U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

www.nhtsa.gov

DOT HS 811 501 July 2011

A Test Track Protocol for Assessing Forward Collision Warning Driver-Vehicle Interface Effectiveness

DISCLAIMER

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. DOT HS 811 501	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A Test Track Protocol for Assessing Forward Collision Warning Driver-Vehicle Interface Effectiveness		5. Report Date July 2011 6. Performing Organization Code NHTSA/NVS-312
7. Author(s) Garrick Forkenbrock; NHTSA Andrew Snyder, Mark Heitz, Richard L. (Dick) Hoover, Bryan O'Harra, Scott Vasko, and Larry Smith; Transportation Research Center, Inc.		8. Performing Organization Report No.
9. Performing Organization Name and Address National Highway Traffic Safety Administration Vehicle Research and Test Center 10820 SR 347; P.O. Box B37 East Liberty, OH 43319-0337		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Avenue SE. Washington, DC 20590		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code NHTSA/NVS-312

15. Supplementary Notes

The authors acknowledge the support of Lisa Daniels, Don Thompson, Thomas Gerlach Jr., Randy Landes, John Martin, Tim Van Buskirk, Matt Hostetler, Josh Orahood, Patrick Biondillo, and Ralph Fout, for assistance with vehicle preparation, instrumentation installation, test conduct, and data processing; and Scott Baldwin and Tom Ranney for insights into experimental design.

16. Abstract

The primary objective of the work described in this report was to develop a protocol suitable for evaluating forward collision warning (FCW) driver-vehicle interface (DVI) effectiveness. Specifically, this protocol was developed to examine how distracted drivers respond to FCW alerts in a crash imminent scenario.

To validate the protocol, a diverse sample of 64 drivers was recruited from central Ohio for participation in a small-scale, test track based human factors study. Each participant was asked to follow a moving lead vehicle (MLV) within the confines of a controlled test course and, while attempting to maintain a constant headway, instructed to perform a series of four distraction tasks intended to briefly divert their attention away from a forward-viewing position. With the participant fully distracted during the final task, the MLV was abruptly steered out of the travel lane, revealing a stationary lead vehicle (SLV) in the participant's immediate path (a realistic-looking full-size balloon car). At a nominal time-to-collision (TTC) of 2.1s from the stationary vehicle, one of eight FCW alerts was presented to the distracted participant. Each alert modality was intended to emulate one or more elements from those presently available in contemporary vehicles.

The timing of the critical events contained within the protocol appears to be repeatable, appropriate, and effective. With respect to evaluation metrics, the data produced during this study indicate that reaction time and crash outcome provide good measures of FCW alert effectiveness, where reaction time is best defined as the onset of FCW to the instant the driver's forward-facing view is reestablished. Using these criteria, the seat belt pretensioner-based FCW alerts used in this study elicited the most effective crash avoidance performance. That said, of the 32 trials performed with some form of seat belt pretensioner-based FCW alert, 53.1 percent of them still resulted in a crash.

FCW modality had a significant effect on the participant reaction time from the onset of an FCW alert, and on the speed reductions resulting from the participants' avoidance maneuvers (regardless of whether a collision ultimately occurred). Differences in participant response times from the instant their forward-facing view was reestablished to throttle release, brake application, and avoidance steer were not significant, nor were brake application and avoidance steer magnitudes.

17. Key Words Crash Warning Interface Metrics (CWIM), Forward Collision Warning (FCW), Driver Vehicle Interface (DVI), Test Track Evaluation		18. Distribution Statement Document is available to the public from the National Technical Information Service www.ntis.gov	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 143	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
in	inches	2.54	centimeters	cm
ft	feet	30.48	centimeters	cm
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.45	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
mi^2	square miles	2.59	square kilometers	km^2
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.45	kilograms	kg
		PRESSURE		
psi	pounds per $inch^2$	0.07	bar	bar
psi	pounds per $inch^2$	6.89	kilopascals	kPa
		VELOCITY		
mph	miles per hour	1.61	kilometers per hour	km/h
		ACCELERATION		
ft/s^2	feet per $second^2$	0.30	meters per $second^2$	m/s^2
		TEMPERATURE (exact)		
°F	Fahrenheit	5/9 (Fahrenheit) - 32°C	Celsius	°C

Approximate Conversions to English Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.39	inches	in
m	meters	3.3	feet	ft
km	kilometers	0.62	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	10.76	square feet	ft^2
km^2	square kilometers	0.39	square miles	mi^2
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
		PRESSURE		
bar	bar	14.50	pounds per $inch^2$	psi
kPa	kilopascals	0.145	pounds per $inch^2$	psi
		VELOCITY		
km/h	kilometers per hour	0.62	miles per hour	mph
		ACCELERATION		
m/s^2	meters per $second^2$	3.28	feet per $second^2$	ft/s^2
		TEMPERATURE (exact)		
°C	Celsius	9/5 (Celsius) + 32°F	Fahrenheit	°F

NOTE REGARDING COMPLIANCE WITH AMERICANS WITH DISABILITIES ACT SECTION 508

For the convenience of visually impaired readers of this report using text-to-speech software, additional descriptive text has been provided for graphical images contained in this report to satisfy Section 508 of the Americans with Disabilities Act (ADA).

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

EXECUTIVE SUMMARY

The current phase of the National Highway Traffic Safety Administration's (NHTSA) Crash Warning Interface Metrics (CWIM) program is intended to identify which alert modalities most effectively assist distracted drivers in forward collision and lane departure crash scenarios. Once identified, the program seeks to develop test protocols and evaluation metrics to help assess the safety benefits associated with these alerts. Ultimately, it is envisioned that NHTSA will use the outputs of the CWIM program to encourage vehicle manufacturers to implement FCW and Lane Departure Warning (LDW) alerts with a standardized interface design and operational characteristics.

The primary objective of the work described in this report was to develop a protocol suitable for evaluating forward collision warning (FCW) driver-vehicle interface (DVI) effectiveness. Specifically, this protocol was developed to examine how distracted drivers respond to FCW alerts in a crash imminent scenario.

To validate the protocol, a diverse sample of 64 drivers was recruited from central Ohio for participation in a small-scale, test track based human factors study. Each participant was asked to follow a moving lead vehicle (MLV) within the confines of a controlled test course and, while attempting to maintain a constant headway, perform a series of four distraction tasks intended to briefly divert their attention away from a forward-viewing position. With the participant fully distracted during the final task, the MLV was abruptly steered out of the travel lane, revealing a stationary lead vehicle (SLV) in the participant's immediate path (a realistic-looking full-size balloon car). At a nominal time-to-collision (TTC) of 2.1s from the SLV, one of eight FCW alerts was presented to the distracted participant. Each alert modality was intended to incorporate one or more elements from those presently available in contemporary vehicles. Table 1 lists the alert modalities used in this study, and the vehicle's they originated in.

Table 1. FCW Alert Modality Summary.

FCW Modality	Alert Origin
None	Baseline (no alert)
Visual Only	2008 Volvo S80 (HUD)
Auditory Only	2010 Mercedes E350 (repeated beeps)
Haptic Seat Belt	2009 Acura RL (reversible seat belt pretensioner)
Visual + Auditory	2008 Volvo S80 + 2010 Mercedes E350
Visual + Haptic Seat Belt	2008 Volvo S80 + 2009 Acura RL
Auditory + Haptic Seat Belt	2010 Mercedes E350 + 2009 Acura RL
Visual + Auditory +Haptic Seat Belt	2008 Volvo S80 + 2010 Mercedes E350 + 2009 Acura RL

The timing of the critical events contained within the protocol appears to be repeatable, appropriate, and effective. Presentation of task instructions and FCW alerts was accurately controlled and repeatable. With very few exceptions, participants maintained an acceptable headway, began the random number recall task when instructed to do so, and were fully distracted when presented with an FCW alert.

With respect to evaluation metrics, the data produced during this study indicate that driver reaction time and crash outcome provide good measures of FCW alert effectiveness. Many variants of reaction time were explored in this study, however the interval defined by the onset of the FCW alert to the end of visual commitment (i.e., VC_{end}, the instant the driver returns their attention to a forward-facing viewing position) appears to be the most appropriate. While reaction time from FCW to throttle release, brake application, and/or steering input also provide good indications of FCW alert effectiveness, it is important to consider that drivers can use different techniques to arrive at a successful crash avoidance outcome (e.g., some drivers may use steering but no braking). Interestingly, while FCW modality had a significant effect on the participant reaction time, differences from the instant their forward-facing view was reestablished to throttle release, brake application, and avoidance steer were not significant, nor were brake application and avoidance steer magnitudes.

Overall, 17 of the 64 participants avoided collisions with the SLV (26.6 percent). Fifteen of the successfully-avoided crashes (88.2 percent) occurred during trials performed with the haptic alert, or an alert combination inclusive of the haptic modality. One crash (1.6 percent) was avoided during a trial performed with the auditory only alert, one with a modality based on a combination of the auditory and visual alert. These results clearly indicate the seat belt pretensioner-based haptic alert used in this study offered better crash avoidance effectiveness than the other individual modalities on the test track. However, the authors emphasize that of the 32 trials performed with some form of this haptic alert, 53.1 percent of them still resulted in a crash.

When considering the crash vs. avoid data presented in this report, it is important to recognize that being involved in a crash does not necessarily indicate the participant did not respond to the FCW modality used in their individual trial. Although most participants crashed into the SLV because they failed to respond to the various FCW alerts used in this study (or were not presented with one), some crashed because their avoidance strategy was simply not effective.

To quantify this phenomenon, the crash avoidance response of each participant was categorized in one of three ways:

1. FCW alert response likely, crash avoided
2. FCW alert response likely, crash not avoided
3. FCW alert response not likely, crash not avoided

A summary of crash outcome, presented as a function of FCW modality and crash avoidance response, is shown in Table 2. Results of this categorization were used in conjunction with FCW⇨VC_{end} duration as a means of quantifying response time, as shown in Figure 1. Here, the range of response times where FCW alert responses were likely and the crash avoided was 270 to 870 ms. For the cases where FCW alert responses were likely but the crash still occurred, response times were between 330 ms to 1.0 second. Finally, for the instances where FCW alert responses were not likely, response times were between 870 ms to 1.74 seconds. If the participant did not respond to the FCW alert, a crash always occurred.

Table 2. FCW Alert Response Summary.

FCW Alert Modality	# of Participants		
	Response Likely, Crash Avoided	**Response Likely, Crash Not Avoided**	**Response Not Likely, Crash Not Avoided**
None (no alert)	--	--	8
Visual Only (Volvo HUD)	--	--	8
Auditory Only (Mercedes Beep)	1	3	4
Haptic Seat Belt Only (Acura Belt)	3	--	5
Auditory + Visual	1	2	5
Visual + Haptic Seat Belt	5	1	2
Auditory + Haptic Seat Belt	3	2	3
Visual + Auditory + Haptic Seat Belt	3[1]	3	1
Total *(percent of 63 participants[1])*	**16[1]** *(25.4%)*	**11** *(17.5%)*	**36** *(57.1%)*

[1] *VC_{end} video data not available for one of the 64 participants.*

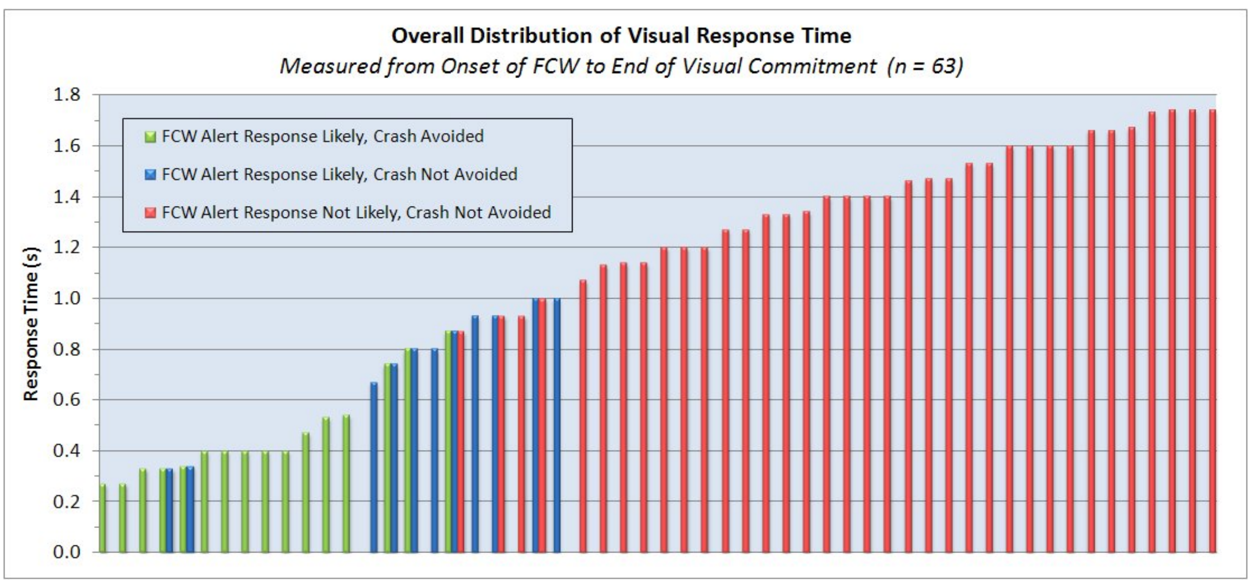

Figure 1. FCW⇨VC_{end} duration as a function of alert response likelihood and crash outcome.

1.0 BACKGROUND

1.1 The Rear End Crash Problem

Using 2004 General Estimates System (GES) statistics, a data summary assembled by the Volpe Center[1] indicated that approximately 6,170,000 police-reported crashes of all vehicle types, involving 10,945,000 vehicles, occurred in the United States [1]. Many of these crashes involved rear-end collisions, with the most common pre-crash scenarios being the Lead Vehicle Stopped, Lead Vehicle Decelerating, and Lead Vehicle Moving at Lower Constant Speed. Table 1.1 presents a summary of the frequency, cost, and harm (expressed as functional years lost) for these crash types. For each parameter, the relevance with respect to the overall crash problem is provided in parentheses.

Table 1.1. Crash Rankings By Frequency (2004 GES data).

Pre-Crash Scenario	Frequency	Cost ($)	Years Lost
Lead Vehicle Stopped	975,000 *(16.4%)*	15,388,000,000 *(12.8%)*	240,000 *(8.7%)*
Lead Vehicle Decelerating	428,000 *(7.2%)*	6,390,000,000 *(5.3%)*	100,000 *(3.6%)*
Lead Vehicle Moving at Lower Constant Speed	210,000 *(3.5%)*	3,910,000,000 *(3.3%)*	78,000 *(2.8%)*

1.2 Forward Collision Warning (FCW)

NHTSA defines a forward collision warning (FCW) system as one intended to passively assist the driver in avoiding or mitigating a rear-end collision. These systems have forward-looking vehicle detection capability, presently provided by sensing technologies such as RADAR, LIDAR (laser), cameras, etc. Using information from these sensors, an FCW system driver-vehicle interface, or DVI, alerts the driver that a collision with another vehicle in the anticipated forward pathway of their vehicle may be imminent unless corrective action is taken. Contemporary FCW systems typically include various combinations of audible, visual, and/or haptic warning modalities, presented together as a single concurrent alert.

1.3 The Crash Warning Interface Metrics (CWIM) Program

The current phase of the National Highway Traffic Safety Administration's (NHTSA) Crash Warning Interface Metrics (CWIM) program is intended to identify which alert modalities most effectively assist distracted drivers in forward collision and lane departure crash scenarios.

[1] The Volpe Center is part of the US Department of Transportation's Research and Innovative Technology Administration (RITA).

Once identified, the program seeks to develop test protocols and evaluation metrics to help assess the safety benefits associated with these alerts. Ultimately, it is envisioned that NHTSA will use the outputs of the CWIM program to encourage vehicle manufacturers to implement FCW and Lane Departure Warning (LDW) alerts with a standardized interface design and operational characteristics.

In support of the CWIM program, the University of Iowa is presently using the National Advanced Driving Simulator (NADS) to develop test protocols relevant to the forward collision and lane departure safety concerns. The work described in this report was the output of a concurrent program performed at NHTSA's Vehicle Research and Test Center (VRTC), designed to provide objective test track-based data relevant to the forward collision problem. This work was completed in three phases:

Phase I. A small sample population was exposed to a large number of FCW alert modalities in a simple detection exercise using a repeated measure experimental design. Results from these tests were used to reduce the number of FCW alert combinations used in Phase II.

Phase II. A small sample of drivers recruited from the general public participated in an experimental drive on the test track. Observations made during the conduct of this phase were used to refine the test protocol ultimately used in Phase III.

Phase III. Sixty-four drivers recruited from the general public participated in an experimental drive on the test track. Seven FCW alert modality combinations and a baseline condition were used in this phase. Data output from trials performed with each FCW alert were compared between test participants.

1.3.1 CWIM Phase I Research Performed at VRTC—Static Tests

The CWIM work performed at VRTC began by identifying what FCW alert modalities existed on contemporary production vehicles. A description of the systems representative of those available on US-specification vehicles is presented in Table 1.2. Of significance is the diversity of the alerts. At the time the tests described in this report were performed, the number of contemporary light vehicles available in the United States with FCW was quite low.

Since it was not feasible to perform a large-scale evaluation inclusive of each FCW modality shown in Table 1.2, Phase I research consisted of a small static study designed to reduce the number of auditory and visual alerts to one apiece.

1.3.1.1 Phase I Experimental Design

Preparation for the Phase I static study began with FCW alerts representative of each modality shown in Table 1.2 being installed into a common subject vehicle (SV), a 2009 Acura RL[2]. While

[2] This retrofit only involved installation of multiple alerts, not of the other hardware, etc. used to activate them.

the authors are sensitive to the likelihood vehicle manufacturers design their respective FCW alerts to be integrated systems appropriate for the vehicle in which they were installed (e.g., the auditory alert was selected to complement the visual alert, etc.), installing multiple alert modalities into one vehicle removed the confounding effect of vehicle type from subsequent analyses.

Table 1.2. Example of Contemporary FCW Modalities.

Alert	Vehicle					
	2009 Acura RL	**2010 Toyota Prius**	**2010 Mercedes E350**	**2008 Volvo S80**	**2010 Ford Taurus**	**2011 Audi A8**
Haptic	Seat Belt Pretensioner	--	Seat Belt Pretensioner	--	--	Brake Pulse (≈0.25g)
Visual	"Brake" on the MDC[1]	"Brake" on the MDC[1]	Small IC[2] Icon	LED HUD	LED HUD	"Brake Guard Activated" on the MDC[1]
Auditory	Beep	Beep	Beep	Tone	Tone	Single Gong

[1]MDC = Message Display Center
[2]IC = Instrument Cluster

Three different visual alert implementations were examined. In addition to the SV's manufacturer-equipped message display center alert, an LED head-up display (HUD) from a 2008 Volvo S80 and a small FCW icon from a 2010 Mercedes E350 were installed in the dashboard and instrument cluster, respectively, to emulate the alerts' native environments to the greatest extent possible (see Figure 1.1).

Figure 1.1. Visual alerts presented by the Volvo S80, Acura RL, and Mercedes E350 (from left to right).

Two non-native auditory alerts were used, originating from a 2010 Mercedes E350 (repeated beeping) and a 2008 Volvo S80 (repeated tone). One haptic alert was used, the SV's manufacturer-equipped seat belt pretensioner. Table 1.3 provides a summary of the alerts installed in the SV.

Phase I tests were performed with eight participants recruited from within VRTC. Upon entering the SV, participants were instructed to adjust their seat to a comfortable position and drive to a test course isolated from other facility traffic. Once at the course, participants were instructed to stop the vehicle, put the transmission in park, and face forward with their hands at the 3 and 9 o'clock positions on the steering wheel. Verbal instructions were provided to each participant by an in-vehicle experimenter who occupied the left-rear seat. All Phase I tests were performed during daylight hours.

Table 1.3. FCW Alert Modalities Installed Into NHTSA Acura RL for the Phase I Pilot Tests.

Visual				Auditory			Haptic	
"Brake" on the MDC	Small Icon	LED HUD	None	Beep	Tone	None	Seat Belt Pretensioner	None

*MDC = Message Display Center

A monitor was attached to the base of the windshield near the passenger-side A-pillar to display real-time throttle position. Participants were instructed to watch the monitor for the duration of each test trial in order to maintain a constant throttle application of 3.5 percent[3]. By monitoring the throttle position, the participants' eyes were directed away from a forward-looking viewing position, however peripheral vision still allowed them to detect activity toward the front of the vehicle (i.e., FCW alert status).

Participants were informed that they would be presented with a variety of different FCW alerts, and told to release the throttle and apply force to the brake pedal when the alert first became apparent. Following acknowledgement of an alert, participants were instructed to release the brake pedal, and resume a constant throttle position of 3.5 percent.

Presentation of the FCW alerts used in Phase I was a repeated measure. During their test session, each participant received four randomized sequences of 23 alert combinations (i.e., all possible combinations of the alerts shown in Table 1.3, except the "no alert" configuration). Therefore, each subject received a total of 92 individual alerts during Phase I. To quantify alert detectability, brake response time from the onset of FCW was measured for each trial. Following completion of the final trial, the in-vehicle experimenter presented each participant with a series of questions asking their opinion of the alerts, including which auditory and visual alert was the most apparent[4]. A complete list of the questions and the subsequent responses are provided in Appendix A. Table 1.4 summarizes the brake reaction times observed during the Phase I trials.

[3] It is anticipated that the outside temperature will be very warm during conduct of the Phase I tests. Therefore, participant comfort will require the vehicle's air conditioning (and thus the engine) and be on. Instructing the participants to maintain a moderate-to-large throttle position with the vehicle at rest would result in high engine RPM; a potentially distracting situation that could confound the ability of the participants to detect and/or respond to the FCW alerts.

[4] Subjects 1 and 2 were presented with a smaller set of post-test questions; only questions 1, 7, and 15 were used.

Table 1.4. Phase I Brake Reaction Time Summary (n =728).

Description	Brake Reaction Time (seconds)				Missed Trials
	Min	Max	Mean	Std Dev	
Acura Belt, Acura MDC	0.325	0.820	**0.507**	0.149	--
Acura Belt, Mercedes Beep, Mercedes IC	0.330	0.865	**0.516**	0.155	--
Acura Belt, Volvo Tone	0.285	1.080	**0.518**	0.187	--
Acura Belt, Mercedes Beep, Volvo HUD	0.310	0.850	**0.520**	0.162	--
Acura Belt, Mercedes Beep, Acura MDC	0.310	1.120	**0.524**	0.170	--
Acura Belt	0.320	0.910	**0.527**	0.160	--
Acura Belt, Volvo Tone, Acura MDC	0.290	0.905	**0.529**	0.163	--
Acura Belt, Volvo HUD	0.315	1.025	**0.532**	0.176	--
Acura Belt, Mercedes IC	0.330	0.920	**0.534**	0.180	--
Acura Belt, Mercedes Beep	0.335	0.950	**0.538**	0.188	--
Acura Belt, Volvo Tone, Mercedes IC	0.290	1.070	**0.540**	0.191	--
Acura Belt, Volvo Tone, Volvo HUD	0.320	0.990	**0.557**	0.200	--
Mercedes Beep, Mercedes IC	0.510	1.085	**0.690**	0.143	--
Volvo Tone, Volvo HUD	0.465	1.035	**0.705**	0.156	--
Volvo Tone, Acura MDC	0.470	1.125	**0.708**	0.187	--
Mercedes Beep, Volvo HUD	0.460	1.535	**0.713**	0.237	--
Mercedes Beep, Acura MDC	0.405	1.425	**0.747**	0.245	--
Mercedes Beep	0.495	1.065	**0.752**	0.173	--
Volvo Tone, Mercedes IC	0.460	1.535	**0.786**	0.281	--
Volvo Tone	0.475	1.365	**0.797**	0.200	--
Mercedes IC	0.495	3.395	**1.065**	0.563	**4 of 32**
Acura MDC	0.500	4.330	**1.088**	0.785	**3 of 32**
Volvo HUD	0.505	2.940	**1.158**	0.577	**1 of 32**

Note: HUD = head-up display, IC = instrument cluster, MDC = message display center

In Table 1.4, results from tests performed with auditory alerts only are highlighted in green. Similarly, tests performed with visual alerts only are highlighted in blue. Results from alert configurations containing seat belt pretensioning (i.e., those containing "Acura Belt" in the description column) are shown in orange. Note that a total of 728 data points are summarized in Table 1.4. Of the 736 tests performed (8 subjects * 92 tests per subject), eight resulted in missed trials because the participants did not detect the presentation of the FCW alert. Missed trials only occurred during one of the three visual-only configurations.

