vehicle warning systems.

Chapter 1. Introduction

1.1 Run-Off-Road (ROR) Crashes: Magnitude of the Problem

A run-off-road (ROR) crash occurs when a single vehicle exits the roadway on the left or right, resulting in a roll-over, collision with an object, or collision with another vehicle. In 2013, single-vehicle ROR crashes accounted for approximately 55.6% (18,671) of all fatal crashes (33,561) across the United States (Fatality Analysis Reporting, 2015). In 2013, 387 individuals were killed in traffic crashes in Minnesota alone, and of those deaths, 48.7% can be attributed to ROR crashes (Minnesota Crash Facts, 2013).

These numbers indicates that ROR crashes are still a significant issue for both Minnesota and across the United States. Of greater concern is that the true magnitude of the problem may be underestimated as officers often fail to cite ROR crashes in the traditional crash reporting system (Spainhour & Mishra, 2008).

1.2 Risk Factors for ROR Crashes

ROR crashes occur most frequently on two-lane rural highways. Horizontal curves are associated with increased incidences of ROR crashes. Leading driver contributory factors for ROR crashes include speeding, aggressive driving, driver error, high mental workload, fatigue, and inattention (Bertola, Balk, Shurbutt, 2012; Garder, 2006; Liu & Subramanian, 2009; Liu & Jianqiang, 2011). Interestingly, Dahlen, Martin, Ragan, and Kuhlman (2004) found drivers who exhibit high levels of 'sensation seeking' tend to have decreased concentration and exhibit a multitude of maladaptive driving behaviors (e.g., aggressive driving, loss of control over vehicle, hostile gestures while driving), putting them at an increased risk for crash involvement.

1.3 Current Solutions to Mitigate ROR Crashes

1.3.1 Infrastructure-Based Technique: Shoulder Rumble Strips

Shoulder rumble strip is a commonly employed infrastructure based warning system to help prevent ROR crashes. Shoulder rumble strips are milled or raised patterns installed on paved shoulders, near the outer edge of travelling lanes (FHWA, 2014). Vehicles crossing over the rumble strips triggers a rumbling sound and a vibration of the vehicle, and in effect, alerts drowsy or distracted drivers of their lane departures. Studies have found that shoulder rumble strips effectively decrease ROR crashes by 40-50% (Anund, Kecklund, Vadeby, Hjälmdahl, & Åkerstedt, 2008; Mahoney, Porter, Donnell, Lee, & Pietrucha, 2003; Persaud, Retting, & Lyon, 2004).

However, rumble strips present several drawbacks. Firstly, the abrupt noise and vibration introduced by the rumble strip may actually startle some drivers, leading them to overcorrect. Indeed, research has shown rumble strips increase the risk of overcorrection by 80% on highways with speeds of 70+mph (Spainhour and Mishra, 2008). Secondly, the noise produced by rumble strips can become a nuisance for adjacent residents, which can threaten the long term viability of this solution. Thirdly, rumble strips can be hazardous for cyclists. Rumble strips can lead bicycles traversing these installations to steer out of control and can also cause damage to bicycle wheels. Finally, rumble strips can only be installed on paved shoulders—an important barrier to their widespread implementation.

1.3.2 An Alternative Solution: In-Vehicle Lane Departure Systems (LDWS)

An alternative solution to rumble strips is to install an in-vehicle lane departure warning system (LDWS). An in-vehicle lane departure warning system tracks the vehicle's orientation and position relative to the lane boundary and issues a timely visual, auditory, and/or haptic warning to indicate that the vehicle is exiting the travel lane (Pitale, Shankwitz, & Preston, 2009). Both LDWS and rumble strips have been shown to produce similar behavioral responses in terms of lane return time and deviation of lane position (Eriksonn, Bolling, Alm, Andersson, Ahlstrom, Blissing, and Nilsson, 2013). Eriksonn et al. (2013) also found that rumble strips and lane departure warning systems are equally accepted by drivers, with neither one being preferred over the other. One advantage that in-vehicle LDWS has over rumble strips is that users can deactivate the warning by switching on the turn signal prior to leaving the travel lane. Rumble strips, on the other hand, presents drivers with warnings of lane departures even if they were deliberate maneuvers on the driver's end (Eriksonn et al., 2013).

1.4 Lane Departure Warning Systems

1.4.1 Approaches to Identifying Lane Departures: DGPS vs. Vision-Based System

Most vehicle manufactures have taken two particular approaches to capturing data on lane boundary for in-vehicle LDWS: differential GPS (DPGS) and vision-based system. However, both methods are subject to limitations set forth by environmental constraints. While the performance of vision-based systems may suffer from adverse weather conditions (e.g., visibility of road markings reduced by snow and ice), DGPS requires a constant and strong satellite signal to function at its optimal level. The problem with achieving high accuracy DGPS is typically the lack of a suitable correlation signal and the high cost of such DGPS receivers. In Minnesota, statewide differential GPS is provided by a continuous operating reference system (CORS). Researchers have looked to combining differential DGPS with vision based system to help track lane departures in the event that the vision based system experiences a failure (Wang et al., 2005).

1.4.2 Optimal Alert Modality

Current in-vehicle safety systems often employ auditory and/or visual alerts to warn drivers of impending dangerous situations. However, auditory and visual warnings run the risk of overloading driver senses and negatively influencing driver's affective state and driving performance (Ho, Reed, & Spence, 2007; Fagerlonn, 2010).

Spatially cueing a driver to the direction of the threat has been found to increase driver's situation diagnosis and improve response time (Ho, Tan, and Spence, 2005). Indeed, Navarro, Mars, Forzy, El-Jaafari, Hoc, and Renault (2008) found that in comparison to auditory alerts, motor priming, where the steering wheel moves in the opposite direction of the threat without altering the trajectory of the vehicle, produced faster recovery times, but yielded lower user acceptance. In a study conducted at University of Minesota, Edwards, Morris, and Manser

(2013) looked to identify a less intrusive alternative to torque warnings—one that can potentially strike a balance between user preference and system efficacy (e.g., increased recovery time, decreased lane deviation). Specifically, the researchers investigated 3 types of lateralized haptic feedback modalities, namely motor priming and haptic feedback delivered through the seat pan and the seat back. The researchers found the three types of haptic warning system were comparatively effective; however, motor priming received less favorable ratings from the users compared to the other alert modalities investigated in the study (i.e., lateralized haptic feedback delivered through the seat pan and seatback).

1.4.3 Potential Design Issues for LDWS: User Acceptance, Trust, and Behavioral adaptation

An ongoing design issue for in-vehicle technology lies in achieving an optimal balance between false/early alarms and missed/late alerts. An insensitive LDWS that issues a high rate of late warnings can degrade users' trust in the system, whereas a highly sensitive LDWS can produce a high rate of early alarms, triggering frustration on drivers' end. In any case, a faulty system will lead the drivers to ignore the warning alerts all together or switch off the system entirely. Therefore, providing a positive user experience and promoting users trust in the system are essential criteria in designing a LDWS. However, increased trust in the system can also lead to drivers' overreliance on the system for lane keeping and in effect reducing drivers' expectation of and preparedness for system faults—a phenomenon coined as 'behavioral adaptation.' Interestingly, drivers who possess a belief that they have little personal control over what happens to them, termed 'external locus of control,' and low 'sensation seeking' scores tend to have increased levels of behavioral adaptation (BA) (Rudin-Brown & Noy, 2002).

1.5 Summary

A well designed LDW system must a) facilitate a timely and appropriate response from the users, b) be tailored to user limitations and capabilities, c) minimize annoyance associated with false alarms and d) achieve an optimal level of reliability that promotes drivers' trust in the system and minimizes behavioral adaptation on the drivers' end. The literature review has shown that in achieving this, system design involves the consideration of multiple variables. This study aims to understand the way in which these variables interact—the results can be used to inform the design and deployment of future LDWS.

While LDW systems may not see large vehicle fleet penetration for approximately 10-15 years, it is in Minnesota Department of Transportation's interest to be involved with the research and development of LDW systems to understand how these systems affect driver behavior given that these systems will likely necessitate infrastructural changes and affect future roadway development. This document describes the research approach that was used to investigate the human factors of vehicle-based lane departure warnings systems.

1.5.1 Objectives for Current Study

The current study will look to experimentally manipulate the reliability level of a haptic-based LDW system to identify the optimal level of reliability that a) facilitates system efficacy and users' trust and acceptance in the system, and b) minimizes workload and behavioral adaptation on the users' end.

Chapter 2. Methods

The experiment was conducted under a controlled environment using a portable driving simulator. The lab environment provided a means for researchers to study the effects of the warning system without exposing the participants and other on-road drivers to potentially unsafe situations. Studying driving behavior in a controlled environment also offers better experimental control in comparison to field studies. The entire experiment, which included consent, pre-driving questionnaires, driving tasks, and post-driving questionnaires, and finally a debriefing, lasted approximately 3 hours.

2.1 Participants

A total of 72 adult drivers were recruited to participate in the study. Of the 72 participants, a final total of 60 participants successfully completed the entire study. Twenty participants, evenly divided between males and females, were randomly assigned to one of the three experimental conditions (i.e., system reliability levels). Demographics and driving history were collected for each participant and averages for each experimental group are presented in Table 2.1. The average age and driving experience did not differ significantly between the three experimental groups. All participants underwent visual acuity and color vision screening prior to driving in the simulator. None of the participants had a visual acuity greater than 20/40, nor did any fail the color vision test.

Table 2.1. Participant demographics and driving experience.