1.3.1.2 Utility of the Phase I Results

Depending on the analysis performed, differences in brake reaction time observed in Phase I were either marginally significant or not statistically significant (an analysis is provided in Appendix B). Therefore, the participants' subjective impressions of the two auditory alerts were used to determine which to include in subsequent test phases. When asked which auditory alert was the most noticeable, six of the eight responses indicated the "Mercedes Beep." Two participants indicated both auditory alerts were equally apparent. Five of the six participants indicated the Mercedes beep-based alert was "obvious," "attention getting," or "urgent." Based on this feedback, the "Mercedes Beep" was retained for later use as the sole auditory alert.

The decision on which visual alert to include in subsequent test phases was confounded by the fact each visual-only configuration produced missed trials. Four of the eight participants considered the Acura message display center-based visual alert to be the most apparent, followed by the Volvo HUD (three participants), then the Mercedes instrument cluster-based alert (one participant). Given that the differences in mean brake reaction time were not significantly different across visual alert type, and since the number of missed trials was lowest for tests performed with the Volvo HUD only (i.e., when compared to the other visual-only alerts), the Volvo HUD was retained for later use.

1.3.2 CWIM Phase II Research Performed at VRTC—Protocol Refinement

Once the reduced set of FCW modalities had been identified, work to refine the protocol for evaluating driver-vehicle interface (DVI) effectiveness was performed. Unlike the static testing used in Phase I, Phase II tests were highly dynamic, placing participants recruited from the general public in a realistic crash imminent driving scenario.

1.3.2.1 Phase II Experimental Design

At a high level, the Phase II protocol asked participants to perform two tasks during an experimental drive on a controlled test course. First, they were instructed to maintain a constant distance between their vehicle and another being driven directly in front of them. Second, while maintaining a constant headway, participants were asked to direct their attention away from the road to observe a series of three random numbers presented on an interface located near the right front seat headrest. After the last number had been presented, participants were told to return to a forward-looking viewing position and repeat the numbers aloud to an in-vehicle experimenter (who occupied the left-rear seating position).

Late in their drive, during a period of distraction imposed by the random number recall task, the leading vehicle performed an abrupt lane change that suddenly revealed a stationary lead vehicle directly in the path of the participant's vehicle. Shortly thereafter, distracted participants were presented with an FCW alert selected from the reduced set of alerts output from Phase I. Unlike the repeated measures experimental design used in Phase I, each Phase II participant only received one FCW alert.

1.3.2.2 Phase II Distraction Task Interface

Of particular interest for Phase II was development of a way to direct the participants' forward-facing view away from the road for as long as possible, while retaining excellent task acceptance with a low likelihood of a forward-looking glance. A random number recall task was developed in an attempt to satisfy these criteria.

In Phase II, the random number recall task was based on a 4.5" x 3.5" display, installed to the left of the SV front passenger headrest, as shown in Figure 1.2. As initially conceived, the task required a participant to (1) push a red button to the right of the numerical display, (2) be presented with three random single digit numbers, (3) release the button, and (4) repeat the numbers aloud to an in-vehicle experimenter (in the order they were shown). Observing the numbers required the participant fully avert their forward-facing view from the road. Each number was presented for approximately 750 ms.

Figure 1.2. Random number recall display (the red button was used only during Phase II trials).

Conceptually, the Phase II random number recall task was appealing because it was believed to impose reasonable physical and mental commitments upon the participants while keeping their forward-facing view away from the road for an extended period of time. Pilot tests performed with subjects recruited from within VRTC produced encouraging results; the task was generally considered to be challenging, yet comfortable.

Unfortunately, tests performed with members from the general public revealed a major deficiency in the task design. Although the first participant fully engaged the physical (pushed the button) and cognitive (committed the random numbers to memory) elements of the task immediately after being instructed to do so, the next seven did not. Instead, these participants divided the task into two separate components. When instructed to begin the random number task, these participants reached for the task display and located the task activation button entirely by touch. However, since the participants were able to maintain their forward-looking viewing position while engaged in this spatial detection, they could observe the choreography intended to produce a surprise event near the end of their experimental drive (i.e., the suddenly revealed stationary lead vehicle). Since concealing this choreography was an integral part of the test protocol, additional refinement was required.

1.3.3 CWIM Phase III Research Performed at VRTC—Final Protocol

Using lessons learned from Phases I and II, the authors developed the Phase III FCW evaluation protocol. This protocol offered an excellent combination of participant acceptance, performability, objectivity, and discriminatory capability. The Phase III protocol was used to produce the data discussed in the remainder of this report. A total of 64 subjects participated in the Phase III.

2.0 OBJECTIVES

The objectives of the Phase III CWIM FCW work performed at VRTC were to:

1. Develop a robust protocol for evaluating FCW DVI effectiveness on the test track.
2. Perform a small scale human factors study to validate the CWIM FCW protocol.
3. Evaluate how different FCW alert modalities affect participant reaction times and crash avoidance behavior.

2.1 Protocol Overview

The protocol used in this study was developed to examine how distracted drivers responded to FCW alerts in a crash imminent scenario. A diverse sample of drivers was recruited from central Ohio for participation in the study. These participants, using a government-owned SV, were instructed to follow a moving lead vehicle (MLV) through a test track-based course while maintaining a specified speed and headway. During the drive, participants were instructed to complete a distraction task requiring them to look away from the road for the duration of the task.

To familiarize participants with the vehicle, driving environment, and distraction task, they performed multiple "passes" through the test course. During the final pass, with the driver fully distracted, the MLV unexpectedly swerved out of the lane of travel to reveal a stationary lead vehicle (SLV) in the participant's path. In this study, the SLV was actually a full-size realistic-looking inflatable.

2.2 Evaluation Considerations

The data produced in this study were reduced and analyzed with methods that objectively described how the participants responded to different FCW modalities. Evaluation metrics quantified differences in the timing and magnitude of drivers' avoidance maneuvers.

From a protocol assessment perspective, the authors were interested in confirming that the experimental design and methodology used in this study could effectively, objectively, and repeatably quantify the participants' willingness to perform the protocol's tasks, and the ability of the protocol to discriminate between baseline (i.e., no alert presented), apparent, and non-apparent alerts.

From a driver performance perspective, the primary data of interest straddled the crash imminent scenario: (1) the TTC when participants returned to their forward-looking viewing position, (2) throttle release, brake application, and avoidance steer response times from FCW alert onset, (3) the magnitudes of the participants' brake and steer inputs, (4) the magnitudes of the SV speed reductions and accelerations, and whether the test participants collided with the SLV.

3.0 TEST APPARTATUS AND INSTRUMENTATION

3.1 Test Vehicles

3.1.1 Subject Vehicle (SV)

The SV used in this study was a 2009 Acura RL, shown in Figure 3.1. Originally-equipped, this four-door sedan was equipped with all-wheel drive, four-wheel anti-lock disc brakes with brake assist, electronic stability control (ESC), an FCW system, and a crash imminent brake system (CIB).

During conduct of the tests performed in this study, an in-vehicle experimenter occupied the left-rear seating position. To observe test data as it was being collected, tabulate participant performance, and manually activate elements of the test protocol during pre-test familiarization, an interface with the vehicle's data acquisition and audio system was installed behind the driver seat.

Figure 3.1. 2009 Acura RL, the subject vehicle used in this study.

3.1.2 Moving Lead Vehicle (MLV)

The moving lead vehicle (MLV) used in this study was a 2008 Buick Lucerne, shown in Figure 3.2. This mid-sized sedan was selected primarily out of convenience; it was available, had been previously instrumented with much of the equipment required by the protocol described in this report, and was large enough to effectively obscure the subject's view of the SLV prior to the surprise event presented at the end of the experimental drive. Of note in Figure 3.2 is the solid black vertical panel installed behind the front seats. This panel prevented participants from looking through the MLV during their drive, thereby reducing the likelihood of the SLV being prematurely detected on approach. For this study, the MLV was driven by a professional test driver. MLV speed was maintained using cruise control for much of the experimental drive.

Figure 3.2. 2008 Buick Lucerne, the moving lead vehicle used in this study.

3.1.3 Stationary Lead Vehicle (SLV)

The FCW alerts used in this study were presented at a TTC of 2.1 seconds; a value believed to be representative of those used by algorithms installed in contemporary production vehicles. Responding to an alert presented at this TTC was intended to provide participants with enough time to successfully avoid the SLV. However, since this study also included a baseline condition where no alerts were presented, SV-to-SLV collisions were to be expected. To insure participant safety, a full-size inflatable "balloon car," designed to emulate a 2009 Volkswagen GTI (shown in Figure 3.3) was used.

Figure 3.3. Inflatable balloon car, used at the stationary lead vehicle in this study.

The SLV was approximately 5 ft wide, 5 ft tall, 12 ft long, and weighed 77 lbs. It was strikeable, inflatable in the field, and secured to the ground with zip ties and concrete anchors. The zip ties, present at each corner of the SLV, were strong enough to prevent the vehicle from moving in response to wind gusts, but easily snapped during a SV-to-SLV collision. The SLV restraints are shown in Figure 3.4.

Figure 3.4. Stationary lead vehicle restraint anchor.

3.2 Forward Collision Warning (FCW) Modalities

As previously explained in Section 1.3.1.2, the visual FCW alert originally installed in the SV was disabled in lieu of using that from a 2008 Volvo S80. Specifically, the Volvo S80 visual alert consisted of a 6-inch light bar that, when activated, flashed a series of twelve light-emitting diodes (LED) using a 50 percent duty cycle for 4 seconds (100ms on, 100ms off). A reflection of the light bar illumination was visible to the driver in the form of a head up display (HUD) on the windshield, intended to reside in line-of-sight for easy detection. Figure 3.5 shows where the hardware Volvo FCW HUD hardware was installed in the dash of the SV.

Also as explained in Section 1.3.1.2, the auditory FCW alert originally installed in the SV was disabled in lieu of using that from a 2010 Mercedes E350. Specifically, this auditory alert was comprised of ten sharp beeps using the audio clip provided in Section 1.3.1.1. Although very similar to that installed in the SV, use of the Mercedes-based alert allowed the authors to diversify the origins of the FCW alerts used in this study.

Figure 3.5. Volvo S80 FCW HUD hardware installed in the subject vehicle dashboard.

The magnitude of the seat belt pretensioner activation used in this study was intended to closely emulate that of the original 2009 Acura RL-based configuration. However, the timing of when the intervention occurred was adjusted to be in agreement with the auditory and visual alerts (i.e., the commanded onset of each alert was equivalent).

Note: Although the SV was equipped with a forward-looking radar to provide range and range-rate data to the vehicle's FCW controller, the authors opted to activate each FCW alert using an external control computer and positioned-based trigger points. This provided excellent activation repeatability, and avoided the potential for the original sensing system being unable to acquire and respond to the SLV in the limited time available pre-crash.

3.3 Task Displays

3.3.1 Headway Maintenance Monitor

To assist the participants with achieving and maintaining the appropriate distance to the MLV during each pass, a 3.25" x 2.0" monitor displaying the real-time headway was attached to the base of the windshield, just above the SV dashboard (see Figure 3.6).

Figure 3.6. Headway monitor installed in the SV.

3.3.2 Random Number Recall Display

During each pass, and while maintaining the desired headway, participants were instructed to complete a total of four random number recall tasks. During the conduct of these tasks, five randomly generated single digit numbers were presented on a 4.5" x 3.5" display installed to the left of the SV front passenger headrest (previously shown in Figure 1.2). The increase to five numbers, from the three used during the preliminary Phase I and II research, was made to increase task duration (i.e., the amount of time participants were required to look away from the road) without imposing excessive cognitive overhead [2].

Each of the five random numbers was presented for 472 ms. This duration, which was approximately 37.1 percent less than that used during Phases I and II, was short enough to strongly discourage glances away from the display (i.e., back to a forward-facing view of the road) while still allowing each number to be easily observed and retained. Observing the numbers required the participant fully avert their forward-facing view from the road.

3.4 Instrumentation

The SV was instrumented with two data acquisition systems, one for collecting inertial and highly accurate GPS position data, the other for miscellaneous analog data. Both systems were installed in the SV trunk to minimize participant distraction during the experimental drive. The moving lead vehicle (MLV) was equipped with a similar GPS-enhanced inertial sensing system to facilitate real-time vehicle-to-vehicle range (e.g., SV-to-MLV headway). The balloon-based SLV contained no instrumentation.

3.4.1 Subject Vehicle Instrumentation

The basic analog measurements logged in the SV included brake pedal force, throttle position, steering wheel angle, brake line pressure, the state of the vehicle, and various data flags. To measure the force applied to the brake pedal, a load cell was clamped onto the front surface of the pedal, as show in Figure 3.7. To offset the difference in step height imposed by installation of the load cell, a light-weight adapter was attached to the throttle pedal.

Figure 3.7. Load cell used to measure brake force. Note adapter to increase throttle step height.

Throttle position data were collected through a direct tap of the vehicle's throttle position sensor (TPS). Under the dash, a potentiometer was attached to the steering column and configured to measure steering wheel angle. Transducers were installed at the bleeder screw of each brake caliper to measure brake line pressure. The SV positions, velocities, rotational rates, and accelerations were measured with a GPS-enhanced inertial platform installed in the truck, and were resolved to the vehicle's center of gravity (see Appendix C for a detailed description of this system). Finally, data flags indicating initiation of the random number recall task instructions, random number recall task duration, FCW onset, and the state of each FCW modality were recorded.

3.4.2 Moving Lead Vehicle Instrumentation

In a manner similar to that used for the SV, the MLV positions, velocities, rotational rates, and accelerations were measured with a GPS-enhanced inertial platform. Although this unit was installed in the cabin, these data were still resolved to the vehicle's center of gravity. Using a wireless communication package integrated with the inertial platforms installed in each vehicle, the state of the MLV was broadcast to the SV. The relative position of the MLV with respect to the SV (i.e., the real-time headway) was one of these data channels.

To assist the MLV driver with maintaining the desired velocities, a speed display was secured to the inside of the windshield, just above the dashboard.

3.4.3 Presentation of Auditory Commands and Alerts

An automated system was developed to produce audible instructions and FCW alerts in the SV during the experimental test drive. This system used a trunk-mounted laptop PC to play .wav files through a center-mounted speaker installed in the SV's dashboard. Specifically, the instruction, "Begin Task Now" directed the participant to begin the random number recall task.

Software provided with the a GPS-enhanced inertial platform installed in the SV was used to automatically initiate presentation of the audible instructions and FCW using positioned-based trigger points.

3.4.4 Video Data Acquisition

Four small video cameras were mounted inside the cabin of the SV to observe driver activity during the experimental test drive. One camera was mounted to the underside of the dash near the center console to record throttle and brake pedal activity. The pedals were illuminated by a "light strip" containing 20 infrared LEDs. A second camera was mounted to the rear window interior trim facing forward to observe how the driver engaged with the random number recall task display. Two cameras were mounted to the rearview mirror: (1) a forward-facing camera was mounted to the back side of the interior rearview mirror to observe SV lane keeping, SV-to-MLV headway, and how the SV approached the SLV during the final pass of the experimental drive, and (2) a rear-facing camera used to observe the participants' eye glance activity and physical reactions to the suddenly appearing SLV. A small microphone was mounted in the interior trim above the driver's head. The microphone signal was amplified to achieve good reception of driver comments, experimenter's instructions, and FCW alerts where applicable.

4.0 TEST PROTOCOL

4.1 Overview

Real drivers, ages 25 to 55 years old, were recruited from the general public for participation in this study. Each participant was asked to follow the MLV within the confines of a controlled test course, while attempting to maintain a constant headway, and instructed to perform a series of four distraction tasks intended to briefly divert their attention away from a forward-viewing position. With the participant fully distracted during the final task, the MLV was abruptly steered out of the travel lane to reveal a realistic-looking full-size balloon car, acting as the SLV in the immediate path of the SV.

At a nominal TTC of 2.1s from the SV, one of eight FCW alerts was presented to the distracted participant. The manner in which the driver responded to the FCW alert was used to assess driver-vehicle interface (DVI) effectiveness. The “Lead Vehicle Cut-Out” scenario, as viewed from inside the SV, is shown in Figure 4.1. An example of a rear-end impact with the SLV is shown in Figure 4.2.

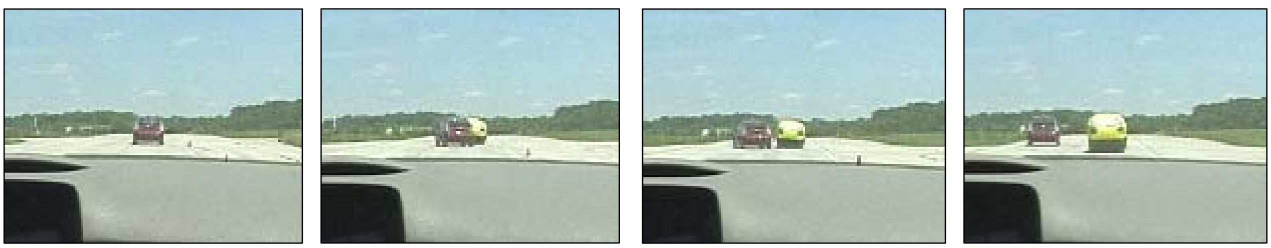

Figure 4.1. Lead vehicle cut-out scenario.

Figure 4.2. Subject vehicle-to-stationary lead vehicle impact.

4.2 Participant Recruitment

Participant recruitment was accomplished by publishing advertisements in local newspapers and online via Craigslist. In these advertisements, shown in Appendix D, prospective subjects were instructed to contact NHTSA's VRTC if interested in study participation. Respondents were screened to ensure they satisfied the health and eligibility criteria described in Appendix E. If these criteria were satisfied, the respondents were provided with additional study details, and more specific personal information was collected from them.

4.3 Pre-briefing and Informed Consent Meeting

Upon arriving at VRTC, participants were greeted and escorted to a conference room. Here, each participant was provided with an informed consent form describing the purpose of the study to be an evaluation of how interfacing with an electronic device may affect their ability to maintain a consistent distance between their vehicle and one being driven directly in front of them. The informed consent form, shown in Appendix E, explained that a windshield-mounted display would be used to report the distance between the two vehicles (the headway monitor), and that the study participants would be asked to interface with the electronic device (a random number display) four times during their test drive.

4.4 Vehicle and Test Equipment Familiarization

Following completion of the pre-briefing, participants were escorted to the Government-owned SV. Each participant was instructed to turn their cell phone off, secure their seat belt, adjust the seat and mirrors to comfortable positions, and to familiarize themselves with the orientation of the basic vehicle controls (e.g., throttle, brake pedal, turn signal indicators, etc.). Participants' use of sunglasses while in the SV was not allowed. An in-vehicle experimenter, who sat behind the participant in the left rear seating position for the duration of the experimental drive, described the location and functionality of the headway monitor and random number display to the participant, and asked that they be adjusted to insure a comfortable viewing position[5]. During this process, the in-vehicle experimenter described details pertaining to the two types of tasks being used during the experimental drive: headway maintenance and random number recall. Together, these tasks were ultimately used to facilitate the choreography designed to evaluate how the participants responded to the various FCW modalities unexpectedly presented at the end of their drive.

4.4.1 Maintaining a Constant Headway

For a majority of their drive, participants were instructed to maintain a constant distance of 110 ft between the front of their vehicle to the rear of the MLV being driven at 35 mph. The magnitude of this distance, or headway, was selected to best balance participant safety,

[5] The attachment points of the headway monitor and random number display were not adjustable, only the viewing angles.

participant compliance (e.g., their willingness to maintain a close proximity to the MLV), and the ability of the MLV to effectively obstruct the participants' view ahead of it. Participants were not permitted to use cruise control while attempting to maintain a constant SV-to-MLV headway. However, participants were encouraged to use the headway maintenance monitor described in Section 3.1.1 to assist them with this task.

Although the participants were instructed to maintain a headway of 110 ft while driving on the straight sections of the test course (subsequently referred to as a "pass"), they were also told that a tolerance of ±15 ft (i.e., a headway between 95 to 125 ft) was acceptable. If the in-vehicle experimenter observed that the actual headway was outside of this range during the experimental drive, the participant was reminded what the acceptable performance was, and encouraged to increase/decrease the SV speed to tighten/lengthen their following gap. Sustained non-compliance with this request resulted in a deduction of the task incentive pay, described in Section 4.5.2.

4.4.2 Random Number Recall

During each pass, participants were instructed to complete a total of four random number recall tasks. Using the display previously shown in Figure 1.2, presentation of five random numbers was initiated 1.0 second after conclusion of the instruction to begin the random number recall task, and approximately 77 seconds after establishing lane position on the test course (i.e., the onset of a given pass). To minimize variability, the random number recall task instruction and presentation of the random number recall task numbers were automatically triggered at the desired points on the test course using a GPS-based closed-loop feedback control algorithm.

4.5 Study Compensation

4.5.1 Base Pay

Test subjects received a nominal compensation of $35.00 for participation in the study and $0.50 per mile for each mile driven from their residence to the study site.

4.5.2 Incentive Pay

To encourage good performance, an incentive schedule was used for each task. If they were able to maintain a consistent headway when instructed to do so, a factor critical to choreography, participants received up to $20.00 more than their base pay. Specifically, participants received $5.00 per pass if a majority of that pass was within a range of 95-125 ft. This incentive was awarded on a pass-to-pass basis; performance observed during any single pass had no influence on the earning potential of the other passes.

If a participant successfully completed all aspects of the random number recall task, they received an additional $45.00. This incentive was larger than that associated with headway maintenance since it was imperative the participants be fully distracted ahead of (and during) the Lead Vehicle Cut-Out maneuver and the subsequent presentation of the FCW alert. During the first pass, participants were awarded $1.50 per number successfully recalled in the order presented. For the second and third passes, participants were awarded $2.50 per number correctly recalled. Due to the presence of the SLV, all participants received the maximum task compensation ($12.50), regardless of task performance, during the final pass. If the number sequence indicated by the participant was not correct for a given pass, there was a $1.00 penalty imposed for the task compensation earned during that pass. Table 4.1 summarizes the incentive pay schedule used in this study, Appendix G presents the log sheet used by the in-vehicle experimenter to tabulate the participants' performance.

Table 4.1. Task Payment Schedule.

Pass #	Headway Maintenance	Random Number Recall		Task-Based Payment
		Correct # Compensation	Incorrect Order Deduction	
1	$5 if within range	$1.50 per # correct	-$1 per order error	Total for pass #1
2	$5 if within range	$2.50 per # correct	-$1 per order error	Total for pass #2
3	$5 if within range	$2.50 per # correct	-$1 per order error	Total for pass #3
4	$5 if within range	$2.50 per # correct	-$1 per order error	Total for pass #4
Total Compensation				**Sum of pass totals**

Throughout the experimental drive, the in-vehicle experimenter informed the participant of their task performance shortly after conclusion of the pass during which the compensation was earned. This feedback was used to keep participants motivated (e.g., "You did well during that pass."), to indicate how acceptable their performance was (i.e., how much of the maximum payment was awarded), and to provide a means for suggesting how task performance may be improved during subsequent passes (e.g., "Your headway was a bit too long during the last trial. Please try to drive closer to the lead vehicle during the next pass.").

4.6 Pre-test Forward Collision Warning Education and Familiarization

No pre-test FCW education, familiarization, or instruction was provided to the participants recruited for this study. Time and budgetary constraints, and the desire to have a reasonable number of participants per test condition, imposed a limitation that either all subjects would, or would not, receive information regarding FCW before the experimental drive. So as to observe the most genuine, untrained responses to the various FCW modalities, responses not artificially influenced by receiving statements or descriptions of an unfamiliar technology less than an hour before receiving the alert during their drive, the authors opted to exclude FCW education or familiarization from the protocol used for this study.

4.7 FCW Alert Modalities

Table 4.2 provides a summary of the eight FCW modalities used in this study. As previously explained, the basis for including these alerts was twofold: prevalence in contemporary FCW implementations and positive results from the Phase I static test.

Table 4.2. FCW Alert Modality Summary.

FCW Modality	Alert Origin
None	Baseline (no alert)
Visual Only	2008 Volvo S80 (HUD)
Auditory Only	2010 Mercedes E350 (repeated beeps)
Haptic Seat Belt	2009 Acura RL (reversible seat belt pretensioner)
Visual + Auditory	2008 Volvo S80 + 2010 Mercedes E350
Visual + Haptic Seat Belt	2008 Volvo S80 + 2009 Acura RL
Auditory + Haptic Seat Belt	2010 Mercedes E350 + 2009 Acura RL
Visual + Auditory +Haptic Seat Belt	2008 Volvo S80 + 2010 Mercedes E350 + 2009 Acura RL

4.8 Test Course

The study's primary driving task was performed on Lane 4 of the Transportation Research Center, Inc. (TRC) Skid Pad. An overview of the Skid Pad and the key logistics associated with the experimental design is provided in Figure 4.3.

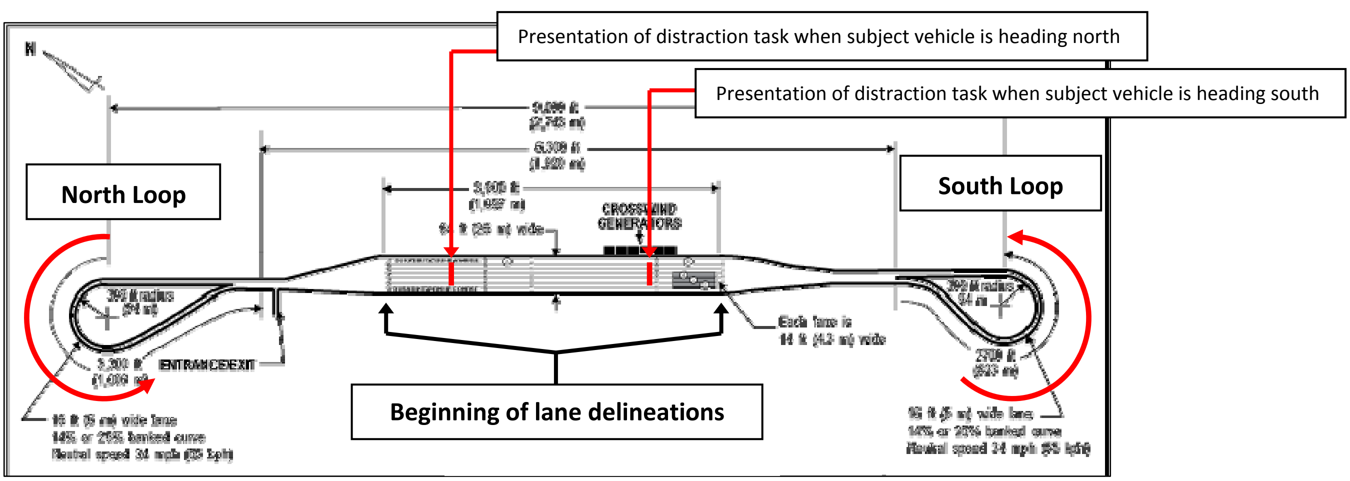

Figure 4.3. TRC Skid Pad dimensional overview.

Since the participants were members of the general public, exclusive use of the entire Skid Pad was used during the periods of test conduct to maximize safety. Performing tests on the Skid Pad provided the subjects with an opportunity to use significant avoidance steering, should they deem it necessary, without risk of a road departure or impact with other vehicles, foreign objects, etc. Tests were performed during daylight hours with good visibility.

4.9 Experimental Test Drive

The experimental drive used in this study began and concluded with the SV and MLV staged in a VRTC parking lot. Following the vehicle and test equipment familiarization, and task orientation, the in-vehicle experimenter indicated the “lead vehicle” to the participant (i.e., the MLV), and instructed them to follow it to the test course. The brief drive to the test course from VRTC was performed at 25 mph, 10 mph less than that specified for a valid straight-line pass during the experimental drive. The low speed of the pre-study drive served two purposes: (1) to increase the participant’s familiarization with the headway monitor operation in a benign operating condition, and (2) to give the participant an opportunity to practice the task of maintaining a desired headway to the MLV in a non-threatening environment.

4.9.1 Pass #1 of 4

Following their test vehicle and equipment familiarization, the in-vehicle experimenter instructed the participants to establish position on Skid Pad Lane 4, heading south, following the MLV with a headway of 110 ft using the windshield-mounted headway monitor as a guide.

At a location approximately 0.75-miles from the point where lane position was first established, and while the participant was driving, the participant was automatically instructed to begin the random number recall task when prompted by a pre-recorded message played through the SV audio system. As described in the task orientation, once the fifth number had been presented, the subject was to tell the in-vehicle experimenter what five numbers were shown in the order they were presented.

After completing the first random number recall task, participants were instructed to continue following the MLV around the Skid Pad’s south curve. After emerging from the curve heading north, they were told to follow the MLV back into Lane 4 heading north, and re-establish a nominal headway of 110 ft using the windshield-mounted distance display as a guide.

4.9.2 Pass #2 of 4

After approximately 0.75-miles from the point where lane position heading north was first established, the participant was automatically instructed to begin their second random number recall task. As before, the task was deemed complete once the subject had told the in-vehicle experimenter what five numbers were shown, in the order they were presented.

After completing the second random number recall task, the in-vehicle experimenter instructed the participants to continue following the MLV around the Skid Pad’s north curve. After emerging from the curve heading south, they were instructed to follow the MLV back into Lane

4 heading south and to re-establish a headway of 110 ft using the windshield-mounted distance display as a guide.

4.9.3 Pass #3 of 4

From this point, the sequence of driving south, performing and completing the random number recall task, and following the MLV around the south Skid Pad curve was repeated. As before, headway was then established and the participants instructed to drive north.

4.9.4 Pass #4 of 4

After approximately 0.75-miles from the point where lane position was first established, the participants were automatically instructed to begin their fourth random number recall task. By this time, the participants were generally quite familiar and comfortable with the SV, the driving environment, their ability to maintain a constant headway to the MLV, and their ability to complete the random number recall task.

During the fourth and final random number recall task, the MLV was abruptly steered out of the travel lane, revealing the SLV in the immediate path of the SV[6]. At a nominal TTC of 2.1s from the SLV, one of eight FCW alerts was presented to the distracted participant. Figure 4.4 presents an overview of the choreography used near the end of the fourth pass.

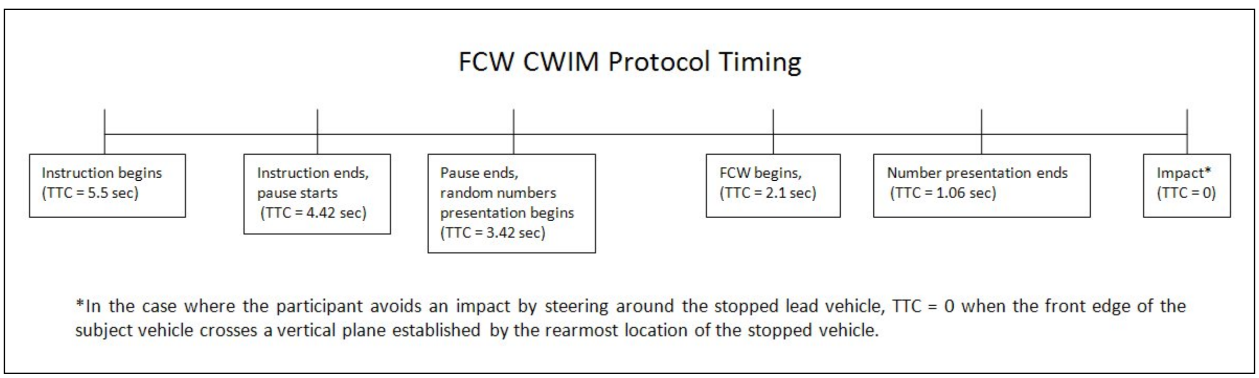

Figure 4.4. Choreography used to assess participant responses to the various FCW modalities used in this study.

Since it had not been incorporated into any of the first three passes during their drive, and all other aspects of the driving experience were identical, participants did not anticipate presentation of an FCW alert during the fourth pass. This factor allowed the study protocol to discriminate which FCW alert modalities were capable of effectively redirecting the attention of a distracted driver back to the driving task. Furthermore, since the presence of SLV was a

[6] In the event that the participant collided with the balloon car, it merely bounced off the front of the subject vehicle. Given the low vehicle speed used for this study (nominally 35 mph), and the strikeable design of the balloon car, the risk of harm to the participant during a test where an impact occurs did not differ from a test where it does not.

surprise, the protocol allowed the authors to quantify how the various FCW modalities affected the participants' crash avoidance behavior.

4.9.5 Participant Debriefing and Post-Drive Survey Administration

Within five seconds of either avoiding or striking the SLV, participants were asked to stop the SV (if still moving), and place the transmission in park. At this time, the in-vehicle experimenter read a short debrief script to the participant (provided in Appendix H). Participants were then instructed to follow the MLV back to VRTC. Once parked, the in-vehicle experimenter escorted the test participants back to the conference room where they had received their pre-test briefing.

During a final debriefing, participants were asked to complete a brief survey containing questions about their experience in the study, their comfort in performing the headway maintenance and random number recall tasks, anticipation of the final conflict event (if any), and their opinions about FCW systems (see Appendix I). Participants were asked not to discuss the main purpose of the study with anyone through the end of October 2010, the end of the study period. The participants were then provided with their compensation and thanked for participating in the study.

5.0 TASK PARTICIPATION AND PERFORMANCE

5.1 Test Validity Requirements

Given the effort used to obtain participants, the test trial validity requirements used for this study were intended to be as accommodating as possible. In a sense, all driving activity leading up to presentation of the FCW alert was performed to groom the participants for comfortably achieving a vehicle speed of 35 mph at two critical times: the onset of the random number recall task instruction, and the onset of the FCW alert. Here, "comfortably" refers to a general sense of ease while performing their commanded tasks (maintaining the proper headway to the MLV and recalling the random numbers after they had been displayed). Therefore, the validity requirements were limited to:

1. The participant not detecting the SLV before presentation of the FCW
2. The participant maintaining a SV speed of at least 30 mph until (1) responding to the FCW, or (2) completion of the random number recall task
3. The participant achieving an SV-to-MLV headway between 95 to 125 ft at the onset of the random number recall task instruction

For this study, achieving eight samples per FCW modality required valid data from 64 subjects. This ultimately required the scheduling of 74 participants. The 10 "extra" subjects were needed for the following reasons:

- Three subjects failed to report to the test site as scheduled.
- Three participants failed to begin the random number recall task when instructed due to inattentiveness.
- One participant deliberately postponed beginning the number recall task until they believed the number presentation would begin (i.e., this individual realized, and adapted to, the 1.0 second pause between the end of the task instructions and revelation of the first number).
- Two participants glanced back to the forward-facing viewing position during the random number recall task.
- The SV speed at the end of visual commitment[7] (VC_{end}) was deemed too low (29.8 mph) for one participant.

Disregarding the three subjects that did not arrive for the study, six of the seven non-valid trials involved participants observing the MLV steer, or begin to steer, around the SLV. Prematurely detecting the presence of the SLV spoiled the surprise nature of the study's ruse and caused the

[7] In the context of this study, the authors defined visual commitment as the time from when the driver first averts their forward-facing view from the road to the time this view was first recovered.

participants to avoid it with little effort. This invalidated the participant's response to the FCW alert since they were (1) no longer fully distracted, and (2) pre-occupied with avoiding the rapidly approaching SLV.

Of the seven non-valid trials, three participants failed to participate in the random number recall task when instructed to do so. Review of the video data and post-test interviews associated with these participants indicated inattentiveness was the most probable explanation for this behavior.

In the case where the SV speed was too low, the participant was able to successfully recall each of the five random numbers and comfortably avoid collision with the SLV. The authors believe the vehicle speed observed at VC_{end} for this particular trial reduced the scenario severity to a level not representative or comparable with the other trials performed in this study.

5.2 Headway Maintenance

Nominally, participants were instructed to maintain a SV-to-MLV headway of 110 ft during each pass. Once established, and given the excellent consistency of the MLV speed, maintaining this headway would result in a SV speed of 35 mph for the duration of each pass. Maintaining the proper headway and speed during the final pass insured the surprise event could be successfully executed.

5.2.1 Overall Headway Maintenance Task Performance

The in-vehicle experimenter maintained a log of acceptable headway maintenance during each pass. This information was used to provide feedback to the participants on a pass-by-pass basis and provided the criteria for their headway maintenance task compensation. Table 5.1 provides a summary of these logs. Note that the in-vehicle experimenter did not record headway performance during the final pass since all participants received the maximum compensation for the final pass due to the presence of the SLV. Fifty-three of the 64 participants (82.8 percent) were able to successfully perform the headway maintenance task for each of the first three passes.

Table 5.1. Headway Maintenance Task Performance.

Acceptable Headway?							
Pass 1		Pass 2		Pass 3		Pass 4	
Yes	No	Yes	No	Yes	No	Yes	No
55	9	63	1	62	2	n/a	

Overall, compliance with the headway maintenance requirement was quite good, particularly for the second and third passes. Acceptable headway maintenance task performance was achieved by 85.9, 98.4, and 96.9 percent of the participants for first, second and third passes, respectfully. Note that the only participant with unacceptable headway performance during the second pass also had unacceptable performance during the third.

5.2.2 Subject Vehicle Performance During Pass #4

Table 5.2 summarizes key test participant and test equipment inputs observed during the fourth pass of the experimental drive. These data can be used to describe the robustness of the protocol. The two primary groupings are SV speed and the SV-to-SLV distance (relevant during the final pass). These independent data were used to calculate the values shown in the third grouping, SV-to-SLV TTC.

Within each grouping, the data associated with four instances in time are shown: (1) initiation of the automated instruction telling the participant to begin the random number recall task; (2) the presentation the first number of random number recall task was shown; (3) the onset of the FCW alert; and (4) conclusion of the participants' VC.

Subject vehicle speed was controlled entirely by the participants' modulation of throttle and brake. The use of cruise control was not permitted during the conduct of the test trials.

With the exception of the data shown in the "VC Concludes" column of Table 5.2, the SV-to-SLV distances were the product of automation. At a nominal distance to the SLV, the various events were automatically trigged via use of GPS-based position and closed-loop feedback.

Subject vehicle to SLV TTC data reflects the participant's ability to maintain the desired test speed (nominally 35 mph, achieved indirectly by attempting to maintain a consistent headway to the rear of the MLV) and the ability of the test equipment to accurately and repeatably initiate events during a participant's drive.

The range and TTC data presented in the "VC Concludes" columns depended strongly on whether a participant responded to the FCW alert prior to completing the random number recall task. Given the choreography of the experimental design, a participant that effectively responded to the FCW alert would end their VC before a participant that tried to observe each of the five numbers presented during the random number recall task. The earlier the VC concluded, the further the participant was from the SLV. This, in turn, resulted in a longer TTC.

5.2.3 Moving Lead Vehicle Performance During Pass #4

Consistent MLV operation played an import role in insuring the SV was being driven at the correct speed at the time of the FCW alert. Table 5.3 summarizes the MLV speed at the onset of random number recall task instruction during the final pass of the test drive, and for key elements of the MLV avoidance maneuver around the SLV. The avoidance maneuver onset was determined from analysis of MLV lateral acceleration data. The period of data considered for peak MLV lateral acceleration and lateral deviation ranged from onset of random number recall task instruction to two seconds after FCW presentation occurred in the SV.

Table 5.2. Repeatability of Key Participant and Test Equipment Inputs Observed During Pass #4.

Description	SV Speed (mph)				SV-to-SLV Distance (feet)				SV-to-SLV TTC (seconds)			
	Task Instruction	Random Numbers Presented	FCW Alert	VC* Concludes	Task Instruction	Random Numbers Presented	FCW Alert	VC* Concludes	Task Instruction	Random Numbers Presented	FCW Alert	VC* Concludes
Min	33.0	31.1	30.8	30.8	278.5	150.7	103.3	16.4	5.070	2.758	1.879	0.319
Max	37.5	38.1	38.3	38.2	279.3	170.5	108.7	94.5	5.765	3.743	2.325	1.872
Mean	**35.2**	**35.2**	**35.1**	**34.9**	**278.9**	**160.5**	**106.1**	**52.7**	**5.412**	**3.117**	**2.064**	**1.030**
Std Dev	1.1	1.3	1.4	1.5	0.2	4.0	1.5	23.9	0.165	0.186	0.094	0.466
Median	**35.2**	**35.2**	**35.2**	**35.1**	**278.9**	**160.2**	**106.1**	**50.0**	**5.410**	**3.112**	**2.055**	**0.927**
Nominal	**35.0**	**35.0**	**35.0**	**35.0**	**282.3**	**172.4**	**107.8**	**Subject Dependent**	**5.5**	**3.4**	**2.1**	**Subject Dependent**

*VC = Visual Commitment, defined as the instant the driver returns their vision to a forward-looking position.

Table 5.3. Repeatability of Key Moving Lead Vehicle Inputs During Pass #4.

Description	MLV Speed at Onset of Task Instruction (mph)	MLV Avoidance Maneuver		
		Longitudinal MLV-to-SLV Distance at Onset (ft)	Peak Lateral Acceleration (g)	Maximum Lateral Deviation (ft)
Min	34.9	55.2	0.48	9.7
Max	35.8	103.5	0.86	15.5
Mean	**35.5**	**74.3**	**0.68**	**12.7**
Std Dev	0.2	10.7	0.074	1.3
Median	**35.4**	**71.8**	**0.69**	**12.9**
Nominal	**35.0**	**As close as possible**	**Low enough to prevent tire squall**	**≈13 (one lane width)**

The range of MLV speeds was very tight during the experimental drive (only 0.9 mph), making it unlikely to have confounded the ability of the participants to maintain a constant SV-to-MLV headway. Similarly, while it is uncertain whether the manner in which the MLV was steered around the SLV affected the participants' crash avoidance maneuvers, it is unlikely MLV avoidance path variability confounded the study outcome. Each MLV avoidance maneuver was performed to the left of the SLV, and the range of MLV maximum lateral deviations was very narrow.

5.2.4 FCW Alert Modalities

For the duration of this report, test results are commonly summarized via use of histograms. The data presented in these charts are organized in two ways: (1) sorted by FCW condition number as a function of whether the respective modality included seat belt pre-tensioning (i.e., "Belt" vs. "No Belt"), and (2) sorted by FCW condition number as a function of whether the SV came in contact with the SLV (i.e., "Crash" vs. "Avoid"). In both chart types, the baseline data (i.e., that produced during tests performed without any form of FCW alert presentation) are shown in light blue. In these charts, and in the subsequent discussions based on them, FCW alert modalities are referred to by condition number (see Table 5.4). In addition to the general overviews of the data, statistical analyses were performed. Due to the manner in which these analyses were performed, and the pairing of certain data sets to increase the number of participants per test condition, short descriptions were used to describe each modality, also described in Table 5.4.

5.2.5 Subject Vehicle Speed at FCW Onset

Since the speed of the MLV was tightly controlled, requiring the participants maintain a constant SV-to-MLV headway provided a means to encourage constant SV speed during each

Table 5.4. FCW Alert Modality Condition Numbers.

FCW Alert Modality	Condition # Used For General Analyses	Descriptions Used For Statistical Analyses
No alert	1	None
Volvo HUD	3	Beep
Mercedes Beep	6	HUD
Acura Belt	7	Belt
Mercedes Beep, Volvo HUD	12	BeepHUD
Acura Belt, Volvo HUD	13	BeltHUD
Acura Belt, Mercedes Beep	18	BeltBeep
Acura Belt, Mercedes Beep, Volvo HUD	23	All

pass of the experimental drive. As presentation of the random number recall task instructions, random number recall numbers, and FCW alert were each initiated at predefined SV-to-SLV distances, variations of SV speed directly affected the TTC at which they occurred. Of particular interest was the state of the SV at the time of FCW alert. Figure 5.1 summarizes the SV speed at FCW alert onset, presented as a function of FCW modality. Figure 5.2 presents these data as a function of FCW modality and crash outcome.

Subject vehicle speeds at FCW alert onset ranged from 30.8 to 38.3 mph, with overall mean and median values of 35.1 and 35.2 mph, respectively. Therefore, the overall mean and median SV speeds were only 0.1 mph (0.3 percent) and 0.2 mph (0.6 percent) greater than the respective target values.

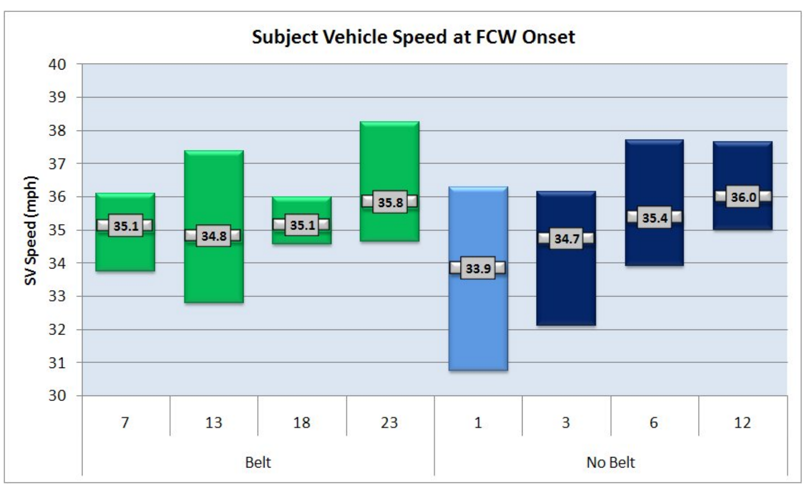

Figure 5.1. SV speed at FCW alert onset, presented as a function of FCW modality.

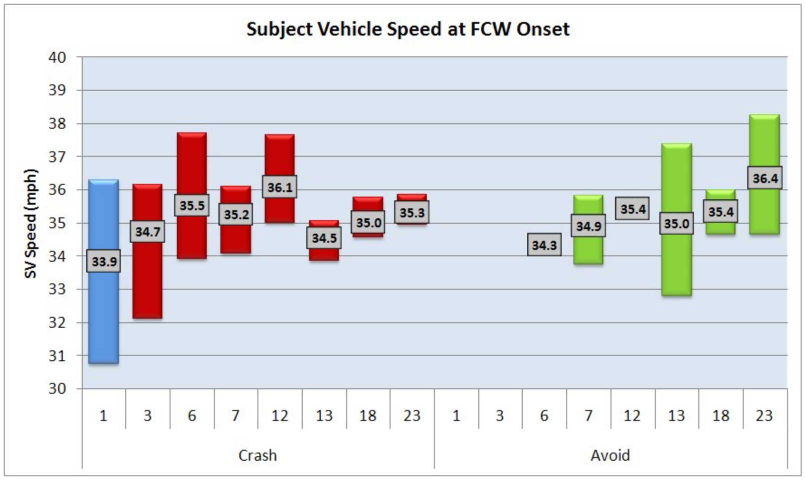

Figure 5.2. SV speed at FCW alert onset, presented as a function of FCW modality and crash outcome.

5.2.6 Range to Stationary Lead Vehicle at FCW Onset

To achieve a TTC of 2.1 seconds at FCW onset, using a nominal SV speed of 35 mph, the alert was to be presented when the SV was 107.8 ft from the SLV. Overall, the SV-to-SLV distance at FCW alert onset ranged from 103.3 to 108.7 ft, with overall mean and median values of 106.1 ft; only 1.7 ft (1.6%) less than the target value. Figure 5.3 summarizes the SV speed at FCW alert onset, presented as a function of FCW modality. Figure 5.4 presents these data as a function of FCW modality and crash outcome.