Reliability Condition	N	Mean Age	Average Yearly Mileage	Average Licensure Duration
100%	20	28.55	12,500	11.65 years
90%	20	26.90	12,500	10.90 years
70%	20	28.15	Less than 10,000	11.55 years

2.2 Materials and Apparatus

2.2.1 Driving Simulator

The experiment was conducted in the HumanFIRST Portable Driving Environment Simulator that was manufactured by Realtime Technologies Incorporated (see Figure 2.1). The driving simulator consisted of a driver's seat, vehicle controls (acceleration, steering, and brake), and vehicle gauges on a custom-fabricated chassis. Three 32-inch high-definition displays provided an 88.2 and 18.4 degree field of view horizontally and vertically, respectfully. Rear-view mirror displays were inset on the forward display. The dashboard was presented on an LCD panel in a normal dashboard location. An eight-inch touch screen LCD display was located to the right of the driver and approximately 25 degrees down from the participant's horizontal line of sight (i.e., center stack HVAC area) and was used to display the secondary task. The position was selected because it required a head movement from participants to focus on the screen and engage in the secondary task, thus emulating the physical and perceptual activities of normally occurring distraction tasks. The portable simulator was outfitted with haptic feedback mechanisms. These mechanisms included tactic motors in the outboard side of the seat pan embedded into the foam.

The current LDW system provided haptic feedback through either the left or right outboard side of the seat pan to indicate the direction of the lane departure.

Figure 2.1. HumanFIRST portable driving environment simulator

2.2.2 Simulated Driving Routes

In this study, two separate driving scenarios were created. Scenario A featured a St. Louis County roadway in which a history of lane departures had previously been documented (see Figure 2.2A). Scenario B featured a south central Minnesota roadway with both straight and curved segments that provided the appropriate roadway geometry and environment to serve as treatment and control sites for this study (see Figure 2.2B). Both simulated roadways were rural two-lane highways with a posted speed limit of 55mph. Each route provided sufficient length to produce meaningful data. All participants experienced both roadways in both directions (e.g., North-South, East-West), creating a total of four driving routes for this study. Each route took approximately 12 minutes to complete.

A. **B.**

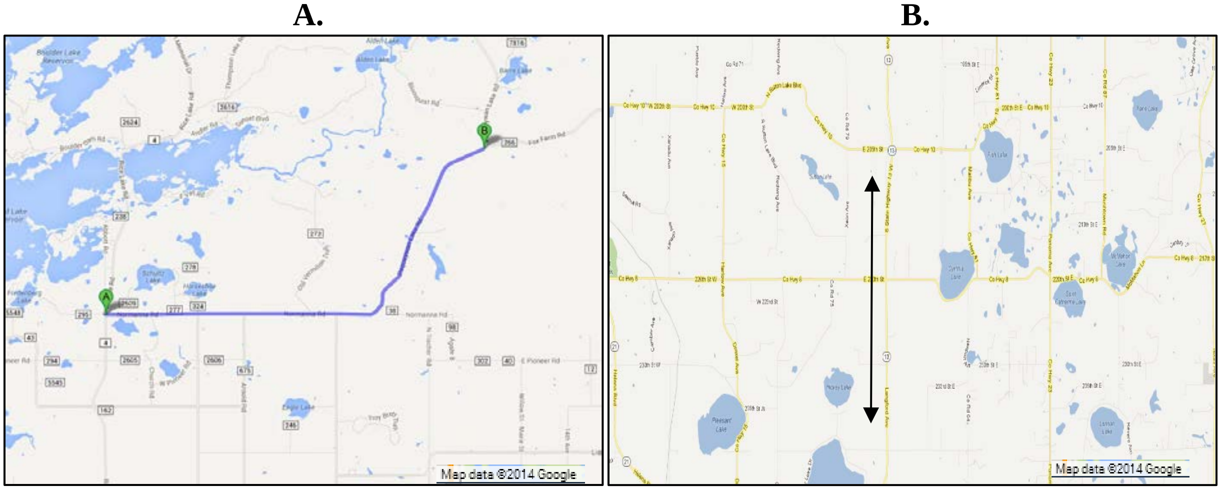

Figure 2.2. A depicts the St. Louis County roadway and Figure 2.2B depicts the South Central Minnesota roadway

2.2.3 Run-Off-Road Events

In each route, the participants encountered a total of 10 wind-induced ROR events that pushed their simulated vehicle either to the left or right, forcing the vehicle to cross the lane lines in either direction. These ROR events were produced using gradual-to-severe 'wind gusts' spanning approximately 4 seconds in length. The peak gust in the current study was comparable to a crosswind of 55 mph (~25 m/s), producing an equal force to the entire vehicle such that the trajectory of the vehicle was pushed to either left or right. These event sequences were programmed to last longer than those in a previous pilot study (Edwards, Morris, & Manser, 2013) as previous findings have found that a gradual, but longer simulated wind force provided more face validity and is comparable to wind gusts encountered in the real world. To further enhance perceptual realism, each lane departure was also accompanied by a wind noise.

2.2.4 Secondary Task

The study employed a secondary task that was performed on a touch screen. The task involved a combination of visual search, target matching, working memory, and response input. As shown in Figure 2.3, the task was comprised of a matrix of arrows around a central "target" arrow. The task became active when the target arrow was pressed. The button press initiated the rotation of each arrow in a different direction and at different speeds for a random time interval (up to 1.5 seconds). The participant's task was to press a button on the keypad corresponding to the number of peripheral arrows in the matrix that matched the orientation of the central target arrow. The task was 'self-paced' in that participants chose how many of the tasks to complete in a pre-defined period of time. In this manner, the secondary task represented the basic components of distraction tasks that are typical of many existing in-vehicle self-paced secondary tasks. That is, the driver self-controlled when to start the engagement in the task and also when to respond.

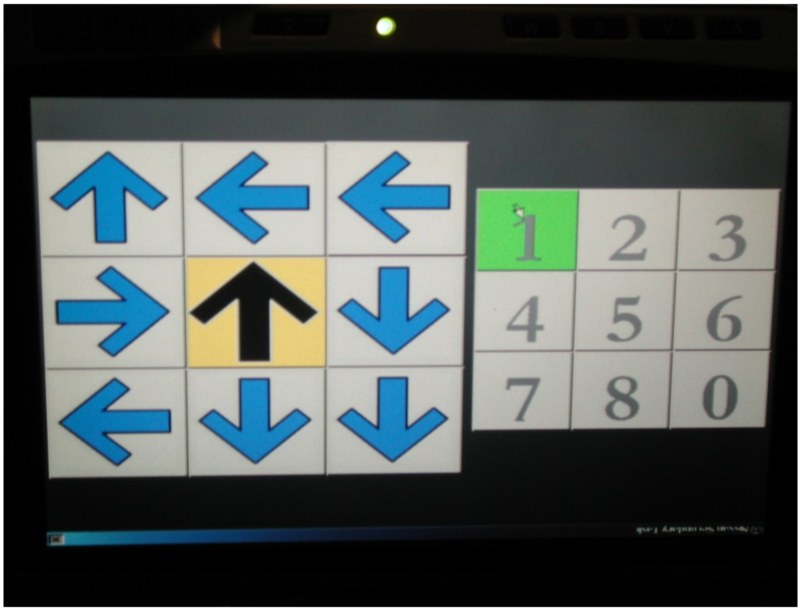

Figure 2.3. Self-paced in-vehicle secondary task

2.2.5 Lane Departure Warning System

The present study used a single haptic LDW system to notify participants of lane departures. The LDW was administered through vibrations on either the left or right side of the seat pan, depending on the direction of the lane departure. The vibration frequency for the LDW was 30Hz—this frequency is similar to that of a vibrating cell phone. Warnings were presented in 1 second increments followed by a 500 m/sec pause between notifications. The effect was intended to be similar to that of a rumble strip encountered on the roadway. This particular LDW was selected over other options for LDW (e.g., steering wheel force) based on user preference and system effectiveness found for the different types of LDW systems in previous work (Edwards, Morris, & Manser, 2013)

2.3 Experimental Design

2.3.1 Independent Variables

To study the effects of the LDWS, a within subject manipulation, *system status*, was introduced into the study. Additionally, two types of between-subject manipulations were introduced into the experiment: *sequence of drives* and *reliability*.

System Status
The LDWS was manipulated throughout the experiment to examine driver behavior to lane departure events when the system was active and inactive. The inactive system, or baseline condition, was presented to subjects at the beginning or end of the experiment, depending on their group assignment (i.e. Group A or Group B). The active system, or LDWS exposure condition, was presented twice (i.e. LDWS Exposure 1 and LDWS Exposure 2) to each participant. The LDWS exposure drives were always paired, either at the start or conclusion of the experiment, depending on group assignment. Participants experienced the same active LDWS in Exposure 2 as they did in Exposure 1.

Sequence of Drives
The order in which the participants experienced the baseline and LDWS exposure drives was counterbalanced across the participants such that half of the participants experienced the set of baseline drives first (Group A) (see Table 2.2), while the other half experienced the baseline last (Group B) (see Table 2.3). In this manner, Group A (baseline first) provided a means for researchers to measure overall system efficacy without posing the participants to any carry-over effects while Group B (baseline last) served as a means for the researchers to observe any effect of behavioral adaptation resulting from exposure to the system across time.

Table 2.2. Sequence of drives for Group A (baseline first)

Reliability	N	Pre-Study	Sequence of Drives for Group A		
100%	10	Practice	Baseline	LDWS Exposure 1	LDWS Exposure 2
90%	10	Practice	Baseline	LDWS Exposure 1	LDWS Exposure 2
70%	10	Practice	Baseline	LDWS Exposure 1	LDWS Exposure 2

Table 2.3. Sequence of drives for Group B (baseline last)

Reliability	N	Pre-Study	Sequence of Drives for Group B		
100%	10	Practice	LDWS Exposure 1	LDWS Exposure 2	Baseline
90%	10	Practice	LDWS Exposure 1	LDWS Exposure 2	Baseline
70%	10	Practice	LDWS Exposure 1	LDWS Exposure 2	Baseline

Reliability

The reliability of the system was manipulated in order to study any effects that it might have on system efficacy, behavioral adaptation, trust, and workload. To manipulate system reliability, the LDWS was preset at 100%, 90%, or 70%. These levels corresponded to the likelihood that the participants would receive a warning in the event of a wind-induced lane departure throughout the course of their drive. For example, if reliability level was preset at 70%, then the participant would receive a warning for 7 out of the 10 wind-induced lane departures. Participants were randomly placed into one of the three reliability groups. All participants from each reliability group received three sets of drives: a set of baseline drives in which the LDW would be turned off and 2 sets of LDWS exposure drives—the LDW's for both of which were preset to the same system reliability level (i.e., 100%, 90%, or 70% depending on the treatment group to which the given participant was preassigned). For each set of drives, participants completed 4 routes (both directions on each of the 2 roadways).