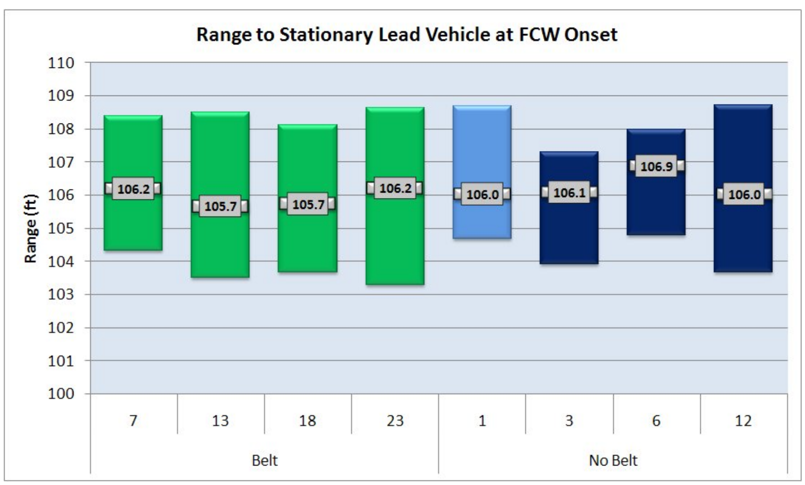

Figure 5.3. SV-to-SLV headway at FCW onset, presented as a function of FCW modality.

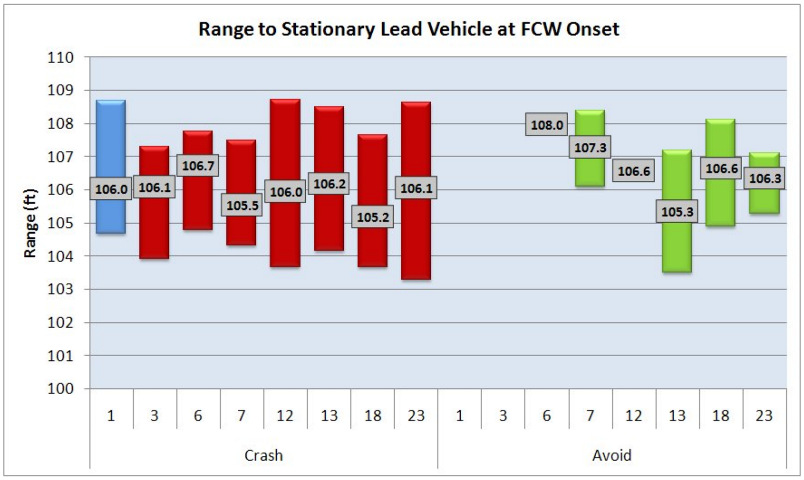

Figure 5.4. SV-to-SLV headway at FCW onset, presented as a function of FCW modality and crash outcome.

5.2.7 Subject Vehicle-to-Stationary Lead Vehicle TTC at FCW Onset

Nominally, presentation of the FCW alerts used in this study was to occur at TTC = 2.1 seconds. Overall, these TTC values ranged from 1.88 to 2.33 seconds, with overall mean and median values of 2.064 and 2.055 seconds, respectively. Therefore, the overall mean and median TTCs at FCW onset were only 36 ms (1.7 percent) and 45 ms (0.6 percent) less than the respective target values. Figure 5.5 summarizes the SV-to-SLV TTCs at FCW alert onset, presented as a function of FCW modality. Figure 5.6 presents these data as a function of FCW modality and crash outcome.

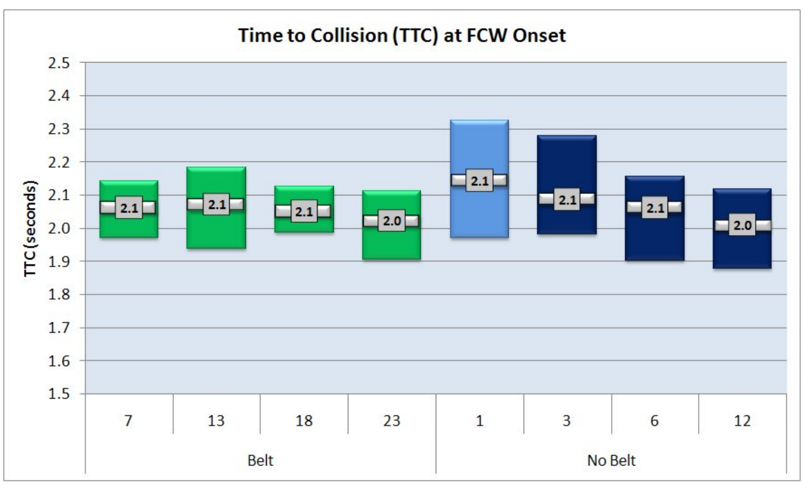

Figure 5.5. SV-to-SLV TTC at FCW onset, presented as a function of FCW modality.

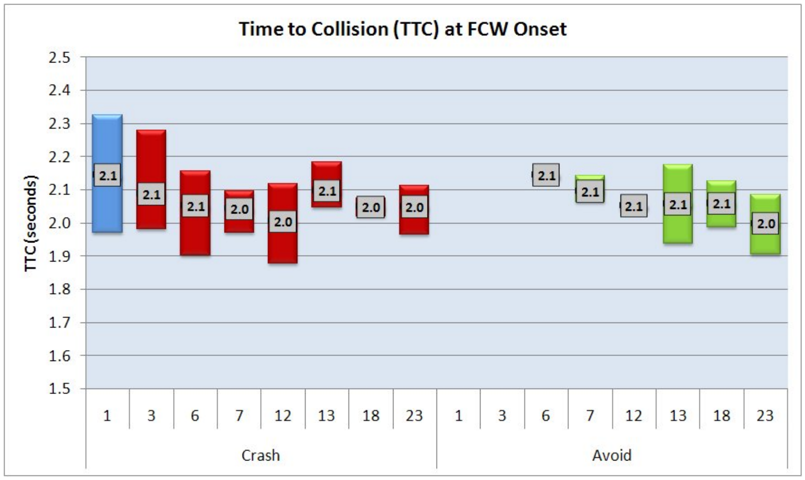

Figure 5.6. SV-to-SLV TTC at FCW onset, presented as a function of FCW modality and crash outcome.

Table 5.5 provides a summary of the data used to statistically compare the mean SV-to-SLV TTCs shown in Figures 5.5. As expected (i.e., given the tight distribution of the data), the means were not found to be significantly different. Similarly, the data shown in Table 5.6 indicate the mean TTCs of the FCW alerts presented to male participants was not significantly different than that of the female participants.

Table 5.5. SV-to-SLV TTC At FCW Onset Comparison By Modality.

TTC at FCW Onset (sec)							
Condition #	**Modality**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
23	All	8	2.023	0.076	1.906	2.112	0.1487
3	Beep	8	2.063	0.082	1.902	2.156	
12	BeepHUD	8	2.010	0.078	1.879	2.117	
7	Belt	8	2.062	0.052	1.970	2.143	
18	BeltBeep	8	2.052	0.043	1.987	2.127	
13	BeltHUD	8	2.071	0.086	1.938	2.184	
6	HUD	8	2.087	0.117	1.982	2.278	
1	None	8	2.144	0.148	1.971	2.325	

Table 5.6. SV-to-SLV TTC At FCW Onset Comparison By Gender.

TTC at FCW Onset (sec) – by Gender						
Gender	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
F	31	2.081	0.088	1.938	2.325	0.1986
M	32	2.051	0.098	1.879	2.304	

5.2.8 Random Number Recall

The in-vehicle experimenter maintained a log of the participants' ability to correctly recall the five random numbers, and their order, presented during each pass. This information was used to provide feedback to the participants on a pass-by-pass basis, and provided the criteria for their random number recall task compensation. Table 5.7 provides a summary of task performance from the in-vehicle experimenter's logs. Generally speaking, task performance was quite good. However the fact not all of the random numbers were recalled correctly indicates the task was also a reasonably demanding one. Seventeen of the 64 participants (26.6 percent) were able to successfully perform the random number recall task without any errors.

Interestingly, the participants who correctly identified each number remained quite consistent throughout the first three passes, with a slight overall improvement being realized by the third pass. Some participants perceived this improvement as well, as indicated by Participant 21 during the drive back to the laboratory after the experimental drive: "I think by the fourth pass, you're starting to trust your driving and focus more on the numbers." Note: this participant correctly identified four numbers during the first pass, and five during passes 2 and 3 (albeit with a sequence error during the third).

Table 5.7. Random Number Task Recall Performance Summary.
(Number of participants, and percentages of the overall 64 participant group, are shown)

Pass #	**Number of Numbers Correctly Recalled**						**Incorrect Recall Order**
	0	**1**	**2**	**3**	**4**	**5**	
1	0	0	0	4 *(6.3%)*	19 *(29.7%)*	41 *(64.1%)*	14 *(21.9%)*
2	0	0	0	6 *(9.4%)*	18 *(28.1%)*	40 *(62.5%)*	7 *(10.9%)*
3	1 *(1.6%)*	0	0	2 *(3.1%)*	15 *(23.4%)*	46 *(71.9%)*	7 *(10.9%)*
4	n/a						

6.0 CRASH AVOIDANCE RESPONSE TIMES

In this section, different ways to assess the participants' crash avoidance response times are provided. This includes an examination of how long participants took to respond to the random number recall task instruction, a detailed breakdown of elements pertaining to different aspects of visual commitment (VC), the interaction between presentation of the FCW and VC, and the TTC at the end of VC (recall the protocol choreography previously shown in Figure 4.4). Throttle release, brake application, and avoidance steering initiation times, measured with respect to end of VC and FCW onset are also provided.

6.1 Random Number Recall Task Instruction Response Time

To better understand the variability associated with each stage of the VC process, the authors began by quantifying how long the participants took to respond to the random number recall task instruction, measured from instruction onset to onset of visual commitment (VC_{start}). Since VC_{start} always occurred before presentation of the FCW, this parameter was expected to remain consistent across all participants. An example of the VC sequence is provided on page 36.

Figure 6.1 presents the distribution of response times to the random number recall task instructions observed in this study, for each FCW modality. Overall, these response times ranged from 760 ms to 2.13 seconds[8], with overall mean and median values of 1.48 and 1.49 seconds, respectively. The mean values for each FCW modality ranged from 1.36 to 1.60 seconds overall, for configurations 3 and 23, respectively.

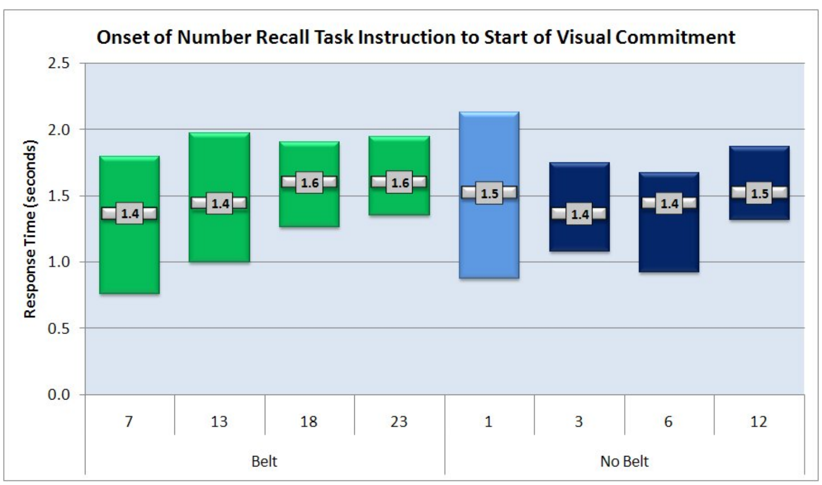

Figure 6.1. Response time from recall task instruction to VC_{start}, presented as a function of FCW modality.

The overall random number recall task instruction response time means observed during tests performed with seat belt pretensioner-based FCW modalities ranged from 1.364 to 1.600

[8] The duration of the random number recall task instruction, from onset to completion, was 1.08 seconds. Four participants initiated their visual commitment during the task instruction.

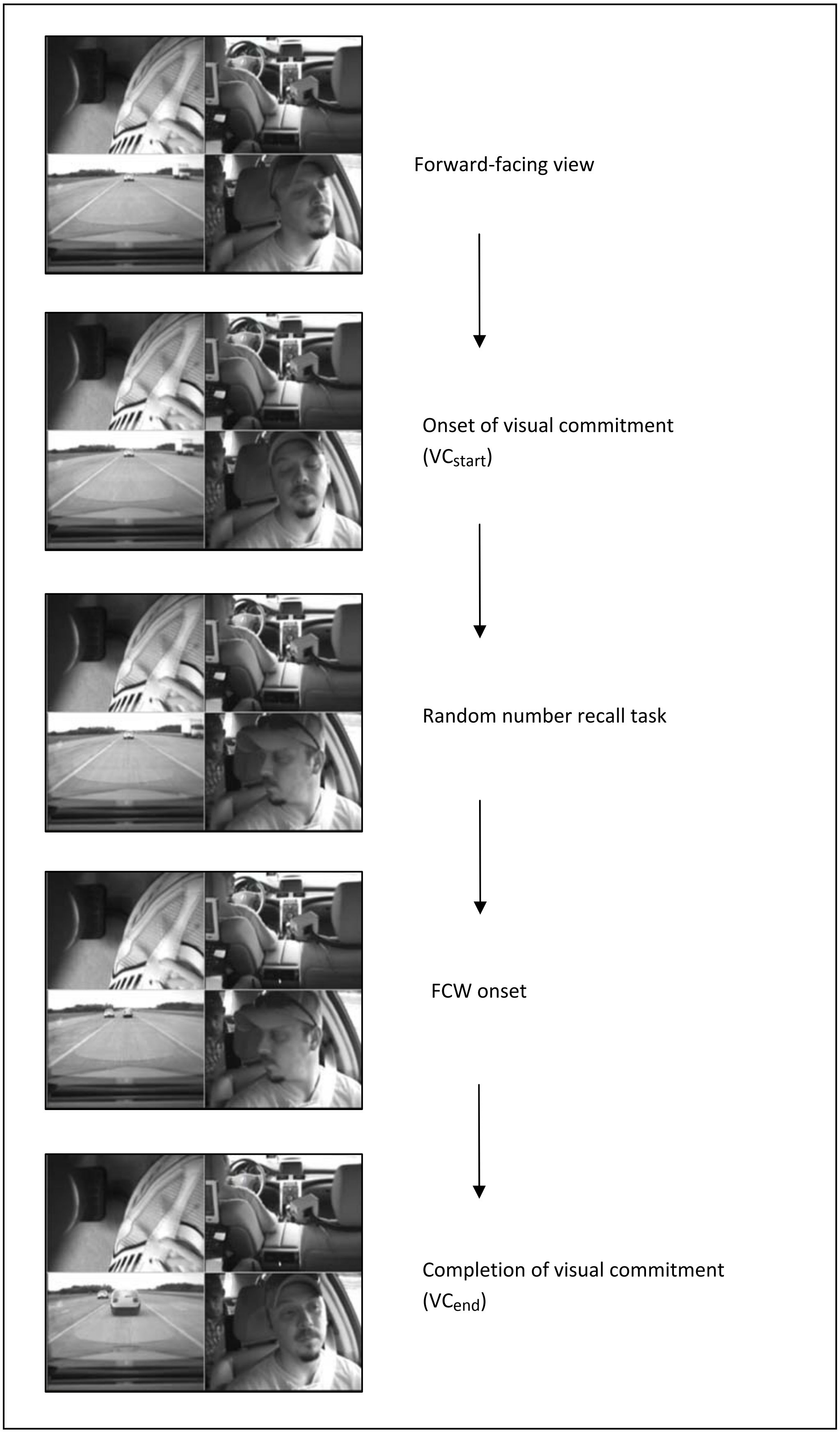

Figure 6.2. Visual commitment (VC) sequence.

seconds, for conditions 7 and 23, respectively. These values very nearly contained the entire range of comparable means established during tests performed without seat belt pretensioner-based FCW modalities, whose range was from 1.363 to 1.520 seconds, established by conditions 3 and 12, respectively. The mean value of the trials performed with no FCW alert (1.529 seconds) resided within the mean range of trials performed with seat belt pretensioning, but was just outside the range of means established without pretensioning.

As expected, the data shown in Figure 6.3 indicate response time to the random number recall task instructions had no apparent affect on crash outcome. The overall task instruction response time means of the trials with and without collisions with the SLV were 1.489 and 1.456 seconds, respectively, differing by only 2.3 percent.

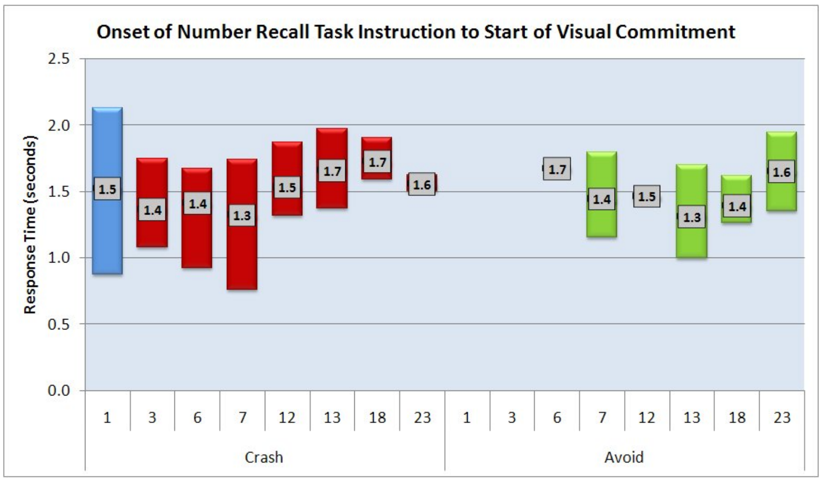

Figure 6.3. Response time from recall task instruction to VC_{start}, presented as a function of FCW modality and crash outcome.

6.2 Overall Visual Commitment Duration

Developing a way to promote sustained VC was an essential component of the experimental design, since a quick forward-looking glance back to the road in the presence of the SLV before the FCW alert was presented would likely invalidate that test trial. In other words, to insure the authors were able to attribute the return of the driver's forward-facing view to either (1) responding to the FCW alert, or (2) completion of the random number recall task, the experimental design required methodology that suppressed the driver's temptation to glance.

Figure 6.4 presents the distribution of overall VC durations observed in this study for each FCW modality. The overall VC durations ranged from 1.27 to 4.33 seconds. The mean values for each FCW modality ranged from 2.35 to 3.51 seconds overall, for configurations 18 and 3, respectively.

The overall VC duration means observed during tests performed with seat belt pretensioner-based FCW modalities ranged from 2.35 to 2.87 seconds, for conditions 18 and 7, respectively. These values overlapped the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, which ranged from 2.84 to 3.51 seconds, for conditions 12 and 3, respectively. The mean value of the trials performed with no FCW alert (3.30 seconds) resided outside of the mean range established by the trials performed with seat belt pretensioning, but within that observed without.

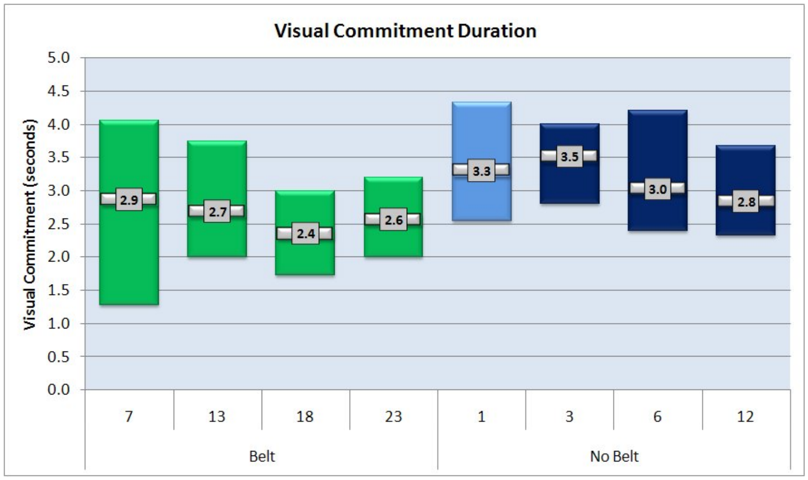

Figure 6.4. Overall visual commitment duration, presented as a function of FCW modality.

The data shown in Figure 6.5 provide an indication that shorter periods of overall VC are closely associated with the ability of the participants' to avoid a crash. The overall mean VC of the trials where the participants collided with the SLV was 35.4 percent longer than that observed when the crash was avoided (3.10 versus 2.29 seconds).

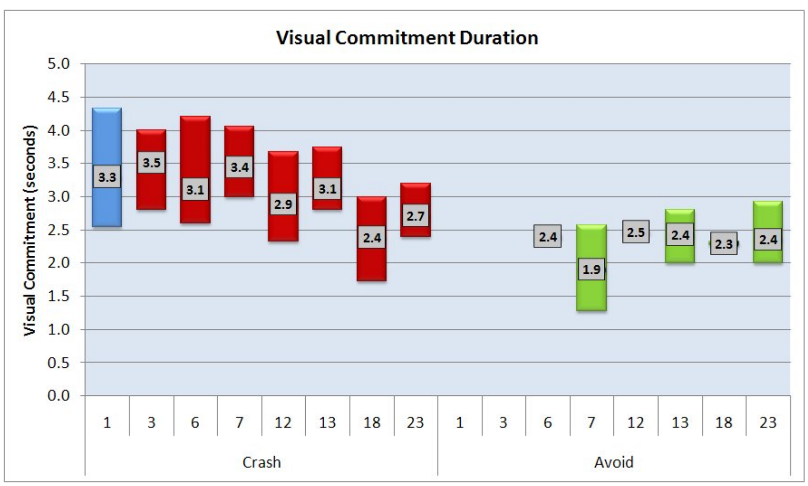

Figure 6.5. Overall visual commitment duration, presented as a function of FCW modality and crash outcome.

6.3 Visual Commitment to Onset of FCW

Overall visual commitment can be broken down into two components: the time from the onset of VC to the onset of the FCW (i.e., VC_{start}⇨FCW), and from the onset of the FCW to completion of the VC (i.e., FCW⇨VC_{end}). Although it is certainly conceivable an FCW may affect the later of these components, it should not affect the former. In other words, regardless of what (if any) FCW modality was used for a particular trial, the alert was always presented after VC had been initiated. Assuming a normal distribution of drivers existed within and across the various FCW configurations, type of FCW alert should be incapable of affecting when the driver was ultimately presented with it.

Figure 6.6 presents the distribution of VC_{start}⇨FCW durations observed in this study. Overall, these durations ranged from 1.20 to 2.73 seconds, with the mean values for each FCW modality ranging from 1.72 (configuration 23) to 2.02 seconds (configuration 3).

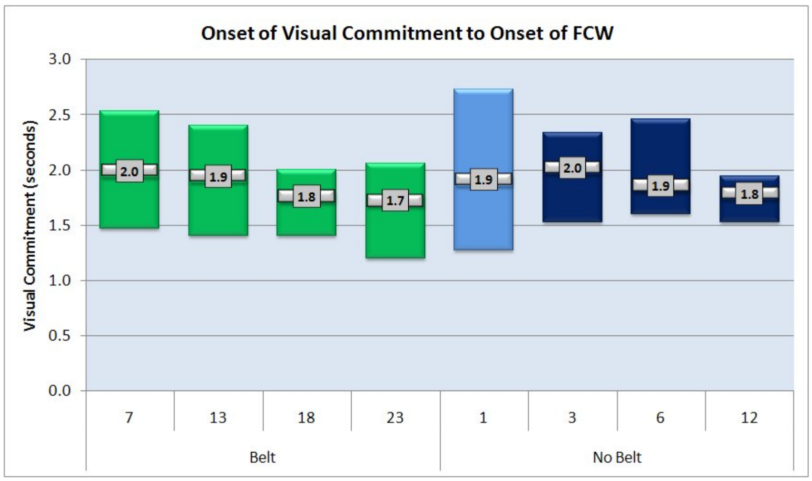

Figure 6.6. VC_{start}⇨FCW duration, presented as a function of FCW modality.

Mean VC_{start}⇨FCW durations observed during tests performed with seat belt pretensioner-based FCW modalities ranged from 1.72 to 1.99 seconds, for conditions 23 and 7, respectively. These values overlapped the comparable (and nearly identical) range established during tests performed without seat belt pretensioner-based FCW modalities, from 1.78 to 2.02 seconds, established during the conduct of conditions 12 and 3. The mean value of the trials performed with no FCW alert (1.91 seconds) resided within the ranges established by the trials performed with and without seat belt pretensioning.

The data shown in Figure 6.7 demonstrate good VC_{start}⇨FCW consistency across each FCW modality, regardless of whether the trials ultimately resulted in a crash or not, and indicates the pre-FCW alert driving behavior encouraged by the experimental design would not confound the analysis of crash outcome. The mean VC_{start}⇨FCW duration of the trials where the participants collided with the SLV (1.87 seconds) was nearly identical to that observed when the crash was avoided (1.89 seconds), differing by only 1.4 percent.

6.4 Onset of FCW to End of Visual Commitment

The data produced during this study indicate FCW⇨VC_{end} duration (i.e., response time) may be the most important time interval for determining the effectiveness of an FCW DVI. If an FCW is

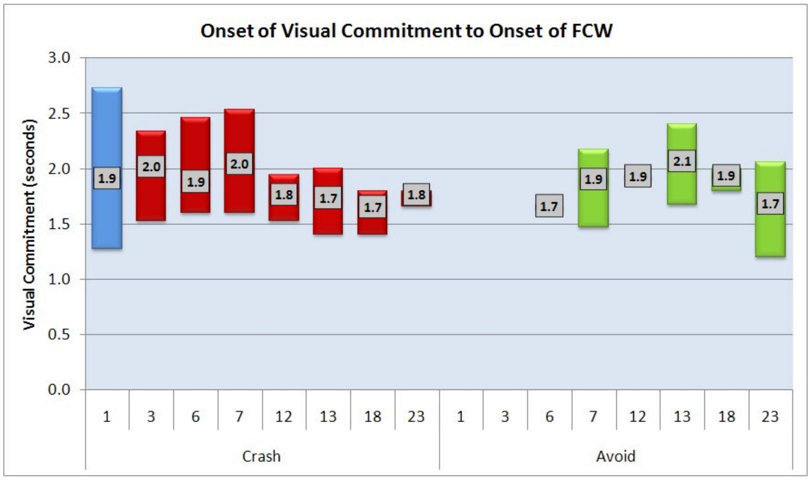

Figure 6.7. VC_{start}⇨FCW duration, presented as a function of FCW modality and crash outcome.

capable of being detected, acknowledged, and correctly interpreted by the driver during the random number recall task used in this study, the FCW⇨VC_{end} duration associated with that modality should be less than the time taken by a driver to return to their forward facing viewing position after simply completing the task. Conceptually, differences in FCW⇨VC_{end} should be in good agreement with the overall VC durations described earlier, however the FCW⇨VC_{end} data are not vulnerable to the potentially confounding effect of VC_{start}⇨FCW duration variability. For this reason, the FCW⇨VC_{end} metric is preferred for quantifying response time.

6.4.1 General FCW to VC_{end} Response Time Observations

Figure 6.8 presents the distribution of FCW⇨VC_{end} durations observed for each FCW modality. Overall, these values ranged from 270 ms to 1.74 seconds. The mean values for each FCW modality ranged from 593 ms to 1.49 seconds overall, for configurations 18 and 3, respectively.

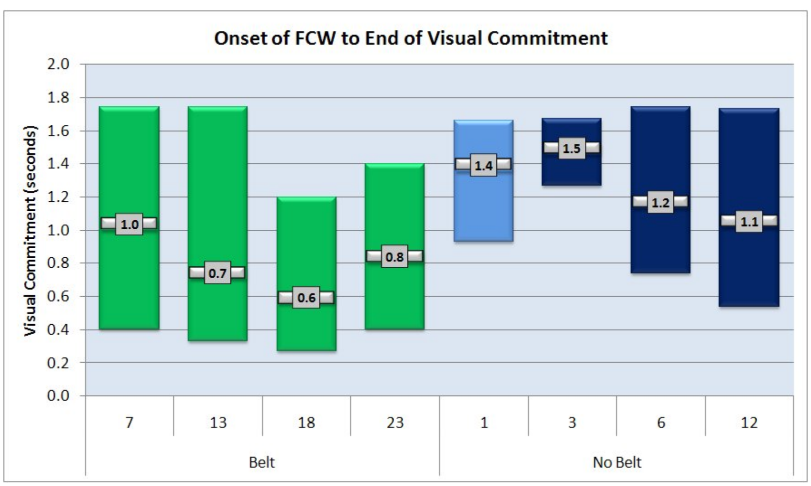

Figure 6.8. FCW⇨VC_{end} duration, presented as a function of FCW modality.

Mean FCW⇨VC_{end} durations observed during tests performed with seat belt pretensioner-based FCW modalities ranged from 593 ms to 1.04 seconds for conditions 18 and 7, respectively. These values overlapped the comparable range of means established during tests performed without seat belt pretensioner-based FCW modalities, from 1.14 to 1.49 seconds, recorded for conditions 12 and 3, respectively. The mean value of the trials performed with no FCW alert (1.39 seconds) resided outside of the mean range established by the trials performed with seat belt pretensioning, but within that observed without.

As expected, the data shown in Figure 6.9 continue to indicate that shorter FCW⇨VC_{end} durations are closely associated with the ability of the participants' to avoid a crash. The overall mean FCW⇨VC_{end} duration of the trials where the participants collided with the SLV was 163.2 percent longer than that observed when the crash was avoided (1.24 seconds versus 470 ms).

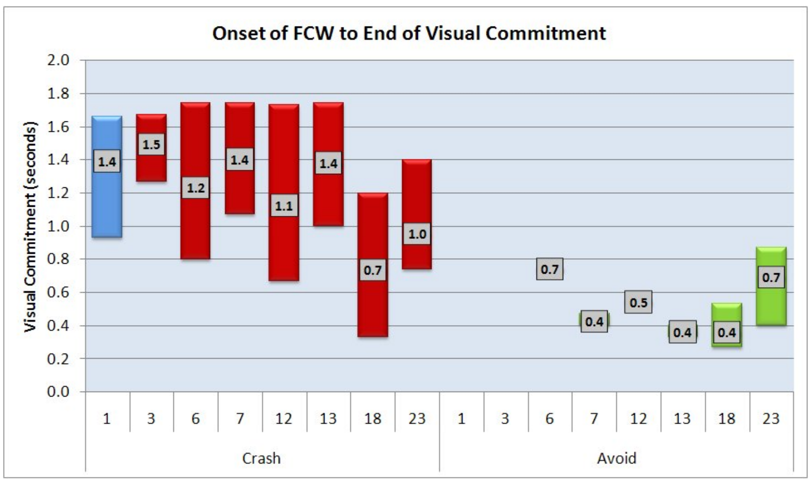

Figure 6.9. FCW⇨VC_{end} duration, presented as a function of FCW modality and crash outcome.

6.4.2 Statistical Assessment of FCW to VC_{end} Response Times

Table 6.1 provides a summary of the data used to statistically compare the mean FCW⇨VC_{end} times shown in Figure 6.8. In this case, the means associated with the FCW modality were found to be significantly different.

Typically, the next step in this analysis would be to objectively rank, with statistical significance, the mean FCW⇨VC_{end} times in order from lowest (quickest response to the alert) to highest (slowest response to the alert). This was not possible because of the low number of subjects per condition (n), and because there are 28 possible unique pair-wise comparisons between the eight different FCW alerts (8 nCr 2 = 28). Controlling the family-wise error rate at alpha = 0.05 would have meant testing at alpha = 0.05/28, or 0.00179. This would be particularly stringent given the low number of subjects. To address the limitations imposed by the small sample size, steps were taken to collapse across certain FCW modalities. This process was intended to increase the number of samples per cell and to reduce the number of comparisons.

Table 6.1. FCW⇨VC_{end} Comparison By Modality.

Time from FCW to VC_{end} (sec)							
Condition	Modality	N	Mean	Std Dev	Minimum	Maximum	Pr > F
23	All	7	0.840	0.295	0.400	1.400	0.0002
3	Beep	8	1.169	0.373	0.740	1.740	
12	BeepHUD	8	1.051	0.366	0.540	1.730	
7	Belt	8	1.035	0.541	0.400	1.740	
18	BeltBeep	8	0.593	0.359	0.270	1.200	
13	BeltHUD	8	0.743	0.564	0.330	1.740	
6	HUD	8	1.491	0.150	1.270	1.670	
1	None	8	1.390	0.258	0.930	1.660	

Subjective ranking of the mean FCW⇨VC_{end} times shown in Table 6.1 (i.e., sorting simply on FCW⇨VC_{end} magnitude) indicated HUD and no alert (none) had the slowest reaction times and were very close overall. This seemed reasonable since the participants receiving the HUD alert were unable to detect its presentation when engaged in the random number recall task. However, to more objectively assess whether this assumption was correct (i.e., that HUD did not affect FCW⇨VC_{end}), the mean FCW⇨VC_{end} reaction times produced by four alert configurations containing HUD-based alerts were compared to those produced by the comparable configurations without the HUD alert. For example, Belt only based reaction times were compared to the Belt + HUD reaction times. Table 6.2 presents the results of this analysis, and indicates the presence of the HUD did not significantly affect FCW⇨VC_{end} reaction times.

Table 6.2. Testing the Effect of HUD on FCW⇨VC_{end}.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Beep vs. BeepHUD	1	0.05522500	0.05522500	0.37	0.5462
Compare BeltBeep vs. All	1	0.22869000	0.22869000	1.53	0.2219
Compare Belt vs. BeltHUD	1	0.34222500	0.34222500	2.28	0.1364
Compare None vs. HUD	1	0.04100625	0.04100625	0.27	0.6029

Combining the comparable FCW alerts (with and without the HUD), shown in Table 6.2, provided four basic alert configurations. As a courtesy to the reader, these combinations were renamed and the convention used for the remainder of this report:

- Beep and BeepHUD ⇨ Auditory
- BeltBeep and All ⇨ Auditory-Haptic
- Belt and BeltHUD ⇨ Haptic
- None and HUD ⇨ None

Table 6.3 provides a statistical comparison of the mean FCW⇨VC_{end} reaction times for these four FCW configurations, and indicates they were significantly different.

Table 6.3. FCW⇨VC_{end} Comparison By Modality, Collapsed.

Time from FCW to VC_{end} (sec) – Alerts With and Without HUD Combined						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	16	1.110	0.362	0.540	1.740	<.0001
Auditory-Haptic	15	0.708	0.344	0.270	1.400	
Haptic	16	0.889	0.555	0.330	1.740	
None	16	1.441	0.210	0.930	1.670	

With 15 to 16 samples per condition, and only six possible unique pair-wise comparisons between the four FCW alert configurations (4 nCr 2 = 6), it was possible to examine all pair-wise comparisons and objectively rank mean FCW⇨VC_{end} reaction times. The family-wise error rate was again controlled at alpha = 0.05, meaning significant main effects would be less than alpha = 0.05/6, or 0.00833. As indicated (*) in Table 6.4, three of these comparisons were significantly different.

Table 6.4. FCW⇨VC_{end} Pair-Wise Comparisons.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Auditory vs. Auditory-Haptic	1	1.25112774	1.25112774	8.29	0.0055*
Compare Auditory vs. Haptic	1	0.39161250	0.39161250	2.59	0.1126
Compare Auditory vs. None	1	0.87450313	0.87450313	5.79	0.0192
Compare Auditory-Haptic vs. Haptic	1	0.25293339	0.25293339	1.68	0.2005
Compare Auditory-Haptic vs. None	1	4.15540173	4.15540173	27.53	<.0001*
Compare Haptic vs. None	1	2.43652813	2.43652813	16.14	0.0002*

*Significant at the alpha = 0.00833 level.

Table 6.5 presents the mean FCW⇨VC_{end} times previously shown in Table 6.3, sorted from quickest to slowest, and an indication of where significant differences between configurations occurred. In this table, no mean was significantly different than an adjacent mean. The significant differences exist at the extremes. For example, the mean FCW⇨VC_{end} times of the Auditory-Haptic and Auditory only configurations were significantly different, but the Auditory-Haptic and Haptic only mean FCW⇨VC_{end} times were not.

Table 6.5. Objective Ranking FCW⇨VC_{end} of Response Times.

Rank of FCW to VC_{end} (sec)			
Relative Rank	Modality	Mean	Significant Differences*
1	Auditory-Haptic	0.708	A
2	Haptic	0.889	A B
3	Auditory	1.110	B C
4	None	1.441	C

*Alert modalities with the same letter were not significantly different.

The analysis presented in Table 6.6 indicates that on average, women responded to the FCW configurations shown in Table 6.5 254 ms quicker than men, and that this was a significant difference.

Table 6.6. FCW⇨VC_{end} Response Times By Gender.

Time from FCW to VC_{end} (sec) – by Gender						
Gender	N	Mean	Std Dev	Minimum	Maximum	Pr > F
F	31	0.913	0.456	0.330	1.730	0.0294
M	32	1.167	0.451	0.270	1.740	

Since both main effects evaluated in this section were significantly different, the interaction term was examined for information-purposes only. Using a gender by FCW configuration model, a significant interaction between gender and alert type was shown to exist. The means from each gender by modality combination are shown in Table 6.7.

Table 6.7. FCW⇨VC_{end} Response Times and Gender Interaction.

Time from FCW to VC_{end} (sec) – Modality by Gender							
Modality	Gender	N	Mean	Std Dev	Minimum	Maximum	Pr > F
Auditory	F	8	1.001	0.408	0.540	1.730	<.0001
	M	8	1.219	0.295	0.930	1.740	
Auditory-Haptic	F	7	0.687	0.335	0.330	1.200	
	M	8	0.726	0.374	0.270	1.400	
Haptic	F	8	0.551	0.302	0.330	1.070	
	M	8	1.226	0.555	0.330	1.740	
None	F	8	1.383	0.277	0.930	1.670	
	M	8	1.499	0.102	1.330	1.600	

6.5 Time-to-Collision (TTC) at End of Visual Commitment

In the previous section, FCW⇨VC_{end} duration was mentioned as a good way to objectively quantify how quickly the participants responded to the various FCW alert modalities. However, once VC_{end} had occurred, knowing how the participants responded was also of interest. To begin analysis of the participants' crash avoidance responses, the TTC at VC_{end} was considered. This provided a way to describe how much time was available for the participants to avoid a collision with the SLV.

6.5.1 General TTC at VC_{end} Observations

Figure 6.10 presents the distribution of TTC at VC_{end} times observed in this study for each FCW modality. Overall, these values ranged from 319 ms to 1.87 seconds. The mean values for each FCW modality ranged from 608 ms to 1.46 seconds overall, for configurations 3 and 18, respectively.

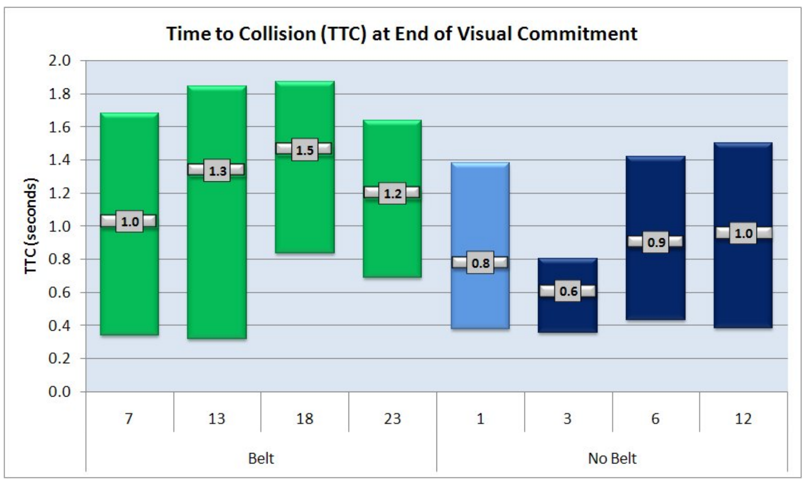

Figure 6.10. TTC at VC_{end}, presented as a function of FCW modality.

The mean TTCs at VC_{end} observed during tests performed with seat belt pretensioner-based FCW modalities ranged from 1.03 to 1.46 seconds, for conditions 7 and 18, respectively. These values were outside of the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 608 to 955 ms, for conditions 3 and 12, respectively. The mean TTC at VC_{end} time observed when no FCW alert was presented (779 ms) was outside the mean range for tests performed with seat belt pretensioning, but was inside the range defined by non-pretensioner based trials.

Figures 6.5 and 6.9, presented previously, indicated that VC duration adversely affected the likelihood that participants would avoid colliding with the SLV. One benefit of the reduced VC duration is shown in Figure 6.11; the earlier VC_{end} occurs, the longer the TTC (assuming each subject uses a common vehicle speed). In other words, the less time the driver spent with their eyes away from the road, the more time they had available to decide on an appropriate crash avoidance countermeasure. Based on the data shown in Figure 6.11, the overall mean TTC at VC_{end} of the trials resulting in a collision with the SLV was 90.8 percent shorter than that observed when the crash was avoided (837 ms versus 1.60 seconds).

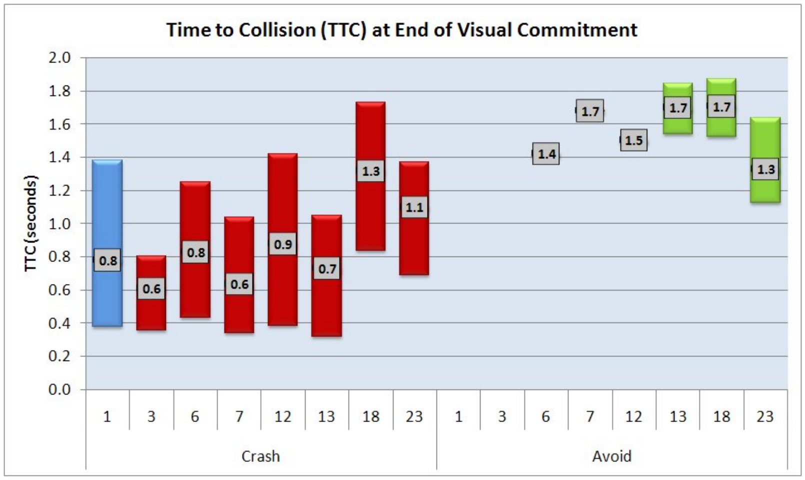

Figure 6.11. TTC at VC_{end}, presented as a function of FCW modality and crash outcome.

6.5.2 Statistical Assessment of TTC at VC_{end}

The statistical analysis provided in Section 6.4 demonstrated that the mean FCW⇨VC_{end} reaction times of "comparable" FCW alerts (with and without the HUD) can be combined. Since TTC at VC_{end} is based on the same VC_{end} data used in this previous analysis (they have the same units, but consider different intervals), re-testing the validity of combining data in this manner was not necessary.

Table 6.8 provides a summary of the data used to statistically compare the mean TTC at VC_{end} times shown in Figure 6.10. The results show the means of these four FCW configurations were significantly different, which was consistent with the previous analyses.

Table 6.8. TTC at VC_{end} Comparison By Modality, Collapsed.

TTC at VC_{end} (sec) – Alerts With and Without HUD Combined						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	16	0.929	0.359	0.384	1.501	0.0002
Auditory-Haptic	15	1.338	0.351	0.689	1.872	
Haptic	16	1.181	0.567	0.319	1.844	
None	16	0.693	0.284	0.357	1.384	

The six possible pair-wise comparisons between the four FCW configurations were examined, and the FCW alert modalities ranked. Family-wise error rate was controlled at alpha = 0.05, meaning significant main effects were less than alpha = 0.05/6, or 0.00833. The results show that three of these comparisons were significantly different; as indicated (*) in Table 6.9.

Table 6.9. TTC at VC_{end} Pair-Wise Comparisons.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Auditory vs. Auditory-Haptic	1	1.29613441	1.29613441	7.88	0.0067*
Compare Auditory vs. Haptic	1	0.50828403	0.50828403	3.09	0.0839
Compare Auditory vs. None	1	0.44203503	0.44203503	2.69	0.1064
Compare Auditory-Haptic vs. Haptic	1	0.19108428	0.19108428	1.16	0.2853
Compare Auditory-Haptic vs. None	1	3.21314492	3.21314492	19.55	<.0001*
Compare Haptic vs. None	1	1.89832612	1.89832612	11.55	0.0012*

*Significant at the alpha = 0.00833 level.

Table 6.10 presents the mean TTC at VC_{end} times previously shown in Table 6.8, sorted from longest (best) to shortest (worse), and an indication of where significant differences between configurations occurred. Like the findings discussed in Section 6.4, no mean was significantly different than an adjacent mean in Table 6.5; the significant differences existed at the extremes.

Table 6.10. Objective Ranking of TTC at VC_{end}.

Rank of TTC at VC_{end} (sec)			
Relative Rank	**Modality**	**Mean**	**Significant Differences***
1	Auditory-Haptic	1.338	A
2	Haptic	1.181	A B
3	Auditory	0.929	B C
4	None	0.693	C

*Alert modalities with the same letter were not significantly different.

The analysis presented in Table 6.11 indicates that because they responded to the FCW alert faster, the mean TTC at VC_{end} for the female participants was 287ms longer than that recorded for the males. This was a significant difference.

Table 6.11. TTC at VC_{end} By Gender.

TTC at VC_{end} (sec) – by Gender						
Gender	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
F	31	1.176	0.441	0.357	1.774	0.0132
M	32	0.889	0.451	0.319	1.872	

Since both main effects evaluated in this section were significantly different, the interaction term was examined for information-purposes only. Using a gender by FCW configuration model, a significant interaction between gender and alert type was shown to exist. The means from each gender by modality combination are shown in Table 6.12.

Table 6.12. TTC at VC_{end} and Gender Interaction.

TTC at VC_{end} (sec) – Modality by Gender							
Modality	**Gender**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	F	8	1.073	0.420	0.384	1.501	<.0001
	M	8	0.784	0.229	0.430	1.120	
Auditory-Haptic	F	7	1.349	0.347	0.834	1.729	
	M	8	1.328	0.379	0.689	1.872	
Haptic	F	8	1.512	0.295	1.039	1.774	
	M	8	0.850	0.593	0.319	1.844	
None	F	8	0.793	0.360	0.357	1.384	
	M	8	0.594	0.144	0.378	0.755	

6.6 Throttle Release Response Time

Acknowledgement of a SLV directly in the path of their vehicle occurred shortly after participants returned their view to a forward-looking position. From this point, eight crash avoidance responses were possible; ranging from nothing (i.e., no avoidance was attempted) to the various combinations of throttle release, braking, and steering. An overall summary of these responses is provided in Table 6.13. In 59 of the 64 trials (92.2 percent), participants fully released the throttle as part of their crash avoidance response.

Table 6.13. Crash Avoidance Response Summary (n=64).

Crash Avoidance Response	# of Participants		
	Crash	**Avoid**	**Total**
No Response	3	--	**3**
Throttle Release Only	3	--	**3**
Braking Only*	1	--	**1**
Steering Only	--	1	**1**
Throttle Release, Braking	14	1	**15**
Throttle Release, Steering	1	--	**1**
Braking and Steering	--	--	**--**
Throttle Release, Braking, Steering	25	15	**40**

* During an attempt to release the throttle and apply the brakes, one participant was unable to fully release the throttle before crashing into the SLV.

6.6.1 General Throttle Release Time Observations

6.6.1.1 Onset of FCW to Throttle Release Time

Figure 6.12 presents the distribution of throttle release times measured from the onset of the FCW alert for each FCW modality. Overall, these values ranged from 260 ms to 2.05 seconds. The mean values for each FCW modality ranged from 896 ms to 1.88 seconds overall, for configurations 13 and 3, respectively.

The mean throttle release times, from the onset of the seat belt pretensioner-based FCW modalities, ranged from 896 ms to 1.16 seconds, for conditions 13 and 7, respectively. The range of these values was outside of the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 1.36 to 1.88 seconds, for conditions 12 and 3, respectively. The mean throttle release time observed when no FCW alert was presented (1.69 seconds) was outside the mean range for tests performed with seat belt pretensioning, but was inside the range defined by pretensioner-based trials.

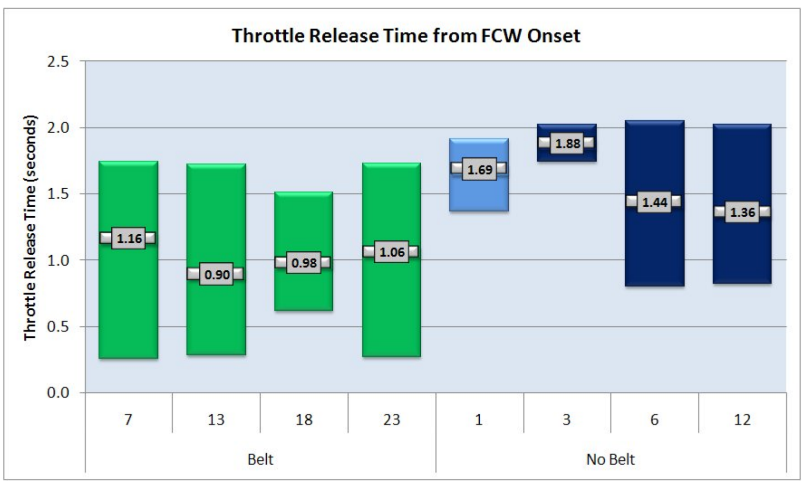

Figure 6.12. Throttle release times, presented as a function of FCW modality.