2.3.2 Dependent Variables

Total Time out of Lane (TTL)

Total time out of lane (TTL) refers to the overall duration of a single lane departure. Specifically, TTL is the time difference—measured in seconds—from the point when the outside front tire crossed the lane line to the point when the edge of the outside front tire crossed back into the lane. Lower time values indicated a shorter lane departure.

Maximum Lane Deviation (MLD)

Maximum lane deviation, measured in meters, is defined as the greatest distance traveled outside of the lane markings throughout the course of a lane departure. MLD provides an estimate for the severity of single lane departure event and how far drivers were out of the lane. These distances are of great interest as objects on the side of the roadway are more likely to be hit with greater magnitudes of lane departures.

Workload
Participants' workload during driving was estimated using the NASA-TLX, a multi-dimensional 100-point scale (0 = very low, 100 = very high) developed by Hart and Staveland in 1988 (Appendix A). Specifically, the scale assessed mental demand, physical demand, temporal demand, effort, performance, and frustration.

Trust
Users' confidence in the LDWS was measured through the System Trust Questionnaire (Appendix B). The System Trust Questionnaire included a 100-point scale (0 = strongly disagree, 100 = strongly agree) for 9 items. Participants' overall feedback on the LDWS was gathered through 7 open-ended questions in a final questionnaire (Appendix C).

2.3.3 Covariates for TTL and MLD

Driver/vehicle factors, road geometry, distraction, age, sex, and personality traits were included as covariates in the model to help the researchers better understand the relationship between reliability levels and TTL/MLD. Brief description for each covariate is provided below.

Road Geometry
The road geometry (straight vs. curve) at which the lane departure occurred.

Driver and Vehicle factors
The following four driver/vehicle factors served as covariates for TTL and MLD:

a) Vehicle velocity
b) Braking – proportion of brake pedal depressed during the lane departure
c) Accelerating – proportion of accelerator pedal depressed
d) Steering – proportion of steering wheel movement past the center position (positive values are clockwise rotations while negative values are counterclockwise rotations)

For each of the four covariates, data were collected at three separate time points across the course of a single lane departure: three-seconds prior to departure (precursor), onset of departure (defined as the point at which the outside front tire exits lane line), and midpoint of departure (defined as the halfway point between onset and return to lane).

Overlapping Secondary Task Engagement
Any engagement in a secondary task (e.g. answering an arrow task) within a four-second span of time before the lane departure, any time during a departure or within the four-second span immediately after a lane departure was coded as overlapping secondary task engagement. Overlapping secondary task engagement marks the presence of potential distraction and served as additional covariates for TTL and MLD.

Driver Demographics
Age and sex of the participants gathered through the Demographic and Driving History Questionnaire (Appendix D) served as covariates for TTL and MLD.

Personality Traits
Personality traits (i.e., locus of control, boredom propensity, sensation seeking) served as additional covariates for TTL and MLD. Brief description of each trait is provided below:

a) Locus of control- A person's expectancies for internal vs. external control of circumstances behind the wheel was measured using the Driving Opinion Locus of Control, a 30-item questionnaire developed by Montag and Comrey in 1987 (Appendix E). Based on the responses from the questionnaire, participants were classified into one of two categories: i) those with an external locus of control and ii) those with an internal locus of control. Drivers with an external locus of control tend to feel that their actions have little effect on certain outcomes (e.g. accidents, collisions) on the road and that events are mostly determined by fate. On the other hand, those with an internal locus of control takes the viewpoint that drivers can prevent and control certain outcomes by following regulations and taking care in difficult road situations (e.g. ice/snow, dense traffic).

b) Boredom propensity- A person's proneness to boredom was measured using the 28-item Boredom Propensity Scale, designed by Farmer and Sundberg in 1986 (Appendix F). Higher scores indicated a higher propensity to become bored. Using a standard cutoff established by Farmer and Sundberg (1986), participants were classified into one of two categories: i) those who are prone to boredom and ii) those who are not prone to boredom.

c) Sensation seeking- Proneness to take risks was assessed using the Arnett Inventory of Sensation Seeking, a 40-item questionnaire developed by Arnett in 1994 (Appendix G). Higher scores indicated a higher need for novelty and stimulation.

2.3.4 Hypotheses

Three hypotheses were developed for the research effort:

Hypothesis 1 (specific to Group A): If the LDWS is indeed effective, improved driving performance—as measured through reductions in TTL and MLD—should be observed in the presence of the LDW system.

Hypothesis 2 (specific to Group B): If the LDWS does impose the risk of behavioral adaptation, then an increase in TTL and MLD should be observed during the final baseline drives, after the participants have been repeatedly exposed to the LDWS.

Hypothesis 3: Reduced system reliability will degrade participants' trust in the LDWS and increase their mental workload.

2.3.5 Analyses

The dependent variables total time out of lane (TTL) and maximum lane deviation (MLD) were measured in the Portable Driving Environment. TTL and MLD were captured for each lane departure event that was experimentally induced (e.g., "wind event"). Each participant was expected to have 120 experimentally induced lane departures, as the simulator was programmed to induce 10 departures per route and each participant experienced 12 routes. Self-induced lane departures were not analyzed.

System Efficacy

The dependent variables were analyzed to determine the overall efficacy of the LDWS at varying conditions (i.e. Baseline, 70%, 90%, and 100% reliability). In effort to provide evidence for system efficacy, comparisons were made between the baseline drives and the two LDWS exposure drives in Group A. Marked reductions in TTL or MLD from baseline to LDWS exposure drives in Group A should provide a clear indicator for system efficacy.

Additionally, TTL and MLD at the first set of drives was examined for Group A vs. Group B. Given that the first set of drives was Baseline for Group A and LDWS Exposure for Group B, any reduction in TTL or MLD in Group B relative to Group A would indicate system efficacy and the beneficial effects of LDWS.

To test for significance, an analysis of covariance (ANCOVA) was conducted on both dependent variables (i.e., TTL and MLD). Reliability, road shape, overlapping secondary tasks, age, sex, personality traits, and multiple driver/vehicle factors (e.g., velocity, braking, accelerating, steering) were included in the model to provide a more robust explanation for any detected variance in the dependent variables. The ANCOVA test controlled for random subject effects (e.g., participant bias).

Behavioral Adaptation

The dependent variables were also examined to test whether the LDWS unintentionally encourages behavioral adaptation after repeated exposure at varying reliability levels (i.e., recovery to lane departures worsen with no active system after exposure to the LDWS system). Behavioral adaptation was measured by testing for differences in TTL and MLD between Group B's initial LDWS exposure drives and its final baseline drives. If the LDWS does impose the risk of behavioral adaptation, then an increase in TTL and MLD should be observed during the final baseline drives. An ANCOVA was conducted to test for significant differences in the TTL/MLD between the baseline and LDWS exposure drives using aforementioned covariates.

User Acceptance

User acceptance for the LDWS at varying reliability levels (i.e., 100%, 90%, 70%) were assessed through measures of workload and trust and compared and contrasted between the three reliability groups.

2.3 Procedure

To begin, participants completed the process of informed consent, followed by an online driving history questionnaire. Next, participants had their vision tested using a standard Snellen Acuity Chart to ensure they met minimum standards for licensure in Minnesota (i.e., 20/40 corrected or uncorrected). Additionally, Ishihara's color test was used to ensure participants' color vision was unimpaired to continue with participation. Following the vision screening, participants were asked to complete three online personality questionnaires.

Participants were then randomly assigned to one of the three LDW reliability groups (i.e., 100%, 90%, and 70%). All efforts were made to ensure that the participants were not aware of their group assignments. Each participant was provided with a detailed explanation of the purpose and functionality of the LDWS. Furthermore, all participants were provided with the general background of the system usefulness and operational limitations. After reviewing the LDWS, participants were then provided with a full description of the secondary task and were given the opportunity to practice the arrow task on paper. Participants were instructed to complete as many secondary tasks as possible at their own pace while prioritizing their primary goal which is to drive safely.

Participants were then instructed to enter the simulator and adjust the seat to a comfortable position. Participants completed a five-minute practice drive prior to starting the experimental portion of the study. The practice drive allowed participants to become acclimated to the portable driving simulator and the driving characteristics of the simulator. The intent of the practice drive was also to standardize the exposure to the driving simulator such that all participants received the same amount of experience and training. During the initial practice drive, participants were also instructed to practice the secondary arrows task while driving. Providing sufficient practice on the secondary task ensured a normalized learning experience across all participants and thereby reducing learning bias.

Once the participants completed the practice session, they were moved onto the experimental portion of the study. The experimental portion involved each participant experiencing three sets of drives: a set of baseline drives in which the LDWS was inactive and two sets of LDWS exposure drives where the LDWS was active and preset to the same system reliability level (i.e., 100%, 90%, or 70% depending on the treatment group to which the given participant was preassigned). For each set of drives, participants completed four routes (both directions on each of the two roadway scenarios). Half of the participants experienced the set of baseline drives first, while the other half experienced the paired sets of LDWS exposure drives first.

Prior to each set of drives, all participants were encouraged to drive as they normally would and to maintain the speed limit of 55 mph. However, instructions varied with the given treatment group such that those in the 100% reliability group were told that the system was "highly reliable," the 90% group was told that the system was "very reliable," and the 70% group was told that the system was "reliable."

Following each set of drives, participants were asked to complete the NASA-TLX workload questionnaire (for the LDWS exposure drives, participants completed an additional questionnaire on trust.)

Once the participants had finished all three sets of drives and questionnaires, they completed a final questionnaire. This final questionnaire asked participants to rate their general opinion of the LDW system they experienced and to indicate to what extent and why they did or did not use the system feedback during the drive. Once the participants completed the final post-drive questionnaire, they were debriefed on the system operation and the rationale for reliability testing and compensated for their time at a rate of $20/hr.