Given that most participants released the throttle shortly after VC_{end}[9], it is not surprising that the throttle release data shown in Figure 6.13 closely resembles the FCW⇨VC_{end} duration data previously presented in Figure 6.5; both figures use the onset of FCW as the reference by which duration (Figure 6.5) or release time (Figure 6.13) was calculated. The overall mean throttle release time of the trials where the participants collided with the SLV was 117.3 percent longer than that observed when the crash was avoided (1.53 seconds versus 705 ms).

[9] Three participants fully released the throttle before the FCW alert was presented. Although it is unclear whether this was in response to being committed to the random number recall task, or being used as an attempt to maintain the desired headway to the moving lead vehicle, the throttle release was certainly not part of the participants' respective avoidance responses. For this reason, these three release times have been omitted from the throttle drop based charts and analyses discussed in this section so as to provide a more accurate portrayal of the relevant throttle-brake phasing.

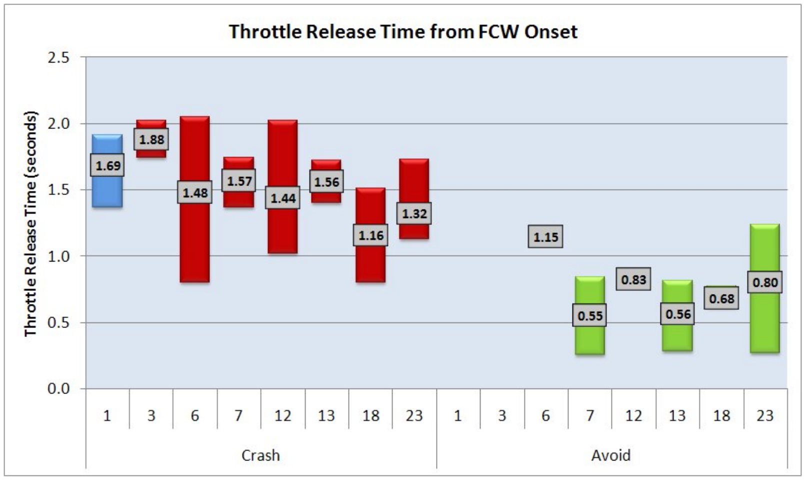

Figure 6.13. Throttle release times, presented as a function of FCW modality and crash outcome.

6.6.1.2 End of Visual Commitment to Throttle Release Time

To better understand whether FCW modality affected the response time from VC_{end} to the onset of throttle release, the reaction time from FCW onset to VC_{end} was removed from the data summarized in Section 6.6.1. Figure 6.14 presents the distribution of throttle release times measured from VC_{end} for each FCW modality. Overall, these values ranged from -530 to 560 ms. The mean values for each FCW modality ranged from 241 to 389 ms overall, for configurations 7 and 13, respectively.

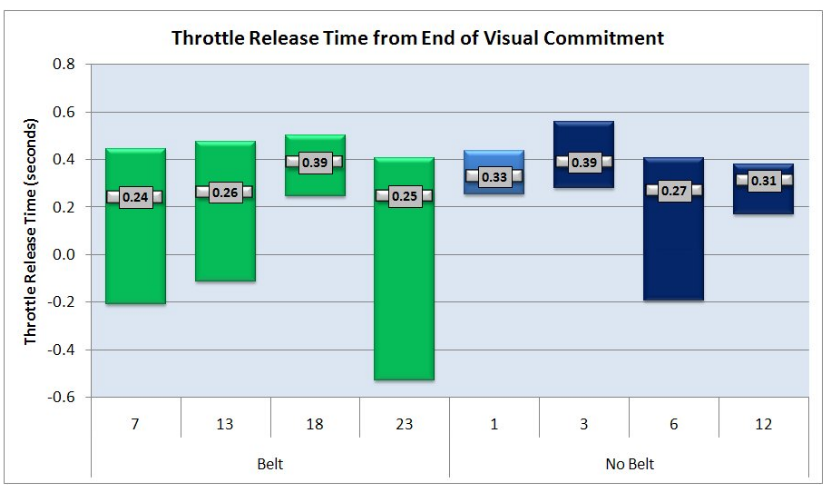

Figure 6.14. Throttle release times, presented from VC_{end} as function of FCW modality and crash outcome.

The negative release times shown in Figure 6.14 indicate some participants released the throttle before returning to a forward-facing viewing position, and do not include data from the three trials where the participants were not on the throttle at the time the FCW alert was presented (as previously mentioned in Section 6.6.1.1). Not considering these data, a total of four participants released throttle before VC_{end}, with response times of -115, -195, -210, and -530 ms. These participants released the throttle 270 to 805 ms after receiving their respective

FCW alerts (for configurations 13, 6, 7, and 23, respectively). Note that three of these alerts were inclusive of the seat belt pretensioner.

The mean throttle release times associated with the seat belt pretensioner-based FCW modalities (from VC_{end}) ranged from 241 to 387 ms, for conditions 7 and 18, respectively. The range of these values overlapped the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 269 to 389 ms for by conditions 6 and 3, respectively. The mean throttle release time observed when no FCW alert was presented (328 ms) was inside the mean ranges for trials performed with and without seat belt pretensioning. Figure 6.15 presents the data previously shown in Figure 6.14, but separated as a function of crash outcome. Overall, these data imply that while FCW modality can affect the driver's response time from FCW onset to VC_{end}, it does not appear to affect the time taken from VC_{end} to initiation of the throttle release. This is discussed in greater detail in Section 6.6.2.2.

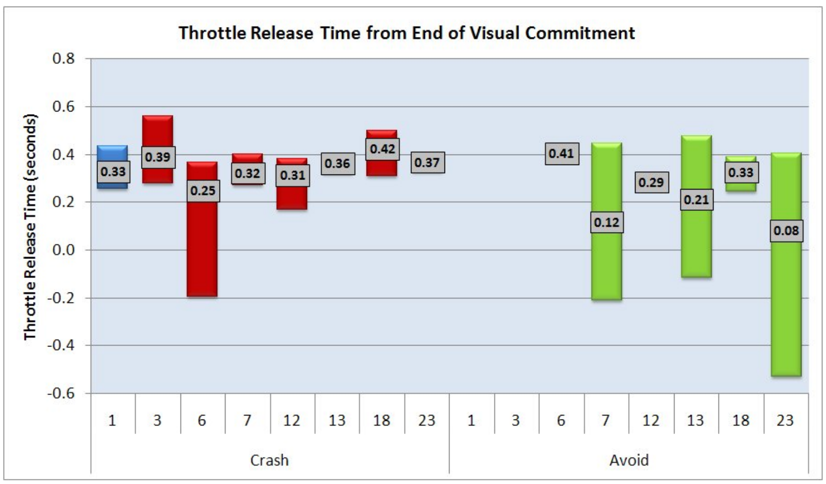

Figure 6.15. Throttle release times, presented from VC_{end} as function of FCW modality and crash outcome.

6.6.2 Statistical Assessment of Throttle Release Times

In this section, two analyses of throttle release time are provided. First, mean release times from FCW alert onset are discussed. In the second analysis, release times from VC_{end} are considered.

6.6.2.1 Throttle Release from FCW Onset

In Section 6.4, an analysis was performed to verify that results from trials performed with FCW alerts differing only by the presence of a HUD could be combined. In this section, the process used in Section 6.4 was repeated because the data analyzed was produced after VC_{end} (i.e., the throttle was released after the driver had returned their view to a forward-facing position. This was a concern because of the HUD-based alert duration; in every case where it was used, it remained on for 2.3 to 3.7 seconds after VC_{end}. Therefore, while the HUD was not detectable by participants engaged in the random number recall task, participants did have an opportunity to notice, and respond to, the HUD shortly after task completion (but before crashing into the SLV). Had this occurred, time to throttle release, brake application, and/or to avoidance steering, may have been affected.

Table 6.14 provides a summary of the data used to statistically compare the mean throttle release times shown in Figure 6.12. The results show the means of these eight FCW modalities were significantly different.

Table 6.14. Throttle Release Response Time from FCW Onset.

Time from FCW to Throttle Release (sec)							
Condition	**Modality**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
23	All	8	1.061	0.424	0.270	1.730	0.0002
3	Beep	8	1.438	0.419	0.805	2.050	
12	BeepHUD	8	1.361	0.377	0.825	2.020	
7	Belt	5	1.163	0.609	0.260	1.740	
18	BeltBeep	8	0.979	0.345	0.615	1.510	
13	BeltHUD	6	0.896	0.571	0.285	1.720	
6	HUD	8	1.880	0.098	1.740	2.020	
1	None	5	1.686	0.262	1.365	1.915	

Pair-wise comparisons were made between the four FCW modalities not inclusive of the HUD, with the corresponding configurations that were. The results, shown in Table 6.15, indicate the mean throttle release times of comparable alerts were not significantly different.

Table 6.15. Testing the Effect of HUD on Throttle Release Time from FCW Onset.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Beep vs. BeepHUD	1	0.02325625	0.02325625	0.14	0.7064
Compare BeltBeep vs. All	1	0.02681406	0.02681406	0.17	0.6859
Compare Belt vs. BeltHUD	1	0.19466735	0.19466735	1.20	0.2784
Compare None vs. HUD	1	0.11580308	0.11580308	0.71	0.4020

Table 6.16 provides a summary of the paired data used to statistically compare the mean throttle release times associated with the four combined FCW modalities. The results show the means were significantly different, which is consistent with the first analysis discussed in this section.

Table 6.16. Throttle Release Time from FCW Onset Comparison By Modality, Collapsed.

FCW to Throttle Release (sec) – Alerts With and Without HUD Combined						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	16	1.399	0.387	0.805	2.050	<.0001
Auditory-Haptic	15	1.020	0.376	0.270	1.730	
Haptic	16	1.017	0.575	0.260	1.740	
None	16	1.805	0.195	1.365	2.020	

Six possible pair-wise comparisons between the four FCW-alert combinations were examined and the FCW alert modalities ranked. Family-wise error rate was controlled at alpha = 0.05, meaning significant main effects would be less than alpha = 0.05/6, or 0.00833. The results show that three of these comparisons were significantly different; they are marked with an (*) in Table 6.17.

Table 6.17. Throttle Release Time from FCW Onset Pair-Wise Comparisons.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Auditory vs. Auditory-Haptic	1	1.14950703	1.14950703	7.35	0.0091
Compare Auditory vs. Haptic	1	0.95171770	0.95171770	6.08	0.0170
Compare Auditory vs. None	1	1.18232800	1.18232800	7.56	0.0082*
Compare Auditory-Haptic vs. Haptic	1	0.00006023	0.00006023	0.00	0.9844
Compare Auditory-Haptic vs. None	1	4.42063280	4.42063280	28.25	<.0001*
Compare Haptic vs. None	1	3.70084207	3.70084207	23.65	<.0001*

*Significant at the alpha = 0.00833 level.

Table 6.18 presents the mean throttle release times previously shown in Table 6.16, sorted from lowest (best) to highest (worse), and an indication of where significant differences between modalities occurred.

Table 6.18. Objective Ranking of Throttle Release Time from FCW Onset.

Rank of FCW to Throttle Release (sec)			
Relative Rank	**Modality**	**Mean**	**Significant Differences***
1	Haptic	1.017	A
2	Auditory-Haptic	1.020	A
3	Auditory	1.399	A
4	None	1.805	

*Alert modalities with the same letter were not significantly different.

The analysis presented in Table 6.19 indicates that there was no significant difference between the mean throttle release times from FCW onset for the male and female participants.

Table 6.19. Throttle Release Time from FCW Onset by Gender.

FCW to Throttle Release (sec) – by Gender						
Gender	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
F	30	1.231	0.501	0.260	2.020	0.2062
M	26	1.402	0.492	0.270	2.050	

Since one of the main effects evaluated in this section was significantly different, the interaction term was examined for information-purposes only. Using a gender by FCW configuration model, a significant interaction between gender and alert type was shown to exist. The means from each gender by modality combination are shown in Table 6.20.

Table 6.20. Throttle Release Time from FCW Onset and Gender Interaction.

FCW to Throttle Release (sec) – Modality by Gender							
Modality	**Gender**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	F	8	1.331	0.384	0.825	2.020	<.0001
	M	8	1.468	0.404	0.805	2.050	
Auditory-Haptic	F	8	1.070	0.271	0.805	1.510	
	M	8	0.971	0.473	0.270	1.730	
Haptic	F	7	0.761	0.491	0.260	1.405	
	M	4	1.466	0.445	0.805	1.740	
None	F	7	1.772	0.259	1.365	2.020	
	M	6	1.844	0.090	1.740	1.960	

6.6.2.2 Throttle Release from End of Visual Commitment

Table 6.21 provides a summary of the data used to statistically compare the mean throttle release times from VC_{end} shown in Figure 6.14. The results show the means of these eight FCW configurations were not significantly different, indicating the significant release time differences described in Section 6.6.2.1 were the result of the significant differences in FCW⇨VC_{end} durations discussed in Section 6.4.

Table 6.21. Throttle Release Response Time from VC_{end}.

Time from VCend to Throttle Release (sec)						
Condition	**Modality**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
23	All	0.246	0.343	-0.530	0.405	0.6703
3	Beep	0.269	0.194	-0.195	0.405	
12	BeepHUD	0.310	0.068	0.170	0.380	
7	Belt	0.241	0.262	-0.210	0.445	
18	BeltBeep	0.387	0.084	0.245	0.500	
13	BeltHUD	0.263	0.252	-0.115	0.475	
6	HUD	0.389	0.080	0.280	0.560	
1	None	0.328	0.066	0.255	0.435	

Pair-wise comparisons were made between the four FCW configurations not based on the HUD, with the corresponding configurations that were. The results, shown in Table 6.22, indicate the mean throttle release times from VC_{end} of comparable alerts were not significantly different.

Table 6.22. Testing the Effect of HUD on Throttle Release Time from VC_{end}.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Beep vs. BeepHUD	1	0.00680625	0.00680625	0.19	0.6669
Compare BeltBeep vs. All	1	0.07439170	0.07439170	2.05	0.1588
Compare Belt vs. BeltHUD	1	0.00126068	0.00126068	0.03	0.8529
Compare None vs. HUD	1	0.01135558	0.01135558	0.31	0.5786

Table 6.23 provides a summary of the paired data used to statistically compare the mean throttle release times from VC_{end} associated with the four combined FCW configurations. The results show the means were not significantly different, which is consistent with the first analysis discussed in this section.

Table 6.23. Throttle Release Time from VC_{end} Comparison By Modality, Collapsed.

VCend to Throttle Release (sec) – Alerts With and Without HUD Combined						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	16	0.289	0.142	-0.195	0.405	0.5007
Auditory-Haptic	15	0.321	0.244	-0.530	0.500	
Haptic	11	0.253	0.244	-0.210	0.475	
None	13	0.365	0.078	0.255	0.560	

The analysis presented in Table 6.24 indicates that there was no significant difference between the mean throttle release times from VC_{end} for the male and female participants.

Table 6.24. Throttle Release Time from VC_{end} by Gender.

VCend to Throttle Release (sec) – by Gender						
Gender	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
F	29	0.325	0.169	-0.210	0.560	0.4977
M	26	0.290	0.207	-0.530	0.475	

6.7 Brake Application Response Time

In 56 of the 64 trials (87.5 percent), participants applied force to the brake pedal as part of their crash avoidance response. In 40 of these 56 instances (71.4 percent), the participants also used steering during their respective avoidance responses. In 11 of 40 trials (27.5 percent), participants began braking before steering. Steering preceded braking during 28 of 40 trials (70.0 percent). A simultaneous input of braking and steering was observed during one trial (2.5 percent). A summary of these data are shown in Table 6.25.

Table 6.25. Brake / Steer Response Summary (n=40).

Crash Avoidance Response	# of Participants		
	Crash	**Avoid**	**Total**
Brake ⇨ Steer	3	7	**11**
Steer ⇨ Brake	21	7	**28**
Simultaneous Inputs (Brake and Steer)	--	1	**1**

6.7.1 General Brake Application Response Time Observations

6.7.1.1 Onset of FCW to Brake Application Response Time

Figure 6.16 presents the distribution of brake application response times measured from the onset of the FCW alert for each FCW modality. Overall, these values ranged from 700 ms to 2.20 seconds. The mean values for each FCW modality ranged from 1.09 to 2.00 seconds overall, for configurations 18 and 3, respectively.

The mean brake application times, from the onset of the seat belt pretensioner-based FCW modalities, ranged 1.09 to 1.436 seconds, for conditions 18 and 7, respectively. The range of these values was just outside of the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 1.437 to 2.00 seconds for conditions 12 and 3, respectively. The mean brake application time observed when no FCW alert was presented (1.80 seconds) was outside the mean range for tests performed with seat belt pretensioning, but was inside the range defined by pretensioner-based trials.

Recalling the data previously presented in Table 6.1, in each of the 55 instances where the avoidance responses included braking, a throttle release always preceded the brake application. When brake applications were used, the inputs were applied 265 to 630 ms after

VC_{end} (as described in Section 6.7.1.2) and 40 to 795 ms after the throttle was fully released[10]. Mean reaction times from VC_{end} and throttle release were 464 and 167 ms, respectively[11].

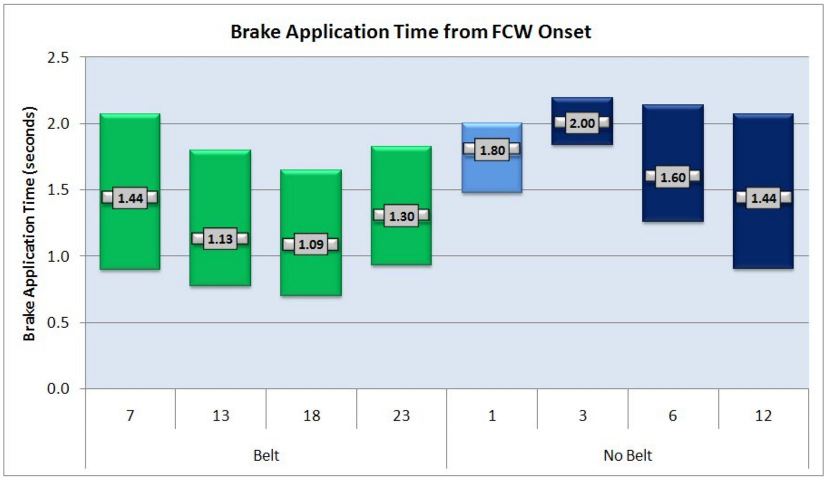

Figure 6.16. Brake application times, presented as a function of FCW modality.

Given the close proximity of the brake application to VC_{end} and the time of throttle release, it is not surprising that presentation of the brake application data shown in Figure 6.17 closely resembles the FCW⇨VC_{end} duration and FCW⇨throttle release time data previously presented in Figures 6.9 and 6.13, respectively.

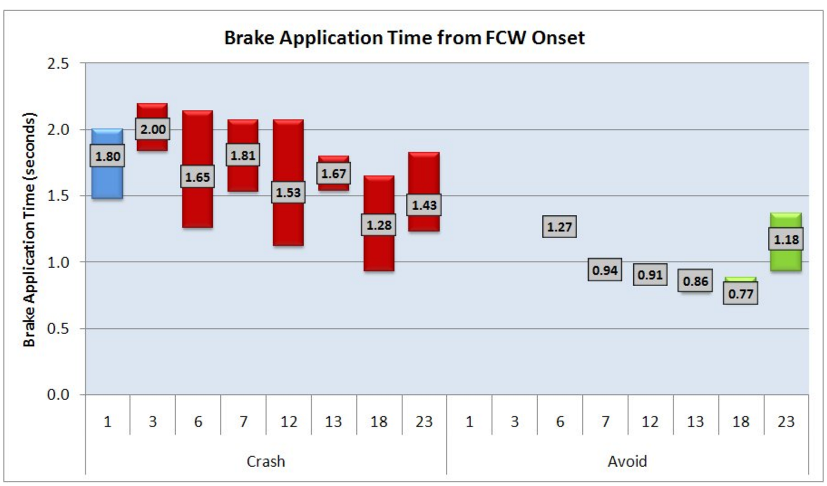

Figure 6.17. Brake application times, presented as a function of FCW modality and crash outcome.

[10] During an attempt to release the throttle and apply the brakes, one participant was unable to fully release the throttle. This attempt was classified as "Braking Only" in Table 6.13.

[11] Three participants fully released the throttle before the FCW alert was presented. Although it is unclear whether this was in response to being committed to the random number recall task, or being used as an attempt to maintain the desired headway to the moving lead vehicle, the throttle release was certainly not part of the participants' respective avoidance responses. For this reason, these three release times have been omitted from the throttle drop based charts and analyses discussed in this section so as to provide a more accurate portrayal of the relevant throttle-steer phasing.

The overall mean brake application time of the trials where the participants collided with the SLV was 74.5 percent longer than that observed when the crash was avoided (1.65 seconds versus 945 ms).

6.7.1.2 End of Visual Commitment to Brake Application Response Time

To better understand whether FCW modality affected the response time from VC_{end} to the onset of brake application, the reaction time from FCW onset to VC_{end} was removed from the data summarized in Section 6.7.1. Figure 6.18 presents the distribution of brake application response times measured from VC_{end} for each FCW modality. Overall, these values ranged from 265 to 630 ms. The mean values for each FCW modality ranged from 407 to 524 ms overall, for configurations 12 and 3, respectively.

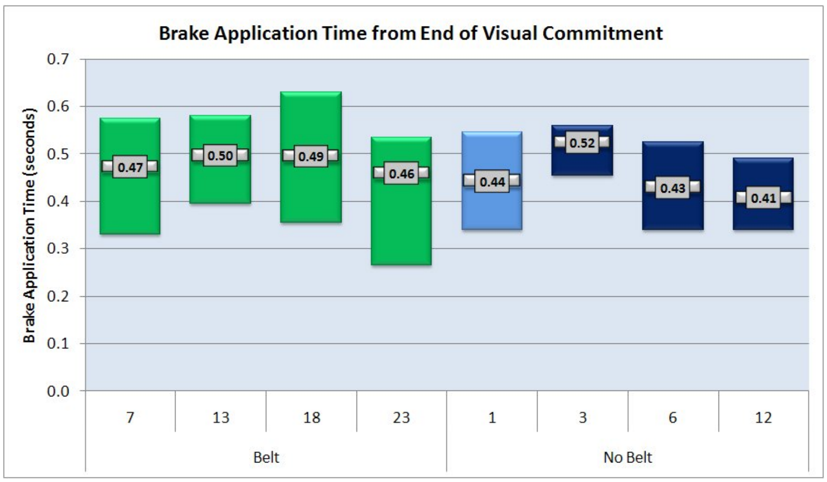

Figure 6.18. Brake application times, presented from VC_{end} as function of FCW modality.

The mean brake application times associated with the seat belt pretensioner-based FCW modalities (from VC_{end}) ranged from 459 to 496 ms, for conditions 23 and 13, respectively. The range of these values was entirely within the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 407 to 524 ms for by conditions 12 and 3, respectively. The mean brake application time observed when no FCW alert was presented (442 ms) was inside the mean range for tests performed without seat belt pretensioning, but was just outside the range defined by pretensioner-based trials. Figure 6.19 presents the data previously shown in Figure 6.18, but separated as a function of crash outcome. Overall, these data imply that while FCW modality can affect the driver's response time from FCW onset to VC_{end}, it does not appear to affect the time taken from VC_{end} to initiation of the brake application. This is discussed in greater detail in Section 6.7.2.2.