Chapter 3. Results

A preliminary examination of the dependent variables (i.e., total time out of lane (TTL) and maximum lane deviation (MLD)) using a multivariate analysis of variance (MANOVA) revealed significant effects for reliability condition ($F(6) = 11.018$, $p < 0.001$) and sequence of drives ($F(1) = 3.812$, $p < 0.02$). Further analysis through univariate testing of the each dependent variable was conducted separately for system reliability and behavioral adaptation using univariate analysis of covariance (ANCOVA).

The results of the MANOVA validated the research plan to proceed with univariate testing of each dependent variable (TTL and MLD) to determine how they are affected by reliability (70%, 90%, and 100%) and sequence of drives (baseline first vs. last).

The following covariates were included in the ANCOVA model:

a) Velocity, braking, accelerating, and steering at:
    i) Three-seconds prior to departure
    ii) Onset of departure
    iii) Midpoint of departure
b) Road shape (e.g. curved vs. straight)
c) Overlapping secondary tasks
d) Age
e) Sex
f) Locus of control score
g) Boredom propensity score
h) Sensation seeking score

Significant results from the ANCOVAs are reported using values from the Z distribution (e.g., *z*-value) due to mixed effects in the model. Significance values among the covariates are reported using the Chi-Squared statistic (e.g., χ^2) rather than an F statistic due to the model being fit with multiple mixed predictors. Reports of the findings for each dependent variable are provided based on the given hypothesis of system efficacy, behavioral adaptation, and reliability.

3.1 System Efficacy

3.1.1 Total Time out of Lane (TTL)

An ANCOVA was performed on Total Time out of Lane (TTL). Group A, which received the baseline drive first, exhibited an overall decrease in the average duration of lane departure events during the drives where the LDWS was active (see Figure 3.1). The decreases in TTL reached significance when comparing the baseline and LDWS Exposure 1 at 100% ($z = 3.83$, $p = 0.002$), 90% ($z = 3.70$, $p = 0.004$), and 70% ($z = 4.90$, $p < 0.001$) levels of reliability. Significant decreases were also observed between baseline and LDWS Exposure 2 at 100% ($z = 4.25$, $p < 0.001$) and 70% ($z = 4.74$, $p < 0.001$) levels of reliability. As depicted in Table 3.1, the greatest TTL reduction compared to baseline was observed at the 70% reliability level for LDWS Exposure 1 (0.69 seconds) and LDWS Exposure 2 (0.66 seconds). TTL did not differ significantly between the three reliability levels for baseline, LDWS Exposure 1, or LDWS Exposure 2. TTL was not significantly different between the first drives for Group A and Group B.

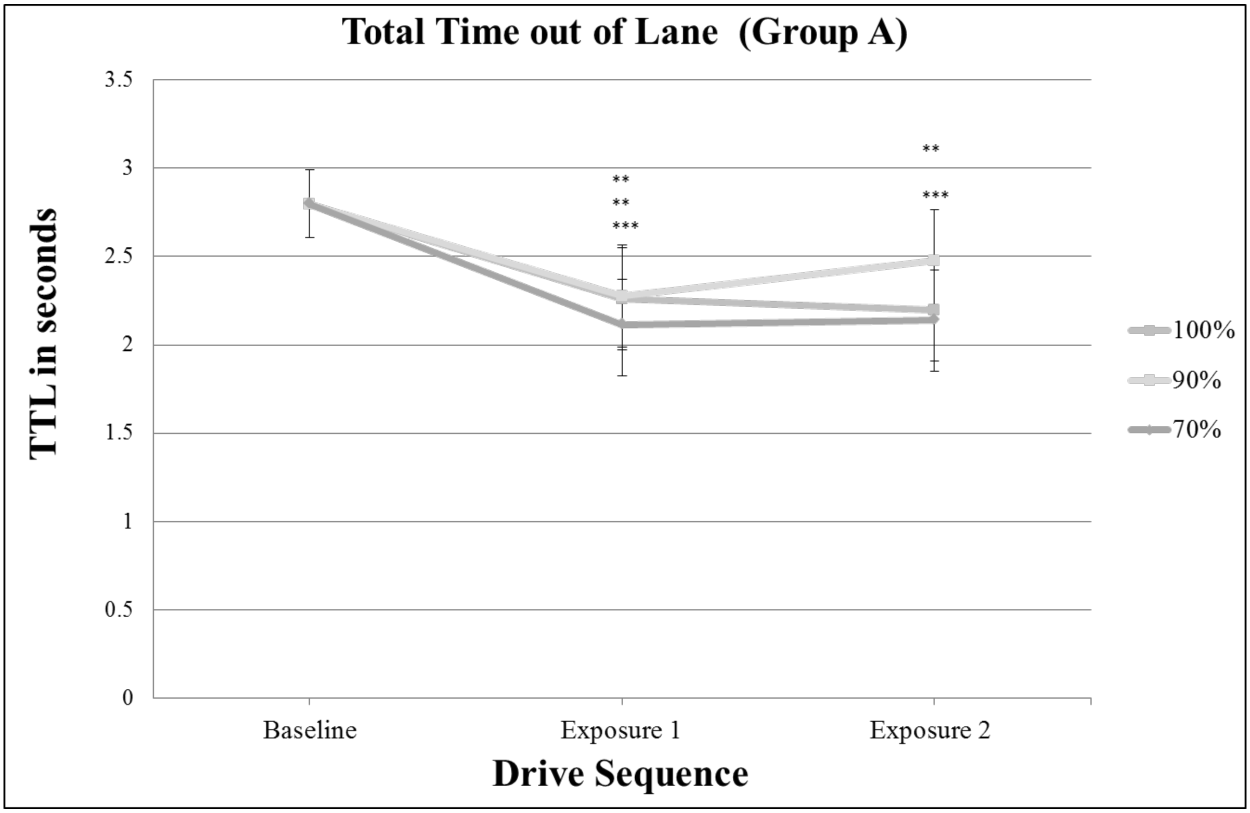

Figure 3.1. Groups A's average TTL for each set of drive by reliability level. Note: ** denotes p<.01; * denotes p<.001**

Table 3.1. TTL means and confidence intervals for baseline and LDWS exposure drives at all reliability levels for Group A.

Condition		Mean (sec.)	95% Confidence Interval
Baseline		2.80	2.61-2.99
100%	LDWS Exposure 1	2.26	1.97-2.55
	LDWS Exposure 2	2.20	1.91-2.49
90%	LDWS Exposure 1	2.28	1.99-2.57
	LDWS Exposure 2	2.47	2.19-2.76
70%	LDWS Exposure 1	2.11	1.82-2.40
	LDWS Exposure 2	2.14	1.85-2.43

The covariates of road shape, velocity (at 3 time points), braking (at 2 time points), accelerating (at 3 time points), and steering (at 2 time points) were found to be significantly predictive of the variance in TTL. The significant covariates are displayed in Table 3.2 with their respective Chi-Square statistic and p-value.

Table 3.2. Covariates that significantly predicts variance in TTL

Covariate	χ^2 (chi-squared) value	df	p-value
Precursor velocity	40.39	1	<0.001
Onset velocity	58.98	1	<0.001
Midpoint velocity	12.51	1	<0.001
Precursor brake	35.85	1	<0.001
Onset brake	25.96	1	<0.001
Precursor accelerating	28.79	1	<0.001
Midpoint accelerating	26.61	1	<0.001
Precursor steering	36.36	1	<0.001
Roadway Shape	7.68	1	0.006
Onset accelerating	10.20	1	0.01
Midpoint steering	5.37	1	0.02

The first examined covariate is consistent with real-world crashes by highlighting the influence that curves have on ROR crashes. The analysis confirmed that drivers were slower to recover back into their lane when on a curved section of the roadway compared to a straight section. Overall, the remaining significant covariates indicate the important influence that speed has in the total time a driver remains out of a lane during a departure. The velocity drivers were traveling just before and as they proceeded into a lane departure were the most significant factors in the duration they were out of lane. The influence of greater velocity and longer TTL is mirrored in braking, accelerator, and steering force. Participants who were traveling at higher velocities were likely remain out of the lane longer and were likely to have depressed the accelerator to a greater degree and required a greater braking and steering maneuver.

3.1.2 Maximum Lane Deviation (MLD)

An ANCOVA revealed that Group A exhibited significant differences in maximum lane deviation (MLD) between baseline and LDWS exposure drives (i.e., LDWS Exposure 1 and 2) at the 100% and 70% reliability levels. There was also a significant difference between the baseline and LDWS Exposure 1 drives for the 90% reliability condition (see Figure 3.2 and Table 3.3). There were no significant differences between the baseline and LDWS Exposure 2 drives for the 90% reliability level.

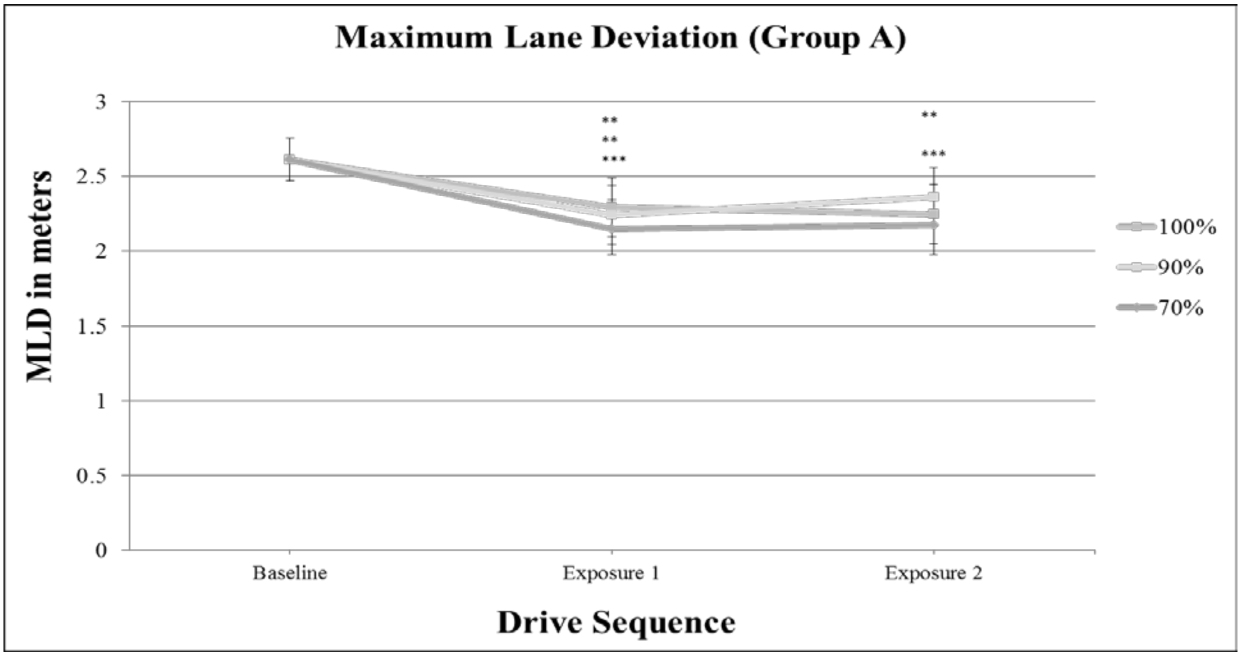

Figure 3.2. Group A's average MLD for Baseline, Exposure 1, and Exposure 2 by reliability. Note: ** denotes p<.01; * denotes p<.001**