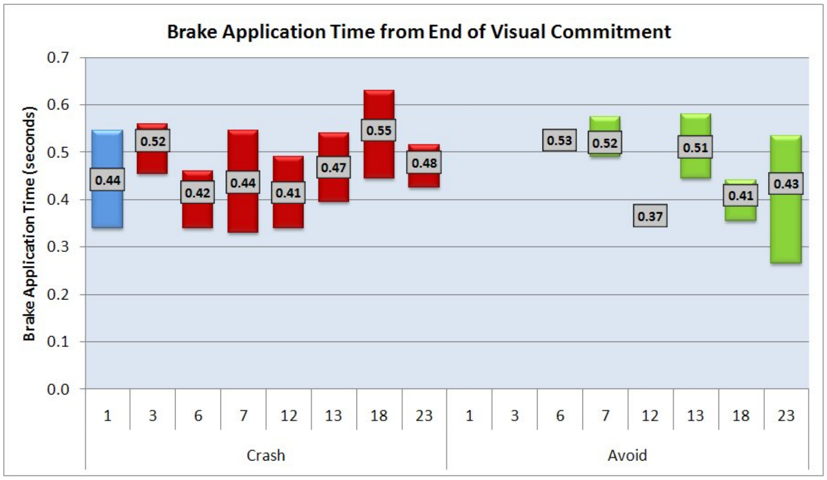

Figure 6.19. Brake application times, presented from VC_{end} as function of FCW modality and crash outcome.

6.7.2 Statistical Assessment of Brake Application Response Times

In a manner consistent with that used to discuss the statistical significance of throttle release time, this section provides two analyses of brake application response time. First, mean application times from FCW alert onset are discussed. In the second analysis, application times from VC_{end} are considered.

6.7.2.1 Brake Application Time from FCW Onset

Table 6.26 provides a summary of the data used to statistically compare the mean FCW to brake application times shown in Figure 6.16. The results show the means of these eight FCW configurations were significantly different.

Table 6.26. Brake Application Time from FCW Onset.

Time from FCW to Brake Application (sec)							
Condition	**Modality**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
23	All	8	1.263	0.320	0.750	1.825	0.0002
3	Beep	8	1.598	0.351	1.260	2.140	
12	BeepHUD	7	1.437	0.384	0.905	2.070	
7	Belt	7	1.436	0.489	0.895	2.070	
18	BeltBeep	8	1.087	0.362	0.700	1.645	
13	BeltHUD	6	1.129	0.428	0.775	1.795	
6	HUD	5	2.002	0.129	1.840	2.195	
1	None	7	1.802	0.207	1.475	2.000	

Pair-wise comparisons were made between the four FCW configurations not inclusive of the HUD, with the corresponding configurations that were. The results, shown in Table 6.27, indicate the mean FCW to brake application times of comparable alerts were not significantly different.

Table 6.27. Testing the Effect of HUD on Brake Application Time from FCW Onset.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Beep vs. BeepHUD	1	0.09600048	0.09600048	0.76	0.3872
Compare BeltBeep vs. All	1	0.12425625	0.12425625	0.99	0.3258
Compare Belt vs. BeltHUD	1	0.30501653	0.30501653	2.42	0.1264
Compare None vs. HUD	1	0.11650006	0.11650006	0.92	0.3413

Table 6.28 provides a summary of the paired data used to statistically compare the mean brake application times associated with the four combined FCW configurations. The results show the means were significantly different, which is consistent with the first analysis discussed in this section.

Table 6.28. Brake Application Time from FCW Onset Comparison By Modality, Collapsed.

FCW to Brake Application (sec) – Alerts With and Without HUD Combined						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	15	1.523	0.363	0.905	2.140	<.0001
Auditory-Haptic	16	1.175	0.342	0.700	1.825	
Haptic	13	1.295	0.470	0.775	2.070	
None	12	1.885	0.200	1.475	2.195	

Six possible pair-wise comparisons between the four FCW-alert combinations were examined and the FCW alert modalities ranked. Family-wise error rate was controlled at alpha = 0.05, meaning significant main effects would be less than alpha = 0.05/6, or 0.00833. The results show that two of these comparisons were significantly different; they are marked with an (*) in Table 6.29.

Table 6.29. Brake Application Time from FCW Onset Pair-Wise Comparisons.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Auditory vs. Auditory-Haptic	1	0.93578409	0.93578409	7.27	0.0094
Compare Auditory vs. Haptic	1	0.36219430	0.36219430	2.81	0.0995
Compare Auditory vs. None	1	0.87725042	0.87725042	6.81	0.0118
Compare Auditory-Haptic vs. Haptic	1	0.10262175	0.10262175	0.80	0.3761
Compare Auditory-Haptic vs. None	1	3.46074405	3.46074405	26.88	<.0001*
Compare Haptic vs. None	1	2.17804801	2.17804801	16.92	0.0001*

*Significant at the alpha = 0.00833 level.

Table 6.30 presents the mean FCW to brake application times previously shown in Table 6.28, sorted from lowest (best) to highest (worse), and an indication of where significant differences between configurations occurred.

Table 6.30. Objective Ranking of Brake Application Time from FCW Onset.

Rank of FCW to Brake Application (sec)			
Relative Rank	Modality	Mean	Significant Differences*
1	Auditory-Haptic	1.175	A
2	Haptic	1.295	A
3	Auditory	1.523	A B
4	None	1.885	B

*Alert modalities with the same letter were not significantly different.

The analysis presented in Table 6.31 indicates that there was no significant difference between the mean throttle release times from FCW onset for the male and female participants.

Table 6.31. Brake Application Time from FCW Onset by Gender.

FCW to Brake Application (sec) – by Gender						
Gender	N	Mean	Std Dev	Minimum	Maximum	Pr > F
F	30	1.360	0.407	0.775	2.195	0.1047
M	26	1.550	0.458	0.700	2.140	

Since one of the main effects evaluated in this section was significantly different, the interaction term was examined for information-purposes only. Using a gender by FCW-alert combination model, a significant interaction between gender and modality was shown to exist. The means from each gender by modality combination are shown in the Table 6.32.

Table 6.32. Brake Application Time from FCW Onset and Gender Interaction.

FCW to Brake Application (sec) – Modality by Gender							
Modality	Gender	N	Mean	Std Dev	Minimum	Maximum	Pr > F
Auditory	F	8	1.428	0.377	0.905	2.070	<.0001
	M	7	1.631	0.338	1.320	2.140	
Auditory-Haptic	F	8	1.234	0.262	0.930	1.645	
	M	8	1.116	0.418	0.700	1.825	
Haptic	F	8	1.056	0.302	0.775	1.540	
	M	5	1.677	0.455	0.895	2.070	
None	F	6	1.842	0.282	1.475	2.195	
	M	6	1.929	0.061	1.840	1.995	

6.7.2.2 Brake Application Time from End of Visual Commitment

Table 6.33 provides a summary of the data used to statistically compare the mean brake application times from VC_{end} shown in Figure 6.18. The results show the means of these eight FCW configurations were not significantly different, indicating the significant application time differences described in Section 6.7.2.1 were the result of the significant differences in the FCW⇨VC_{end} durations discussed in Section 6.4.

Table 6.33. Brake Application Time from VC_{end}.

Time from VCend to Brake Application (sec)						
Condition	**Modality**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
23	All	0.459	0.092	0.265	0.535	0.1205
3	Beep	0.429	0.059	0.340	0.525	
12	BeepHUD	0.407	0.057	0.340	0.490	
7	Belt	0.472	0.083	0.330	0.575	
18	BeltBeep	0.494	0.093	0.355	0.630	
13	BeltHUD	0.496	0.076	0.395	0.580	
6	HUD	0.524	0.044	0.455	0.560	
1	None	0.442	0.068	0.340	0.545	

Pair-wise comparisons were made between the four FCW configurations not based on the HUD, with the corresponding configurations that were. The results, shown in Table 6.34, indicate the VC_{end} to brake application times of comparable alerts were not significantly different.

Table 6.34. Testing the Effect of HUD on Brake Application Time from VC_{end}.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Beep vs. BeepHUD	1	0.00174298	0.00174298	0.31	0.5778
Compare BeltBeep vs. All	1	0.00478574	0.00478574	0.86	0.3577
Compare Belt vs. BeltHUD	1	0.00181323	0.00181323	0.33	0.5702
Compare None vs. HUD	1	0.01954339	0.01954339	3.52	0.0667

Table 6.35 provides a summary of the paired data used to statistically compare the mean VC_{end} to brake application times associated with the four combined FCW configurations. The results show the means were not significantly different, which is consistent with the first analysis discussed in this section.

The analysis presented in Table 6.36 indicates that following VC_{end}, male participants applied force to the brake pedal an average of 50 ms quicker than the females. This was a marginally significant difference.

Table 6.35. Brake Application Time from VC_{end} Comparison By Modality, Collapsed.

VCend to Brake Application (sec) – Alerts With and Without HUD Combined						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	15	0.419	0.057	0.340	0.525	0.0825
Auditory-Haptic	15	0.478	0.091	0.265	0.630	
Haptic	13	0.483	0.077	0.330	0.580	
None	12	0.476	0.071	0.340	0.560	

Table 6.36. Brake Application Time from VC_{end} by Gender.

VCend to Brake Application (sec) – by Gender						
Gender	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
F	29	0.486	0.074	0.340	0.630	0.0153
M	26	0.436	0.074	0.265	0.565	

Since one of the main effects evaluated in this section was significantly different, the interaction term was examined for information-purposes only. Using a gender by FCW configuration model, a significant interaction between gender and alert type was shown to exist. The means from each gender by modality combination are shown in Table 6.37.

Table 6.37. Brake Application Time from VC_{end} and Gender Interaction.

VCend to Brake Application (sec) – Modality by Gender							
Modality	**Gender**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	F	8	0.426	0.063	0.340	0.525	0.0228
	M	7	0.410	0.053	0.340	0.490	
Auditory-Haptic	F	7	0.533	0.064	0.445	0.630	
	M	8	0.429	0.086	0.265	0.530	
Haptic	F	8	0.504	0.054	0.445	0.580	
	M	5	0.449	0.102	0.330	0.565	
None	F	6	0.488	0.084	0.340	0.560	
	M	6	0.464	0.060	0.395	0.560	

6.8 Avoidance Steer Response Time

In 42 of the 64 trials (65.6 percent), participants used steering inputs as part of their crash avoidance response. During 40 of 42 trials (95.2 percent), these responses also included braking. In 33 of the 42 trials with steering (78.6 percent), the participants' primary avoidance attempt was to the left of the SLV (i.e., following the path of the MLV around the SLV). A direction of steer response summary is shown in Table 6.38.

Table 6.38. Direction of Steer Summary (n=42).

Crash Avoidance Response	# of Participants					
	Left Steer			Right Steer		
	Crash	Avoid	Total	Crash	Avoid	Total
Steering Only	--	1	**1**	--	--	--
Throttle Release and Steering	1	--	**1**	--	--	--
Brake ⇨ Steer	3	6	**9**	1	1	**2**
Steer ⇨ Brake	17	3	**21**	3	4	**7**
Simultaneous Inputs (Brake and Steer)	--	1	**1**	--	--	--
Overall	**33**			**9**		

6.8.1 General Avoidance Steer Response Time Observations

6.8.1.1 Onset of FCW to Avoidance Steering Input

Figure 6.20 presents the distribution of avoidance steer response times measured from the onset of the FCW alert for each FCW modality. Overall, these values ranged from 635 ms to 2.14 seconds. The mean values for each FCW modality ranged from 960 ms to 1.80 seconds overall, for configurations 13 and 3, respectively.

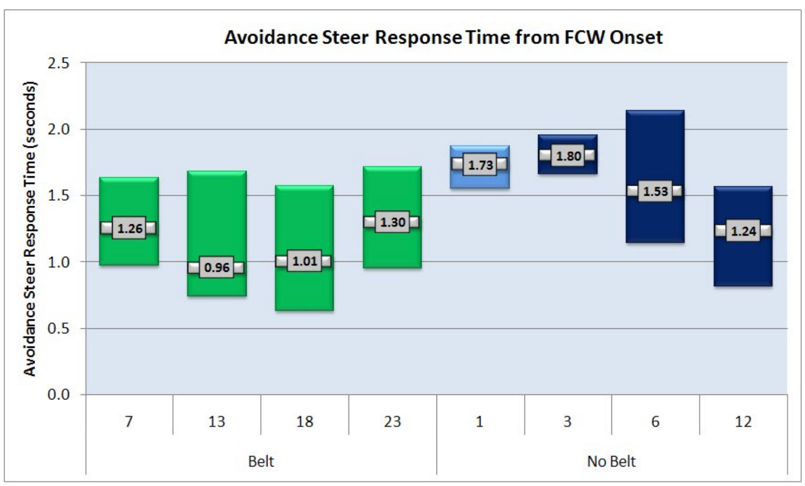

Figure 6.20. Avoidance steer response times, presented as a function of FCW modality.

The range of mean avoidance steer response times, from the onset of the seat belt pretensioner-based FCW modalities, ranged 960 ms to 1.30 seconds, for conditions 13 and 23, respectively. The range of these values overlapped that of the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 1.24 to 1.80 seconds for conditions 12 and 3, respectively. The mean avoidance steer time observed when no FCW alert was presented (1.73 seconds) was outside the mean range for tests performed with seat belt pretensioning, but was inside the range defined by pretensioner-based trials.

For the 42 of the 64 participants who used steering inputs, the initiation of these inputs occurred 85 to 690 ms after VC_{end} (described in greater detail in Section 6.8.2), with a mean gap time of 395 ms. Unlike the trend observed when evaluating the relationship of throttle release and brake application, not all participants released the throttle before initiating their avoidance steer inputs. For 15 trials, initiation of steering preceded release of the throttle by 5 to 315 ms, with a mean gap time of 69 ms. For 23 trials[12], initiation of steering occurred 5 to 950 ms after the throttle was fully released, with a mean gap time of 195 ms.

Figure 6.21 presents the distribution of avoidance steer response times, presented as a function of FCW modality and crash outcome. Given the close proximity of the avoidance steer initiation to VC_{end} and the time of throttle release, it is not surprising that presentation of the steering response time data shown in Figure 6.19 closely resembles the FCW⇨VC_{end} duration, FCW⇨throttle release time, and FCW⇨brake application time data previously presented in Figures 6.9, 6.13, and 6.17 respectively. The overall mean avoidance steer response time of the trials where the participants collided with the SLV was 66.3 percent longer than that observed when the crash was avoided (1.56 seconds versus 939 ms).

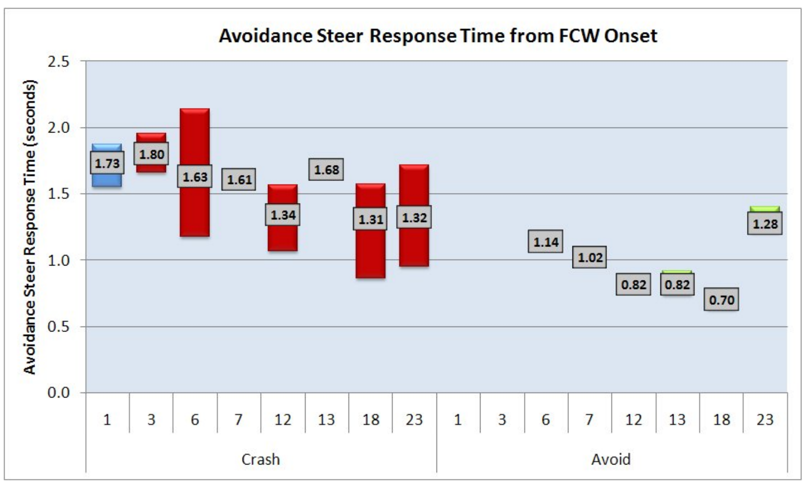

Figure 6.21. Avoidance steer response times, presented as a function of FCW modality and crash outcome.

6.8.1.2 End of Visual Commitment to An Avoidance Steering Input

To better understand whether FCW modality affected the response time from VC_{end} to the onset of avoidance steering, the reaction time from FCW⇨VC_{end} was removed from the data summarized in Section 6.8.1. Figure 6.22 presents the distribution of avoidance steer response times measured from the VC_{end} for each FCW modality. Overall, these values ranged from 85 to

[12] Three participants fully released the throttle before the FCW alert was presented. Although it is unclear whether this was in response to being committed to the random number recall task, or being used as an attempt to maintain the desired headway to the moving lead vehicle, the throttle release was certainly not part of the participants' respective avoidance responses. For this reason, these three release times have been omitted from the throttle drop based charts and analyses discussed in this section so as to provide a more accurate portrayal of the relevant throttle-steer phasing.

690 ms. The mean values for each FCW modality ranged from 344 to 467 ms overall, for configurations 23 and 7, respectively.

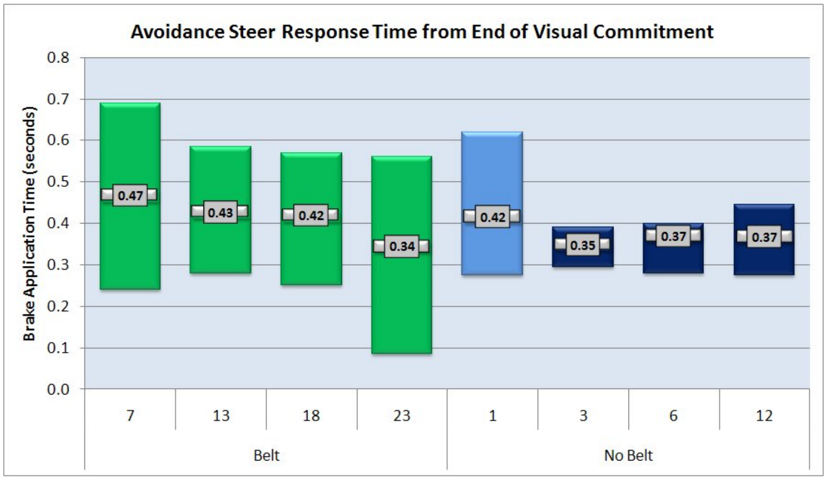

Figure 6.22. Avoidance steer response times, presented from VC_{end} as function of FCW modality and crash outcome.

The mean avoidance steer times associated with the seat belt pretensioner-based FCW modalities (from VC_{end}) ranged from 344 to 467 ms, for conditions 23 and 7, respectively. The range of these values completely contained the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 348 to 369 for conditions 3 and 6, respectively. The mean brake application time observed when no FCW alert was presented (415 ms) was also inside the mean range for tests performed with seat belt pretensioner-based alerts, but was outside the range defined by trials without pretensioning. Figure 6.23 presents the data previously shown in Figure 6.22, but separated as a function of crash outcome. These data imply that while FCW modality significantly affected the participants' FCW⇨VC_{end} mean response times, it does not appear to affect the time taken from VC_{end} to initiation of the avoidance steer.

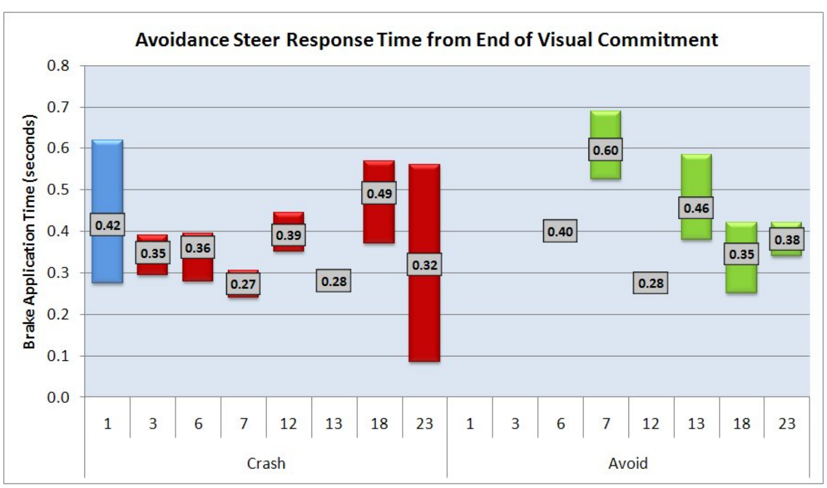

Figure 6.23. Avoidance steer response times, presented from VC_{end} as function of FCW modality and crash outcome.

6.8.2 Statistical Assessment of Avoidance Steer Response Times

In a manner consistent with that used to discuss the statistical significance of throttle release and brake application times, this section provides two analyses of avoidance steer response time. First, mean response times from FCW alert onset are discussed. In the second analysis, response times from VC_{end} are considered.

6.8.2.1 Onset of FCW to Avoidance Steer Response Time

Table 6.39 provides a summary of the data used to statistically compare the mean FCW to avoidance steer response times shown in Figure 6.20. The results show the means of these eight FCW configurations were significantly different.

Table 6.39. Avoidance Steer Response Time from FCW Onset.

Time from FCW to Steering Input (sec)						
Condition	**Modality**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
23	All	1.300	0.251	0.955	1.715	0.0006
3	Beep	1.533	0.408	1.140	2.135	
12	BeepHUD	1.235	0.299	0.815	1.565	
7	Belt	1.255	0.325	0.975	1.635	
18	BeltBeep	1.007	0.417	0.635	1.570	
13	BeltHUD	0.960	0.358	0.740	1.680	
6	HUD	1.800	0.124	1.660	1.955	
1	None	1.733	0.147	1.550	1.875	

Pair-wise comparisons were made between the four FCW configurations not inclusive of the HUD, with the corresponding configurations that were. The results, shown in Table 6.40, indicate the mean FCW to avoidance steer response times of comparable alerts were not significantly different.

Table 6.40. Testing the Effect of HUD on Avoidance Steer Response Time from FCW Onset.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Beep vs. BeepHUD	1	0.22201000	0.22201000	2.22	0.1456
Compare BeltBeep vs. All	1	0.25813333	0.25813333	2.58	0.1176
Compare Belt vs. BeltHUD	1	0.23734091	0.23734091	2.37	0.1329
Compare None vs. HUD	1	0.01012500	0.01012500	0.10	0.7524

Table 6.41 provides a summary of the paired data used to statistically compare the mean avoidance steer response times associated with the four combined FCW configurations. The results show the means were significantly different, which is consistent with the first analysis discussed in this section.

Table 6.41. Avoidance Steer Response Time from FCW Onset Comparison By Modality, Collapsed.

FCW to Steering Input (sec) – Alerts With and Without HUD Combined						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	10	1.384	0.372	0.815	2.135	0.0002
Auditory-Haptic	12	1.153	0.362	0.635	1.715	
Haptic	11	1.094	0.361	0.740	1.680	
None	9	1.770	0.131	1.550	1.955	

Six possible pair-wise comparisons between the four FCW-alert combinations were examined and the FCW alert modalities ranked. Family-wise error rate was controlled at alpha = 0.05, meaning significant main effects would be less than alpha = 0.05/6, or 0.00833. The results show that two of these comparisons were significantly different; they are marked with an (*) in Table 6.42.

Table 6.42. Avoidance Steer Response Time from FCW Onset Pair-Wise Comparisons.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Auditory vs. Auditory-Haptic	1	0.29022061	0.29022061	2.67	0.1105
Compare Auditory vs. Haptic	1	0.44024766	0.44024766	4.05	0.0513
Compare Auditory vs. None	1	0.70577053	0.70577053	6.49	0.0150
Compare Auditory-Haptic vs. Haptic	1	0.02014242	0.02014242	0.19	0.6693
Compare Auditory-Haptic vs. None	1	1.95571429	1.95571429	17.99	0.0001*
Compare Haptic vs. None	1	2.26142284	2.26142284	20.80	<.0001*

*Significant at the alpha = 0.00833 level.

Table 6.43 presents the mean FCW to avoidance steer response times previously shown in Table 6.41, sorted from lowest (best) to highest (worse), and an indication of where significant differences between configurations occurred.

The analysis presented in Table 6.44 indicates there was no significant difference between the mean avoidance steer response times from FCW onset for the male and female participants.

Since one of the main effects was significantly different, the interaction term was examined for information-purposes only. Using a gender by FCW-alert combination model, a significant interaction between gender and modality was shown to exist. The means from each gender by modality combination are shown in Table 6.45.

Table 6.43. Objective Ranking of Avoidance Steer Response Time from FCW Onset.

Rank of FCW to Steering Input (sec)			
Relative Rank	Modality	Mean	Significant Differences*
1	Haptic	1.094	A
2	Auditory-Haptic	1.153	A
3	Auditory	1.384	A B
4	None	1.770	B

*Alert modalities with the same letter were not significantly different.