Table 3.3. MLD means and confidence intervals for baseline and LDWS exposure drives at all reliability levels for Group A

Condition		Mean (in meters)	95% Confidence Interval
Baseline		2.61	2.47-2.76
100%	LDWS Exposure 1	2.29	2.10-2.49
	LDWS Exposure 2	2.25	2.05-2.44
90%	LDWS Exposure 1	2.24	2.05-2.44
	LDWS Exposure 2	2.36	2.16-2.56
70%	LDWS Exposure 1	2.15	1.95-2.35
	LDWS Exposure 2	2.17	1.98-2.37

An ANCOVA was conducted to test for significant differences in MLD between Group A (baseline first) and Group B (LDWS exposure first)'s first set of drives. While the baseline drives of the two groups were significantly different, with Group B maintaining lower average MLD values than Group A, the baseline drives for Group A had significantly higher MLD values than the LDWS Exposure 1 drives for Group B (see Figure 3.3 and Table 3.4) for all reliability levels. It is important to note that the initial drive for Group A was baseline (no active LDWS) while Group B was exposed to active LDWS in their first drive. This observed difference between these two specific drives highlights the immediate effects of the first exposure to the LDWS in the simulator in the experiment.

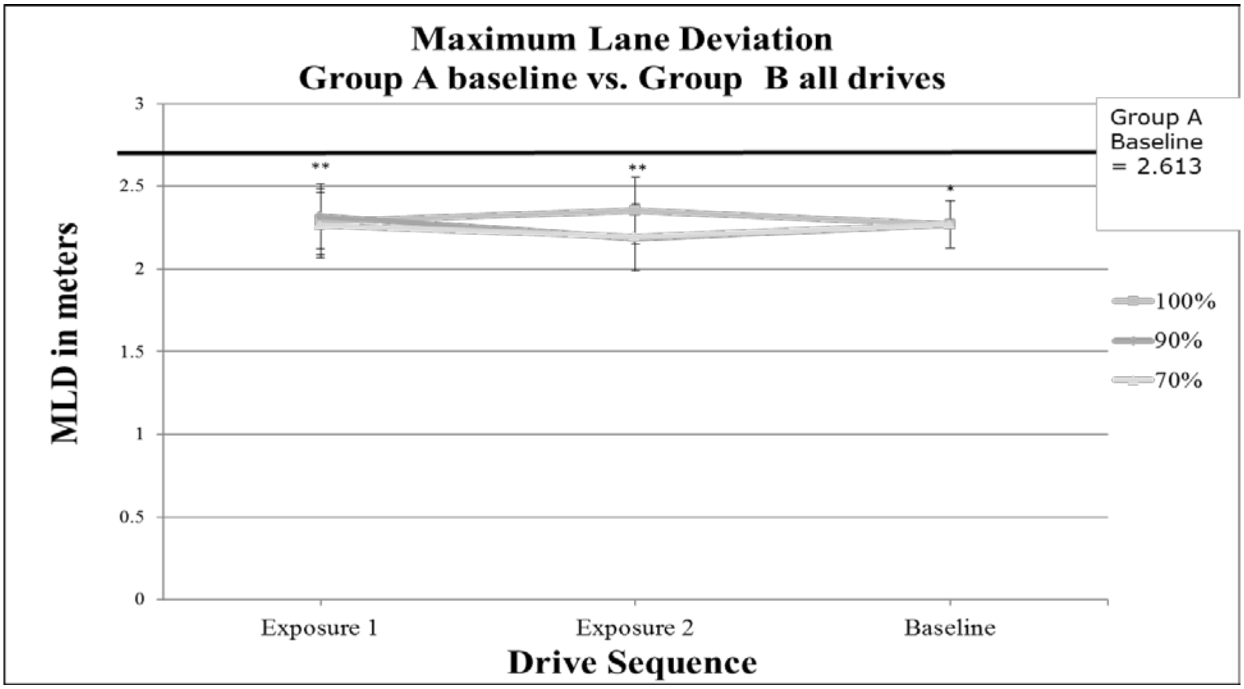

Figure 3.3. Average MLD comparing Group A (baseline) to Group B (all drives). Note: *denotes p<.05; **denotes p<.01

Table 3.4. Means and confidence intervals for MLD - Group A (baseline) and Group B (all drives)

Group	Condition		Mean	95% Confidence Interval
A	Baseline		2.61	2.47-2.76
B	100%	LDWS Exposure 1	2.29	2.09-2.49
B	100%	LDWS Exposure 2	2.35	2.15-2.55
B	90%	LDWS Exposure 1	2.32	2.12-2.51
B	90%	LDWS Exposure 2	2.19	1.99-2.38
B	70%	LDWS Exposure 1	2.27	2.07-2.46
B	70%	LDWS Exposure 2	2.20	2.00-2.39
B	Baseline		2.27	2.13-2.41

The covariates of a) precursor steering, b) onset and midpoint accelerating, and c) overlapping secondary tasks were significantly predictive of variance in MLD. Shape, on its own, did not significantly predict variance in MLD; however, the interaction between shape and precursor velocity, onset velocity, onset braking, and onset steering accounted for significant variance in MLD (see Table 3.5).

Table 3.5. Covariates that significantly predicted MLD variance for both Groups A and B.

Covariate	Chi-Square value	df	p-value
Midpoint accelerating	14.47	1	<0.001
Precursor steering	15.69	1	<0.001
Overlapping secondary task	94.75	1	<0.001
Shape*Onset steering	17.36	1	<0.001
Shape*Precursor velocity	9.28	1	0.002
Shape*Onset velocity	8.28	1	0.004
Shape*Onset braking	5.95	1	0.014
Onset accelerating	5.52	1	0.020

An important covariate to predict MLD was overlapping secondary task. The analysis highlighted the role that distraction has on the degree to which a driver leaves their lane during a ROR event. Participants who were more engaged in the secondary task were more likely to travel a greater distance out of lane compared to those less distracted by the task. Similar to TTL, speed was determined to be an important factor in predicting the degree of MLD. Participants who had a greater depress on the acceleration pedal at and during the ROR event, along with those who did not have proper control over the steering wheel prior to the ROR event, were predicted to travel further out of their lane. Finally, shape alone was not found to be an important predictor in MLD; however, shape was influential depending on the drivers' velocity, braking and steering. These results suggest that curves tend to be less forgiving for drivers who are traveling at high velocities and are required to engage in hard braking and steering maneuvers. Participants were more likely to travel further out of the lane under these combined conditions compared to those who were traveling slower in these road segments.

3.2 Behavioral Adaptation

3.2.1 Total Time out of Lane (TTL)

For Group B, there was no significant difference in TTL for the three reliability groups (i.e., 100%, 90%, and 70%) or system status (i.e., Active and Inactive), and there was no significant interaction between the two. Additionally, no significant differences were observed between the baseline and LDWS exposure conditions with Group B (Figure 3.4).

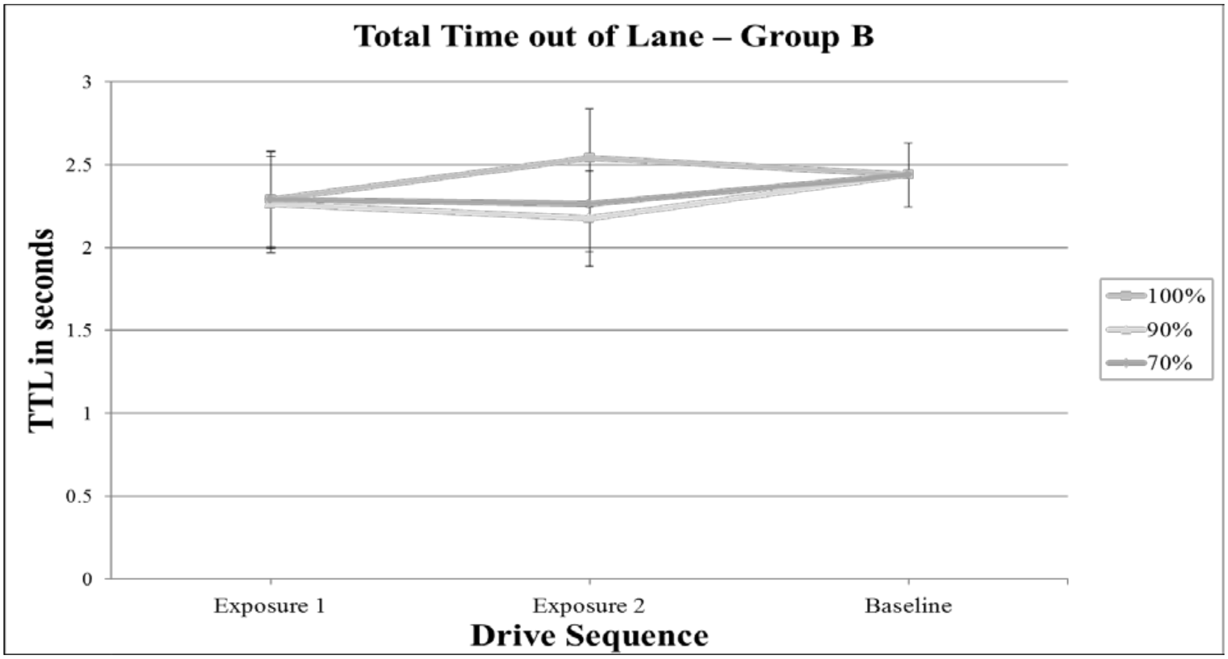

Figure 3.4. Average TTL across the sets of drives and reliability levels for Group B

3.2.2 Maximum Lane Deviation (MLD)

For Group B, there was no significant difference in MDL for the three reliability groups (i.e., 100%, 90%, and 70%) or system status (i.e., Active and Inactive), and there was no significant interaction between the two. Additionally, no significant differences were observed between the baseline and LDWS exposure conditions with Group B (Figure 3.5).

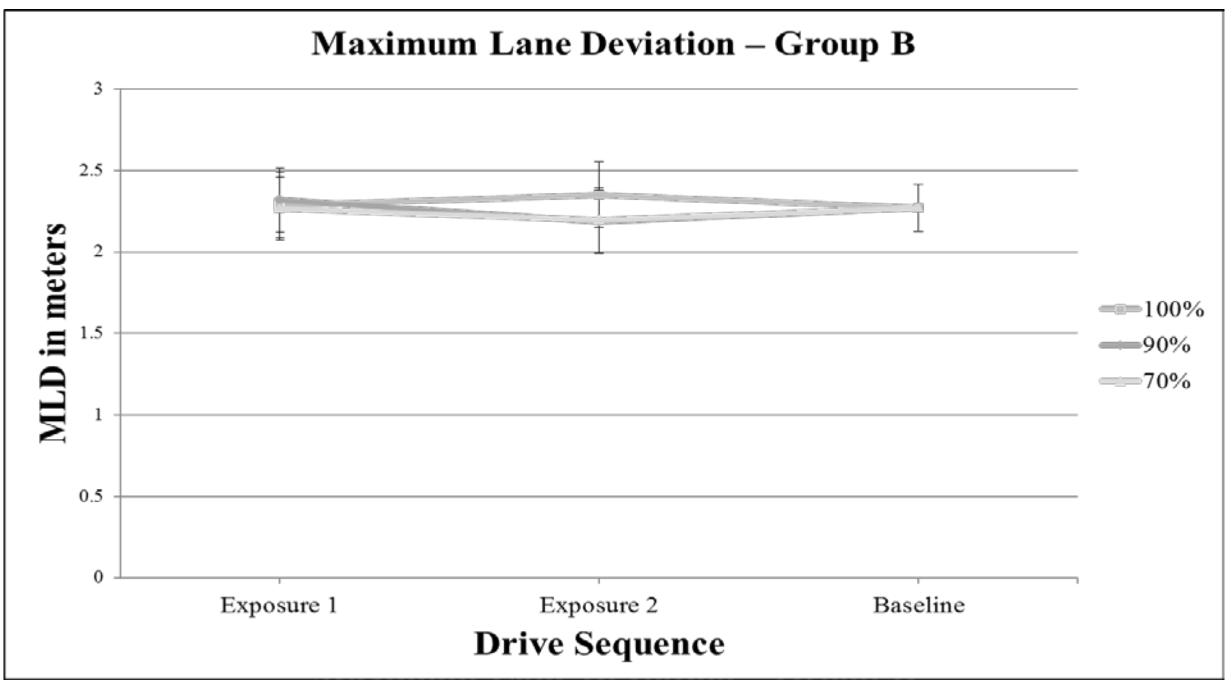

Figure 3.5. Average MLD across three drives by reliability level for Group B

3.3 User Acceptance: Workload and Trust

3.3.1 NASA-TLX Results

The averages for the total workload score and each subscale score were calculated for both Group A and Group B. For both groups, no significant differences were found between reliability conditions and drive conditions (i.e., baseline, exposure 1, and exposure 2) within each reliability level. Nevertheless, a notable trend in the frustration, effort, and mental demand subscale scores were observed for Group A (see Table 3.6). Specifically, lower frustration, effort, and mental demand scores were associated with higher system reliability; however, these values did not reach statistical significance.

Table 3.6. Average responses for Group A on NASA-TLX items related to frustration, effort, and mental demand

Condition		Mean Frustration score	Mean Effort score	Mean Mental Demand score
100%	Baseline	30	50	43
	LDWS Exposure 1	39	55	44
	LDWS Exposure 2	34	52	47
90%	Baseline	30	63	50
	LDWS Exposure 1	40	64	65
	LDWS Exposure 2	51	54	68
70%	Baseline	51	62	63
	LDWS Exposure 1	49	66	68
	LDWS Exposure 2	48	64	65

3.3.2 Trust Survey

Participants were asked to complete the trust survey after each set of exposure drives. The responses for LDWS Exposures 1 and 2 from both Groups A and B were combined and one-way ANOVA's were conducted to observe any significant differences between reliability levels. The predicted positive relationship between reliability and trust emerged from six items on the trust survey, two of which revealed statistically significant values (see Figure 3.6). Mean differences between 100% and 70% reliability conditions were statistically significant for the item "the system is reliable" ($F = 3.17$, $p = 0.046$). Additionally, mean differences between 100% and 70% reliability conditions were statistically significant for the item "the system is dependable" ($F = 3.38$, $p = 0.037$). Overall, it is evident that participants with greater reliability demonstrated greater trust in their system.

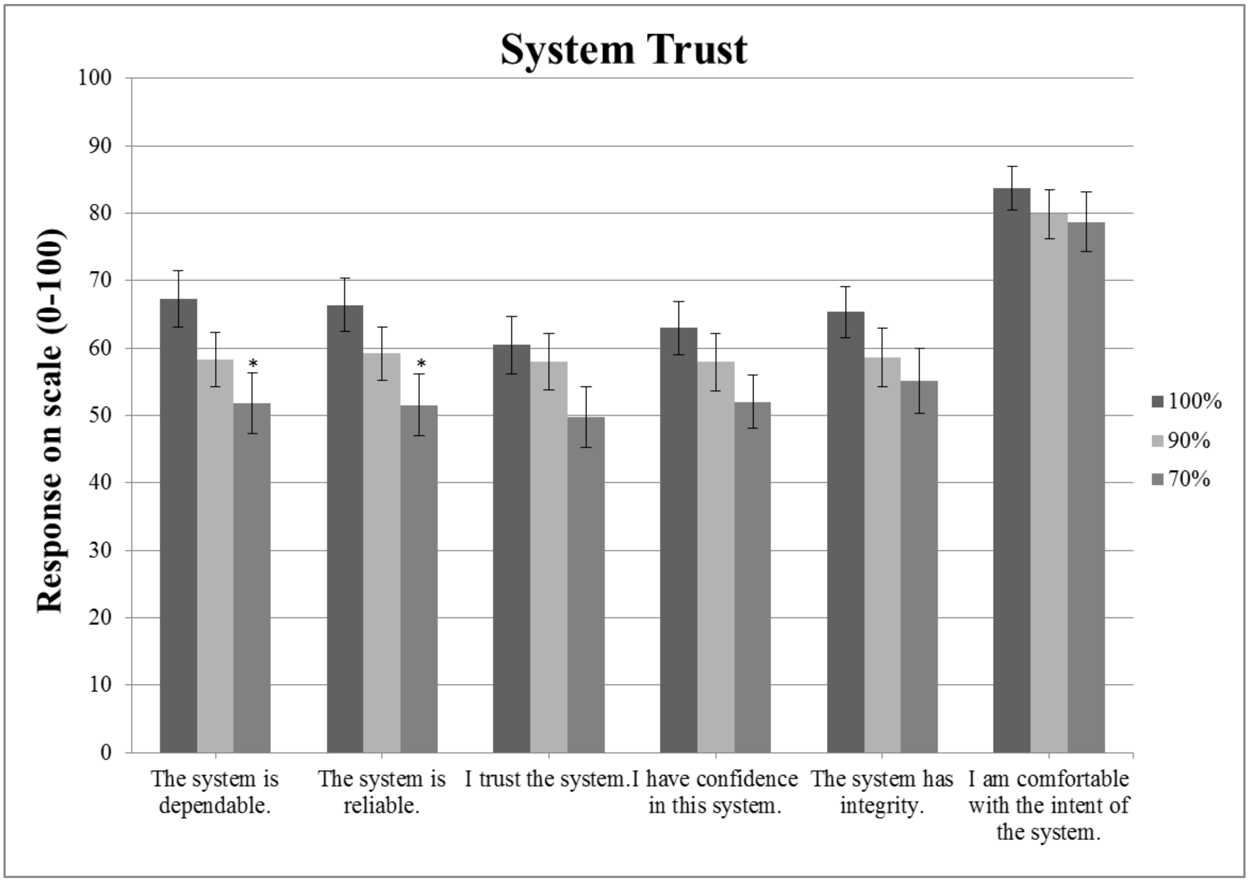

Figure 3.6. Average responses to 6 items on the system trust questionnaire. Note: *denotes $p<0.05$

3.3.3 Final Questionnaire

Percentage of positive response to six "yes/no" items on the final questionnaire were calculated for each reliability group and results are presented in Table 3.7. The values presented in the table depict the number of participants that responded "yes" to the given question. Generally speaking, it was found that participants in the 100% reliability group showed more favor toward the system than those in the 70% reliability group. However, the difference was not significant at a statistical level. Participants' open-ended responses for the two LDWS efficacy items on the final questionnaire were coded into themes and presented in Table 3.8. The values in the table represent the total number of responses that fell under a given theme.

Table 3.7. Percentage of positive responses to a given question by reliability level.

Question	Reliability		
	100%	**90%**	**70%**
Do you think the timing of the warning system was appropriate?	80%	55%	50%
Did it warn you soon enough?	55%	40%	45%
Do you feel that the warning improved your ability to return to the lane quickly?	60%	45%	40%
Do you think the warning system was reliable enough?	70%	40%	30%
Would you feel comfortable with this warning system in your vehicle?	70%	60%	35%
Would you be willing to purchase an LDWS?*	20%	20%	15%

*Note: 1 participant mentioned that he would purchase the LDWS system on the condition that they lived in a rural setting.

Question	Theme	Reliability		
		100%	**90%**	**70%**
How did you feel about the effectiveness of the lane departure warning system you experienced today?	Triggered too late, false alarms, etc.	8	8	12
	Distracting, startling, irritating	2	6	2
	Effective, helpful, etc.	8	5	5
Do you feel the warning improved your ability to return to the lane quickly? If not, why?	Distraction concern	0	4	1
	Over-correcting concern	2	0	1

Table 3.8. Number of positive responses to a given LDWS efficacy item by reliability level

Chapter 4. General Discussion and Conclusions

4.1 Lane Departure Warning System Efficacy

System efficacy was demonstrated through a significantly reduced total time out of lane (TTL) in the LDWS exposure drives (active LDWS) compared to the baseline drives (inactive LDWS), indicating that the presence of the LDWS helped reduce the severity of a lane departure. Generally speaking, LDWS led to shorter durations of lane departure events. Numerous covariates (e.g., road shape, vehicle velocity) were found to predict the variance in TTL, showing that ROR events can be mitigated from a variety of vantage points. Most notably, a reduction in speed could have the most significant impact on reducing the severity of a lane departure event by TTL. This finding is supported by previous studies that demonstrated speed to be one of the leading contributors in the occurrence of ROR crashes (Garder, 2006; Liu & Subramanian, 2009; Liu & Jianqiang, 2011). Together, the findings suggest that drivers can possibly benefit from timely speed warnings at dangerous curves.

System efficacy was also supported by the evidence that participants who first experienced the lane departure events without the assistance of a LDWS (Group A) traveled farther out of their lane, as exhibited by a larger maximum lane deviation (MLD), than those who were supported by the LDWS initially (Group B). Specifically, participants in Group A who began with the baseline drives (i.e., inactive LDWS) had significantly higher MLD than those in Group B who began with the LDWS exposure drives (i.e., active LDWS)—this was observed with LDWS of all reliability levels (70%, 90%, and 100%). When the participants in Group B eventually drove without the LDWS (i.e., baseline), they maintained significantly reduced deviation measures (i.e., MLD), suggesting long-term benefits of the LDWS. Notably, the covariate of *overlapping secondary tasks* (i.e., participants engaged in a distraction task at the time of the lane departure event) was found to significantly predict the variance in MLD, suggesting that distraction plays a significant role in lane departures. This finding aligns with previous research that found distraction to be a leading contributor to the occurrence of ROR crashes (Garder, 2006; Liu & Jianqiang, 2011).

4.2 Evidence of Behavioral Adaptation

Based on the findings of this report, behavioral adaptation (BA) was not observed with LDWS. Those who drove without the LDWS after they had been exposed to it did not appear to experience any decrements in driving performance (as measured by TTL and MLD), indicating that the LDWS does not impose the risk of behavioral adaptation or overreliance on the system. This finding may reflect the short time periods studied in this project—the total system exposure period may not be sufficient in length to produce behavioral adaptation in drivers.

4.3 Effects of Reliability on Driver Trust

Those in the 100% reliability condition had the highest level of trust and belief in the dependability of the system. Notably, all reliability conditions saw a disproportionately large number of participants reporting that the system gave them “false positives” or “false alarms” during the experiment. While the experiment did not introduce any false positives into the system, this finding is not surprising, since striking an optimal balance between false/early alarms and missed/late alerts is difficult to achieve with all in-vehicle warning devices. Future iterations of haptic LDWS can look to adjust the sensitivity of lane marking detection techniques to help reduce drivers' perception of false alarms.

Chapter 5. Limitations and Future Research

5.1 Limitations

This project may be subject to some of the limitations inherent to all driving simulation studies. Specifically, it may be difficult for participants to feel vulnerable driving in a simulator. They may not feel that they will cause any real damage to their vehicle or to the occupants on board, and their driving behavior may accordingly reflect this perception (e.g., more risk taking behaviors). Alternatively, knowing that they are exempt from any penalties associated with speeding (e.g., ticketing) may lead the participants to exhibit more speeding behavior in the simulator than might have been observed in the field, in effect threatening the external validity of this study (i.e., the extent to which the results gathered from this particular set of participants can be generalized to the population at large in the real world).

Conversely, the driving simulation provided a means for the researchers to place participants in near-crash scenarios, study their driving behavior, and evaluate LDW system design without exposing them to any real risks. Driving simulation also provided an optimally controlled environment to help eliminate the confounding variables (e.g., weather, lighting, and traffic) that occur with on-road driving and the associated unintended effects on driving performance—this ensured that any observed effect on driving performance can be safely attributed to the manipulation variables.

5.2 Conclusions and Future Research

Future studies should look to increase sample size and testing periods to better understand the relationship between drivers' overreliance on LDWS and behavioral adaptation. Overall results of this study have demonstrated that LDWS offers a promising means to reduce the severity of run-off-road events through a lateralized haptic feedback in the seat. Future iterations of the LDWS should look to reduce false alarm rates while maintaining a level of reliability that facilitates users' trust in the system.

An important research finding was that distraction predicted the severity of a participant's ROR event. Participants that were engaged in the secondary distraction task were more likely to travel further out of lane than those not engaged in the secondary task (i.e., not distracted) at the onset of the lane departure event. The additional interaction demonstrated between velocity and curves to predict MLD severity highlights the fatal combination of distracted drivers who enter a curve at an unsafe speed. Given the propensity of cell phone distraction, a smartphone-based curve warning system may be an elegant solution to help reduce driver distraction and speed approaching curves, ultimately decreasing ROR crashes. This research points to the need to develop a system to alert drivers to disengage from any distraction tasks and slow their speed as they approach curves.

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Appendix A
NASA-TLX

NASA-TLX SURVEY

1. How mentally demanding was the task?

Very low Very high

0--5--10--15--20--25--30--35--40--45--50--55--60--65--70--75--80--85--90--95--100

2. How physically demanding was the task?

Very low Very high

0--5--10--15--20--25--30--35--40--45--50--55--60--65--70--75--80--85--90--95--100

3. How hurried or rushed was the task?

Very low Very high

0--5--10--15--20--25--30--35--40--45--50--55--60--65--70--75--80--85--90--95--100

4. How successful were you in accomplishing what you were asked to do?

Perfect Failure

0--5--10--15--20--25--30--35--40--45--50--55--60--65--70--75--80--85--90--95--100

5. How hard did you have to work to accomplish your level of performance?

Very low Very high

0--5--10--15--20--25--30--35--40--45--50--55--60--65--70--75--80--85--90--95--100

6. How insecure, discouraged, irritated, stressed, or annoyed were you?

Very low Very high

0--5--10--15--20--25--30--35--40--45--50--55--60--65--70--75--80--85--90--95--100

Appendix B
System Trust Questionnaire

SYSTEM TRUST QUESTIONNAIRE

1. The performance of the system enhanced my driving safety.

Strongly Disagree	Strongly Agree

0-------10-------20-------30--------40-------50-------60-------70-------80-------90------100

2. I am familiar with the operation of the system.

Strongly Disagree	Strongly Agree

0-------10-------20-------30--------40-------50-------60-------70-------80-------90------100

3. I trust the system.

Strongly Disagree	Strongly Agree

0-------10-------20-------30--------40-------50-------60-------70-------80-------90------100

4. The system is reliable

Strongly Disagree	Strongly Agree

0-------10-------20-------30--------40-------50-------60-------70-------80-------90------100

5. The system is dependable.

Strongly Disagree	Strongly Agree

0-------10-------20-------30--------40-------50-------60-------70-------80-------90------100

6. I have confidence in this system.

Strongly Disagree	Strongly Agree

0-------10-------20-------30--------40-------50-------60-------70-------80-------90------100

7. The system has integrity.

Strongly Disagree | Strongly Agree

0-------10-------20-------30--------40-------50-------60-------70-------80-------90------100

8. I am comfortable with the intent of the system.

Strongly Disagree | Strongly Agree

0-------10-------20-------30--------40-------50-------60-------70-------80-------90------100

9. I am confident in my ability to drive the car safely without the system.

Strongly Disagree | Strongly Agree

0-------10-------20-------30--------40-------50-------60-------70-------80-------90------100

Appendix C
Final Questionnaire

WARNING SYSTEM FINAL QUESTIONNIARE

For each of the following questions, please write a few sentences. If you would like the experimenter to type your responses, please let the experimenter know.

1. How do you feel about the effectiveness of the lane departure warning system you experienced today?

2. a) Do you think the timing of the warning system was appropriate? b) Did it warn you too soon?

3. Do you feel that the warning improved your ability to return to the lane quickly? Why or why not?

4. a) Do you think the warning system was reliable enough? b) Would you feel comfortable with this warning system in your vehicle?

5. Do you think the lane departure warning system was effective for this type of driving (rural/two-lane roadway)? If yes, please explain why you think so. If "No", what needs to be changed?

6. Some warning systems can be more reliable than others (warning at the right time), while some systems give you more false alarms or warn you at the wrong time. What level (in percent e.g., 0-100%) do you think the warning system needs to be set at so you'd trust the system?

7. a) Would you be willing to purchase a lane departure warning system? b) Would you be willing to take a free one if it was offered to you?

Appendix D
Driving History Questionnaire

DRIVING HISTORY QUESTIONNAIRE **Participant #______**

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

1. Your age: ______________ years

2. Your sex:

☐ Male

☐ Female

3. What is your highest educational level completed?

☐ High School / Vocational School

☐ Associates Degree

☐ Bachelor of Arts / Bachelor of Science

☐ Masters

☐ PhD

4. Are you currently taking any college level classes?

☐ Yes

☐ No

5. Please state your occupation:____

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

7. About how often do you drive nowadays?

☐ ======= ☐ ======= ☐ ======= ☐ ======= ☐

Never	Hardly Ever	Sometimes	Most Days	Every Day

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

☐ Less than 5000 miles

☐ 5000-10,000 miles

☐ 10,000-15,000 miles

☐ 15,000-20,000 miles

☐ Over 20,000 miles

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

☐ ======= ☐ ======= ☐ ======= ☐ ======= ☐

Never	Hardly Ever	Sometimes	Most Days	Every Day

10. Do you drive frequently on…

	Yes	No
Highways?	☐	☐
Main Roads other than Highways?	☐	☐
Urban Roads?	☐	☐
Country Roads?	☐	☐

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

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

12. During the last three years, how many <u>major</u> road crashes have you been involved in where you were at fault? A major crashes 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 crashes ____ (if none, write 0)

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

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

17. 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 E
Driving Opinion Locus of Control

DRIVING OPINION LOCUS OF CONTROL QUESTIONNAIRE

PARTICIPANT #___

The following questions will ask you to rate how much you agree or disagree with the statement presented. Please identify your response to each statement by checking the box by your preferred answer. Use the following scale to answer each question:

- (•) Very much disagree
- ( ) Disagree quite a bit
- ( ) Disagree a little
- ( ) Agree a little
- ( ) Agree quite a bit
- ( ) Very much agree

1. Driving with no accidents is mainly a matter of luck:

2. Accident happen mainly because of different unpredictable events:

3. The driver can do nothing more than drive according to traffic regulations:

4. Accidents happen because of so many reason we will never know the most important one:

5. People who drive a lot with no accidents are merely lucky; it is not because they are careful:

6. The careful driver can prevent any accident:

7. When a driver is involved in an accident, it is because the driver did not drive as they should:

8. When a driver is involved in an accident, it is because they did not pay attention to their driving:

9. Accidents are only the result of mistakes made by the driver:

10. The driver is to be blamed almost always when an accident occurs:

11. It is difficult to prevent accidents in bad conditions such as darkness, rain, narrow roads, curves, and so on:

12. Most accidents happen because of bad roads, lack of appropriate signs, and so on:

13. It is very hard to prevent accidents involving pedestrians who come out from between parked cars:

14. Accidents in which children are involved are hard to prevent because they do not know how to be careful:

15. It is very hard to prevent accidents in which old people are involved because they cannot hear nor see well:

16. Accidents happen because drivers have not learned how to drive carefully enough:

17. It is always possible to predict what is going to happen on the road and so it is possible to prevent almost any accident:

18. Accidents happen when the first driver does not take into consideration all the possible actions of the second driver:

19. Accidents happen because the driver does not make enough effort to detect all sources of danger while driving:

20. Most accidents happen because of lack of knowledge or laziness on the part of the driver:

21. If you are to be involved in an accident, it is going to happen anyhow, no matter what you do:

22. Most accidents happen because the second driver does not pay attention to traffic regulations even when the first driver does:

23. The driver does not have enough control over what happens on the road:

24. Most accidents happen because of mechanical failures:

25. There will always be accidents no matter how much drivers try to prevent them:

26. Accidents happen when the driver does not take into consideration all the possible behaviors of pedestrians:

27. Accident-free driving is a result of the driver's ability to pay attention to what is happening on the roads and sidewalks:

28. The driver can always predict what is going to happen; that is why there is no room for surprises on the road:

29. It is possible to prevent accidents even in the most difficult conditions such as narrow roads, darkness, rain, and so on:

30. Prevention of accidents depends only on the driver and their characteristics rather than on external factors:

Appendix F
Boredom Propensity Scale

BOREDOM PROPENSITY SCALE **PARTICIPANT #__**

Please answer the following statements using a rating scale of 1 to 7, with 1 being "Strongly Disagree" and 7 "Strongly Agree". Click on the answer choice matching your rating.

1= Strongly Disagree
2= Disagree
3= Somewhat Disagree
4= Neither Agree or Disagree
5= Somewhat Agree
6= Agree
7= Strongly Agree

1. It is easy for me to concentrate on my activities.
2. Frequently when I am working I find myself worrying about other things.
3. Time always seems to be passing slowly.
4. I often find myself at "loose ends", not knowing what to do.
5. I am often trapped in situations where I have to do meaningless things.
6. Having to look at someone's home movies or travel slides bores me tremendously.
7. I have projects in mind all the time, things to do.
8. I find it easy to entertain myself.
9. Many things I have to do are repetitive and monotonous.
10. It takes more stimulation to get me going than most people.
11. I get a kick out of most things I do.
12. I am seldom excited about my work.
13. In any situation I can usually find something to do or see to keep me interested.
14. Much of the time I just around doing nothing.
15. I am good at waiting patiently.
16. I often find myself with nothing to do, time on my hands.
17. In situations where I have to wait, such as in line, I get very restless.
18. I often wake up with a new idea.
19. It would be very hard for me to find a job that is exciting enough.
20. I would like more challenging things to do in life.
21. I feel that I am working below my abilities most of the time.
22. Many people would say that I am a creative or imaginative person.
23. I have so many interests, I don't have time to do everything.
24. Among my friends, I am the one who keeps doing something the longest
25. Unless I am doing something exciting, even dangerous, I feel half-dead and dull.
26. It takes a lot of change and variety to keep me really happy.
27. It seems that the same things are on television or in the movies all the time; it's getting old.
28. When I was young, I was often in monotonous and tiresome situations.

Appendix G
Sensation Seeking Scale

SENSATION SEEKING SCALE **PARTICIPANT # __**

Directions: Each of the items below contains two choices, A and B. Please indicate (click on) which of the choices most describes your likes or the way you feel. In some cases you may find items in which both choices describe your likes or feelings. Please choose the one which better describes your likes or feelings. In some cases you may find items in which you do not like either choice. In these cases, mark the choice you dislike least. Please try to answer each item.

It is important you respond to all items with only one choice, A or B. We are interested only in your likes or feelings, not in how others feel about these things or how one is supposed to feel. There are no right or wrong answers. Be frank and give your honest appraisal of yourself.

1. A. I like "wild" uninhibited parties
   B. I prefer quiet parties with good conversation

2. A. There are some movies I enjoy seeing a second or even a third time
   B. I can't stand watching a movie that I've seen before

3. A. I often wish I could be a mountain climber
   B. I can't understand people who risk their necks climbing mountains

4. A. I dislike all body odors
   B. I like some for the earthly body smells

5. A. I get bored seeing the same old faces
   B. I like the comfortable familiarity of everyday friends

6. A. I like to explore a strange city or section of town by myself, even if it means getting lost
   B. I prefer a guide when I am in a place I don't know well

7. A. I dislike people who do or say things just to shock or upset others
   B. When you can predict almost everything a person will do or say he or she must be a bore

8. A. I usually don't enjoy a movie or play where I can predict what will happen in advance
   B. I don't mind watching a movie or a play where I can predict what will happen in advance

9. A. I have tried marijuana or would like to
   B. I would never smoke marijuana

10. A. I would not like to try any drug which might produce strange and dangerous effects on me
    B. I would like to try some of the new drugs that produce hallucinations

11. A. A sensible person avoids activities that are dangerous
B. I sometimes like to do things that are a little frightening

12. A. I dislike "swingers" (people who are uninhibited and free about sex)
B. I enjoy the company of real "swingers"

13. A. I find that stimulants make me uncomfortable
B. I often like to get high (drinking liquor or smoking marijuana)

14. A. I like to try new foods that I have never tasted before
B. I order the dishes with which I am familiar, so as to avoid disappointment and unpleasantness

15. A. I enjoy looking at home movies or travel slides
B. Looking at someone's home movies or travel slides bores me tremendously

16. A. I would like to take up the sport of water skiing
B. I would not like to take up water skiing

17. A. I would like to try surf boarding
B. I would not like to try surf boarding

18. A. I would like to take off on a trip with no preplanned or definite routes, or timetable
B. When I go on a trip I like to plan my route and timetable fairly carefully

19. A. I prefer the "down to earth" kinds of people as friends
B. I would like to make friends in some of the "far out" groups like artists or "punks"

20. A. I would not like to learn to fly an airplane
B. I would like to learn to fly an airplane

21. A. I prefer the surface of the water to the depths
B. I would like to go scuba diving

22. A. I would like to meet some persons who are homosexual (men or women)
B. I stay away from anyone I suspect of being "gay or lesbian"

23. A. I would like to try parachute jumping
B. I would never want to try jumping out a plane with or without a parachute

24. A. I prefer friends who are excitingly unpredictable
B. I prefer friends who are reliable and predictable

25. A. I am not interested in experience for its own sake
B. I like to have new and exciting experiences and sensations even if they are a little frightening, unconventional, or illegal

26. A. The essence of good art is in its clarity, symmetry or form and harmony of colors
B. I often find beauty in the “clashing” colors and irregular forms of modern paintings

27. A. I enjoy spending time in the familiar surroundings of home
B. I get very restless if I have to stay around home for any length of time

28. A. I like to dive off the high board
B. I don’t like the feeling I get standing on the high board (or I don’t near it at all)

29. A. I like to date people who are physically exciting
B. I like to date people who share my values

30. A. Heavy drinking usually ruins a party because some people get loud and boisterous
B. Keeping the drinks full is the key to a good party

31. A. The worst social sin is to be rude
B. The worst social sin is to be a bore

32. A. A person should have considerable sexual experience before marriage
B. It’s better if two married persons begin their sexual experience with each other

33. A. Even if I had the money I would not care to associate with rich persons like those in the “jet set”
B. I could conceive of myself seeking pleasures around the world with the “jet set”

34. A. I like people who are sharp and witty even if they do sometimes insult others
B. I dislike people who have their fun at the expense of hurting the feelings of others

35. A. There is altogether too much portrayal of sex in movies
B. I enjoy watching many of the “sexy” scenes in movies

36. A. I feel best after taking a couple of drinks
B. Something is wrong with people who need liquor to feel good

37. A. People should dress according to some standard of taste, neatness, and style
B. People should dress in individual ways even if the effects are sometimes strange

38. A. Sailing long distances in small sailing crafts is foolhardy
B. I would like to sail a long distance in a small but seaworthy sailing craft

39. A. I have no patience with dull or boring persons
B. I find something interesting in almost every person I talk to

40. A. Skiing down a high mountain slope is a good way to end up on crutches
B. I think I would enjoy the sensations of skiing very fast down a high mountain slope