Table 6.44. Avoidance Steer Response Time from FCW Onset by Gender.

FCW to Steering Input (sec) – by Gender						
Gender	N	Mean	Std Dev	Minimum	Maximum	Pr > F
F	21	1.249	0.386	0.740	1.955	0.2350
M	21	1.401	0.429	0.635	2.135	

Table 6.45. Avoidance Steer Response Time from FCW Onset and Gender Interaction.

FCW to Steering Input (sec) – Modality by Gender							
Modality	Gender	N	Mean	Std Dev	Minimum	Maximum	Pr > F
Auditory	F	6	1.241	0.323	0.815	1.680	0.0003
	M	4	1.599	0.373	1.280	2.135	
Auditory-Haptic	F	4	1.198	0.341	0.865	1.570	
	M	8	1.131	0.393	0.635	1.715	
Haptic	F	6	0.894	0.144	0.740	1.090	
	M	5	1.334	0.410	0.860	1.680	
None	F	5	1.726	0.153	1.550	1.955	
	M	4	1.825	0.085	1.705	1.895	

6.8.2.2 End of Visual Commitment to Avoidance Steer Response Time

Table 6.46 provides a summary of the data used to statistically compare the mean avoidance steer response times from VC_{end} shown in Figure 6.22. The results show the means of these eight FCW configurations were not significantly different, indicating the significant release time differences described in Section 6.8.2.1 were the result of the significant differences in FCW⇨VC_{end} duration discussed in Section 6.4.

Table 6.46. Avoidance Steer Response Time from VC_{end}.

Time from VCend to Steering Input (sec)						
Condition	Modality	Mean	Std Dev	Minimum	Maximum	Pr > F
23	All	0.344	0.173	0.085	0.560	0.6980
3	Beep	0.369	0.051	0.280	0.400	
12	BeepHUD	0.367	0.063	0.275	0.445	
7	Belt	0.467	0.189	0.240	0.690	
18	BeltBeep	0.418	0.118	0.250	0.570	
13	BeltHUD	0.427	0.100	0.280	0.585	
6	HUD	0.348	0.041	0.295	0.390	
1	None	0.415	0.147	0.275	0.620	

Pair-wise comparisons were made between the four FCW configurations not inclusive of the HUD, with the corresponding configurations that were. The results, shown in Table 6.47, indicate the VC_{end} to avoidance steer response times of comparable alerts were not significantly different.

Table 6.47. Testing the Effect of HUD on Avoidance Steer Response Time from VC_{end}.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Beep vs. BeepHUD	1	0.00001000	0.00001000	0.00	0.9793
Compare BeltBeep vs. All	1	0.01506939	0.01506939	1.03	0.3170
Compare Belt vs. BeltHUD	1	0.00443667	0.00443667	0.30	0.5851
Compare None vs. HUD	1	0.00997556	0.00997556	0.68	0.4143

Table 6.48 provides a summary of the paired data used to statistically compare the mean VC_{end} to avoidance steer response times associated with the four combined FCW configurations. The results show the means were not significantly different, which is consistent with the previous analyses discussed in this section.

Table 6.48. Avoidance Steer Response Time from VC_{end} Comparison By Modality, Collapsed.

VCend to Steering Input (sec) – Alerts With and Without HUD Combined						
Modality	N	Mean	Std Dev	Minimum	Maximum	Pr > F
Auditory	10	0.368	0.054	0.275	0.445	0.4346
Auditory-Haptic	11	0.385	0.143	0.085	0.570	
Haptic	11	0.445	0.141	0.240	0.690	
None	9	0.378	0.101	0.275	0.620	

The analysis presented in Table 6.49 indicates that there was no significant difference between the mean VC_{end} to avoidance steer response times for the male and female participants.

Table 6.49. Avoidance Steer Response Time from VC_{end} by Gender.

VCend to Steering Input (sec) – by Gender						
Gender	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
F	20	0.407	0.136	0.085	0.690	0.5377
M	21	0.384	0.099	0.240	0.585	

7.0 CRASH AVOIDANCE INPUT MAGNITUDES

To quantify the magnitudes of the participants' crash avoidance attempts, peak steering and brake force inputs were considered. The effect of FCW alert modality on these parameters is discussed in this section.

7.1 Peak Brake Pedal Force

7.1.1 General Assessment of Peak Brake Pedal Force

As previously stated 87.5 percent applied force to the brake pedal in an attempt to avoid the SLV. Similar to the process used to assess peak steering wheel angle, peak force was measured from the onset of the FCW alert through the time when the front of the SV crossed the vertical plane established by the rear of the SLV [13]. For some participants, this process reported a brake force magnitude less than the absolute maximum value observed during their respective trial. With respect to crash avoidance, this was deemed acceptable since any post-crash input applied by a driver would have no real world relevance. However, understanding how the authors used this process is important, as it explains how it was possible for an application with a very low "peak" input to still be categorized as an avoidance attempt.

Consider, for example, the case of a participant who began braking only 40 ms before they impacted the SLV. Since the period of consideration for peak force magnitude ends at when the longitudinal range from the SV to the SLV was zero, there was only enough time for an application magnitude of 0.5 lbs to be applied before the impact occurred.

Figure 7.1 presents the distribution of peak brake force magnitudes observed during this study[14]. Overall, these values ranged from 0.5 to 271.8 lbf, and 94.6 percent of these magnitudes (53 of 56 trials) resided within the range of inputs established with configuration 23 (from 17.7 to 271.8 lbf). The mean values for each FCW modality ranged from 27.5 to 119.9 lbf overall, for configurations 3 and 23, respectively.

The mean peak brake forces associated with the seat belt pretensioner-based FCW modalities ranged from 51.4 to 119.9 lbf, for conditions 7 and 23, respectively. The range of these values overlapped the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 27.5 to 71.0 for conditions 3 and 12, respectively. The mean peak brake force observed when no FCW alert was presented (101.3 lbf) was outside the mean range for tests performed without seat belt pretensioning, but was inside the range defined by pretensioner-based trials.

---

[13] In three cases, the SV came to a stop before the SV headway became zero. For these trials, the measured period was from the onset of the FCW alert to the time when the SV came to a stop.

[14] Two participants applied force away from the load cell used to measure force magnitude. As a result, no valid force data were available for these trials.

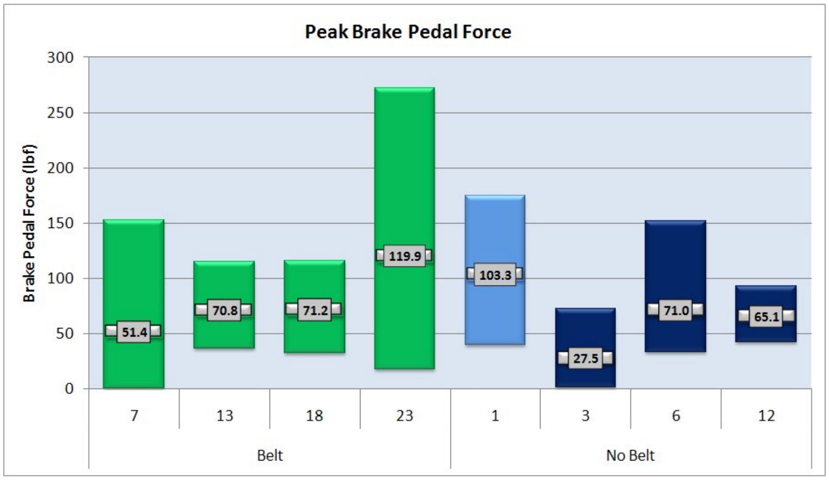

Figure 7.1. Peak brake pedal force, presented as a function of FCW modality.

Figure 7.2 presents the distribution of brake pedal force applications, presented as a function of FCW modality and crash outcome. The overall mean peak forces of the trials where the participants collided with the SLV (75.2 lbf) was nearly identical to that observed when the crash was avoided (78.0 lbf), differing by only 0.4 percent. This finding is in contrast to the trends previous shown in Figures 6.12 through 6.19 where FCW modality was shown to affect crash avoidance via reduced response times. These data imply that while FCW modality significantly affected the participants' mean FCW to brake application response times, it does not appear to affect the magnitude of the pedal force application, as discussed later in this section.

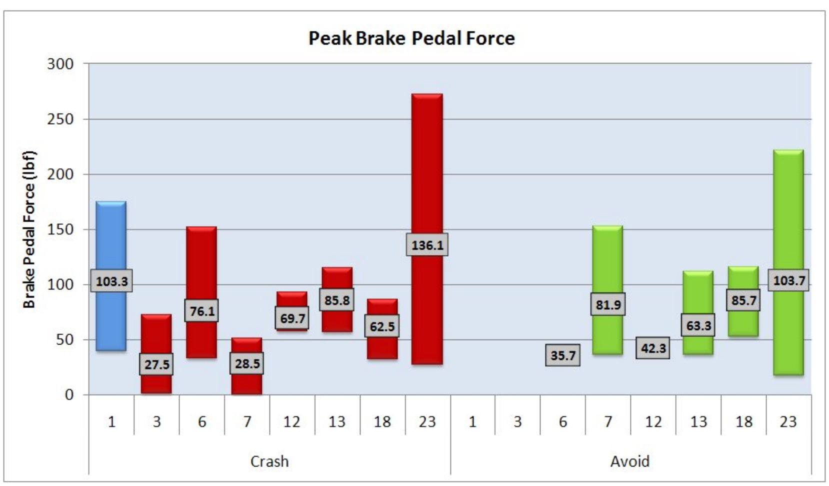

Figure 7.2. Peak brake pedal force, presented as a function of FCW modality and crash outcome.

7.1.2 Statistical Assessment of Peak Brake Pedal Force

Table 7.1 provides a summary of the data used to statistically compare the mean peak brake pedal force magnitudes shown in Figure 7.1. The results show the means for the eight FCW configurations were not significantly different.

Table 7.1. Peak Brake Pedal Force Comparison By Modality.

Peak Brake Pedal Force (lbf)						
Condition	**Modality**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
23	All	119.888	91.751	17.700	271.800	0.0686
3	Beep	71.000	39.278	33.200	152.100	
12	BeepHUD	65.150	16.567	42.300	92.600	
7	Belt	51.429	48.295	0.500	153.000	
18	BeltBeep	71.200	27.804	32.300	116.000	
13	BeltHUD	70.800	34.019	36.600	114.700	
6	HUD	27.475	30.858	1.700	72.200	
1	None	103.271	49.384	39.500	175.000	

Pair-wise comparisons were made between the four FCW configurations not inclusive of a HUD-based alert, with the corresponding configuration that was. The results, shown in Table 7.2, indicate the average peak brake pedal force was not significantly different between each comparable alert. This is consistent with the previous analysis that showed no significant main effect.

Table 7.2. Peak Brake Pedal Force Pair-Wise Comparisons.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Beep vs. BeepHUD	1	117.33429	117.33429	0.05	0.8285
Compare BeltBeep vs. All	1	9481.89062	9481.89062	3.83	0.0563
Compare Belt vs. BeltHUD	1	1212.35341	1212.35341	0.49	0.4874
Compare None vs. HUD	1	14623.88731	14623.88731	5.91	0.0190

Table 7.3 provides a summary of the paired data used to statistically compare the mean peak brake pedal forces associated with the four combined FCW configurations. The results show the means for the combinations were not significantly different, which is consistent with the previous analyses discussed in this section.

Table 7.3. Peak Brake Pedal Force By Modality, Collapsed.

Peak Brake Pedal Force (lbf) – Alerts With and Without HUD Combined						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	14	68.493	30.746	33.200	152.100	0.3170
Auditory-Haptic	16	95.544	70.153	17.700	271.800	
Haptic	13	60.369	41.826	0.500	153.000	
None	11	75.709	56.668	1.700	175.000	

The analysis presented in Table 7.4 indicates that there was no significant difference between male and female participants' peak brake pedal force magnitude.

Table 7.4. Peak Brake Pedal Force By Gender.

Peak Brake Pedal Force (lbf) – by Gender						
Gender	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
F	29	73.007	46.805	15.500	221.800	0.6573
M	25	79.520	60.341	0.500	271.800	

7.2 Peak Steering Wheel Angle

7.2.1 General Assessment of Peak Steering Wheel Angle

As previously stated, 42 of the 64 participants (65.6 percent) used steering wheel inputs in an attempt to avoid the SLV. For this study, peak steering angle was measured from the onset of the FCW alert through the time when the front of the SV crosses the vertical plane established by the rear of the SLV[15].

Figure 7.3 presents the distribution of peak steering wheel angles observed during this study. Overall, these values ranged from 9.4 to 229.7 degrees. The mean values for each FCW modality ranged from 42.6 to 86.0 degrees overall, for configurations 7 and 23, respectively. Although 90.5 percent of these magnitudes (38 of 42 trials) resided within the range of inputs established with FCW configuration 23 (from 17.7 to 229.7 degrees), it should be noted that the descriptive statistics of the condition 23 steering inputs were strongly affected by the presence of a 229.7 degree input, whose magnitude was much larger than any other observed in this study (e.g., 92.6 degrees greater, or 67.5 percent, than the second largest peak steering angle). When the 229.7 degree input is omitted, the mean peak steering angle for condition 23 becomes 57.3 degrees.

The mean peak steering wheel angles associated with seat belt pretensioner-based FCW modalities ranged from 42.6 to 86.0 degrees, for conditions 7 and 23, respectively. The range of these values entirely contained the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 55.8 to 81.3 degrees, for conditions 6 and 12, respectively, as well as the mean value of the trials performed with no FCW alert (60.9 degrees). This finding is in contrast to the trends previously shown in Figures 6.12 through 6.17, where FCW modality appears to affect crash avoidance via reduced response times. These data imply that while FCW modality significantly affected the participants' mean FCW to avoidance steer response times, it does not appear to affect the magnitude of the avoidance steer angle, as discussed later in this section.

[15] In three cases, the SV came to a stop before the SV headway became zero. For these trials, the measured period was from the onset of the FCW alert to the time when the SV came to a stop.

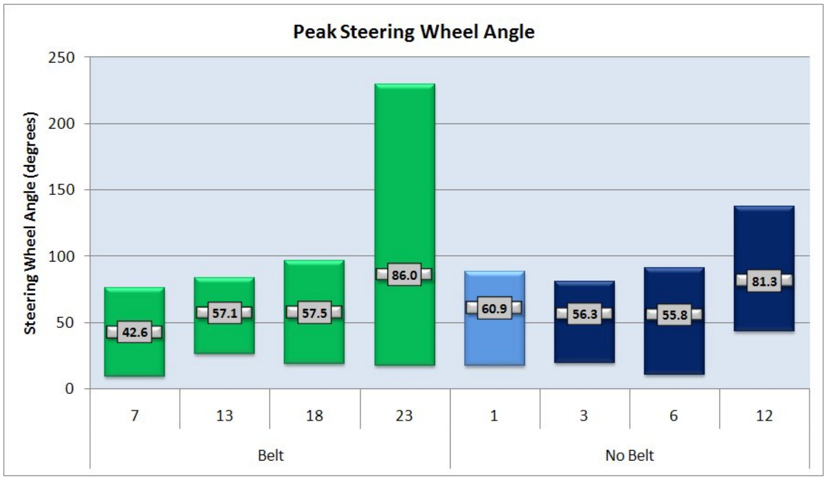

Figure 7.3. Peak steering angle, presented as a function of FCW modality.

Figure 7.4 presents the distribution of peak steering wheel angles, presented as a function of FCW modality and crash outcome. The overall mean peak input of the trials where the participants collided with the SLV (52.4 degrees) was less than that observed when the crash was avoided (79.0 degrees), differing by 50.8 percent. Omitting the 229.7 degree input observed during the "no-crash" configuration 23 test reduces the related group mean to 69.0 degrees, and the "crash vs. avoid" peak steering input disparity to 24.1 percent.

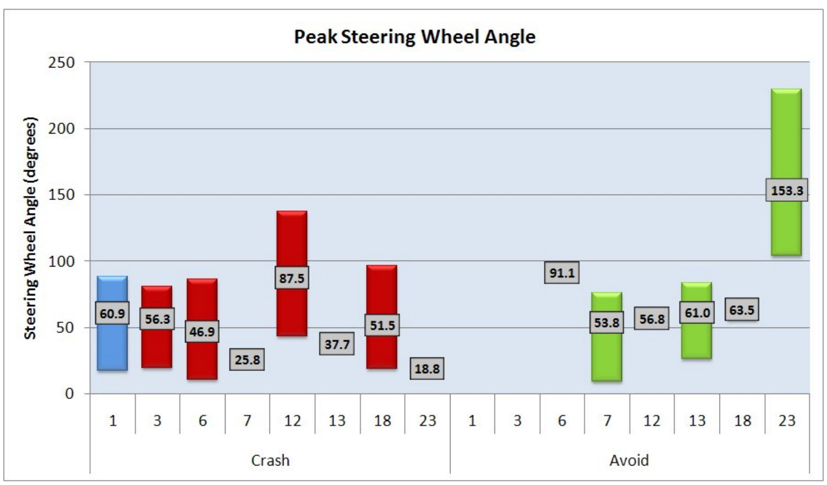

Figure 7.4. Peak steering angle, presented as a function of FCW modality and crash outcome.

Note: As part of an avoidance input that included a peak steering input of 83.5 degrees, one participant braked to nearly a full stop (to 1.3 mph) 6.0 inches from a vertical plane defined by the rear of the SLV before releasing force from the brake pedal. This participant, who received FCW alert configuration 23, ultimately avoided the crash by steering to the right, but braking was the dominate input.

7.2.2 Statistical Assessment of Peak Steering Wheel Angle

Table 7.5 provides a summary of the data used to statistically compare the mean peak steering wheel angles shown in Figure 7.3. The results show the means for the eight FCW configurations were not significantly different.

Table 7.5. Peak Steering Wheel Angle Comparison By Modality.

Peak Steering Wheel Angle (degrees)						
Condition	**Modality**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
23	All	86.033	85.040	17.700	229.700	0.7541
3	Beep	55.780	40.237	10.800	91.100	
12	BeepHUD	81.300	38.113	43.300	137.100	
7	Belt	42.580	31.233	9.400	76.300	
18	BeltBeep	57.500	26.825	18.600	96.700	
13	BeltHUD	57.100	21.917	26.100	83.500	
6	HUD	56.280	24.780	19.200	81.100	
1	None	60.925	31.232	17.500	88.400	

Pair-wise comparisons were made between the four FCW configurations not inclusive of a HUD-based alert, with the corresponding configuration that was. The results, shown in Table 7.6, indicate the average peak steering wheel angle was not significantly different between each comparable alert. This is consistent with the previous analysis that showed no significant main effect.

Table 7.6. Peak Steering Wheel Angle Pair-Wise Comparisons.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Beep vs. BeepHUD	1	1628.176000	1628.176000	0.87	0.3579
Compare BeltBeep vs. All	1	2442.453333	2442.453333	1.30	0.2616
Compare Belt vs. BeltHUD	1	574.992000	574.992000	0.31	0.5833
Compare None vs. HUD	1	47.946722	47.946722	0.03	0.8739

Table 7.7 provides a summary of the paired data used to statistically compare the mean peak steering wheel angles associated with the four combined FCW configurations. The results show the means for the combinations were not significantly different, which is consistent with the previous analyses discussed in this section.

Table 7.7. Peak Steering Wheel Angle By Modality, Collapsed.

Peak Steering Wheel Angle (degrees)– Alerts With and Without HUD Combined						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	10	68.540	39.320	10.800	137.100	0.6316
Auditory-Haptic	12	71.767	61.938	17.700	229.700	
Haptic	11	50.500	26.227	9.400	83.500	
None	9	58.344	26.054	17.500	88.400	

The analysis presented in Table 7.8 indicates that there was no significant difference between male and female participants' peak steering wheel angle.

Table 7.8. Peak Steering Wheel Angle By Gender.

FCW to Brake Application (sec) – by Gender						
Gender	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
F	21	57.838	31.021	9.400	126.300	0.4714
M	21	67.267	50.684	13.300	229.700	

8.0 SUBJECT VEHICLE RESPONSES

8.1 Peak Longitudinal Deceleration

The longitudinal acceleration (i.e., deceleration) results presented in this section were obtained by considering the same time interval used to assess peak steering angle and brake pedal force.

Figure 8.1 presents a distribution of the peak decelerations produced by the 56 participants who used braking as part of their crash avoidance maneuver. Overall, these values ranged from 0.02 (observed during a trial that included a brake pedal misapplication) to 1.13 g. The mean values for each FCW modality ranged from 0.23 to 0.80 g overall, for configurations 3 and 23, respectively.

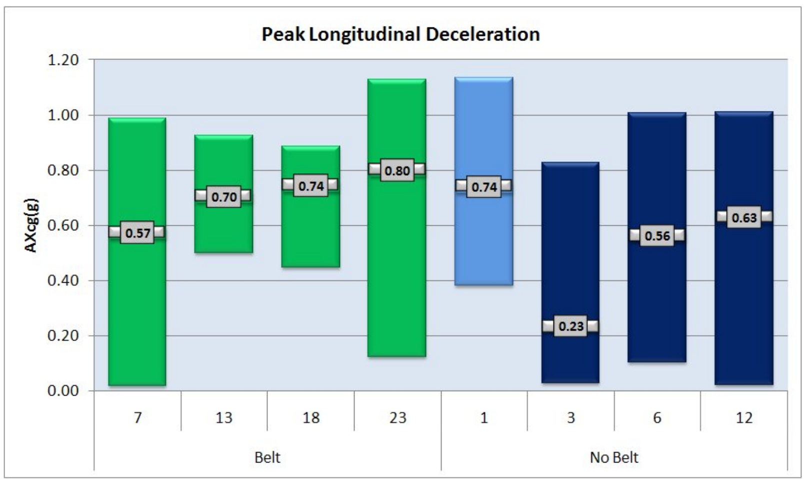

Figure 8.1. Peak deceleration magnitude, presented as a function of FCW modality.

The mean peak decelerations associated with the seat belt pretensioner-based FCW modalities ranged from 0.57 g to 0.80 g, for conditions 7 and 23, respectively. The range of these values overlapped the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 0.23 to 0.63 g for conditions 3 and 12, respectively, and contains the mean value of the trials performed with no FCW alert (0.74 g).

Figure 8.2 presents the distribution of peak decelerations, presented as a function of FCW modality and crash outcome. The overall peak means of the trials where the participants collided with the SLV (0.63 g) was less than that observed when the crash was avoided (0.70 g), differing by 9.9 percent.

8.2 Peak Lateral Acceleration

The lateral acceleration results presented in this section were obtained by considering the same time interval used to assess peak steering angle and brake pedal force, and have been collapsed across direction of steer; no distinction between steering to the left or right has been made.

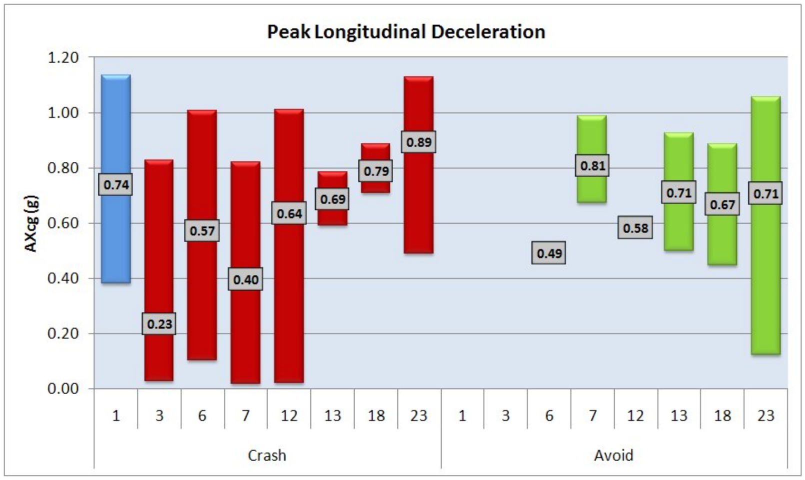

Figure 8.2. Peak deceleration magnitude, presented as a function of FCW modality and crash outcome.

Figure 8.3 presents a distribution of the peak lateral accelerations produced by the 42 participants who used steering as part of their crash avoidance maneuver. Overall, these values ranged from 0.03 to 0.77 g. The mean values for each FCW modality ranged from 0.259 to 0.44 g degrees overall, for configurations 1 and 23, respectively.

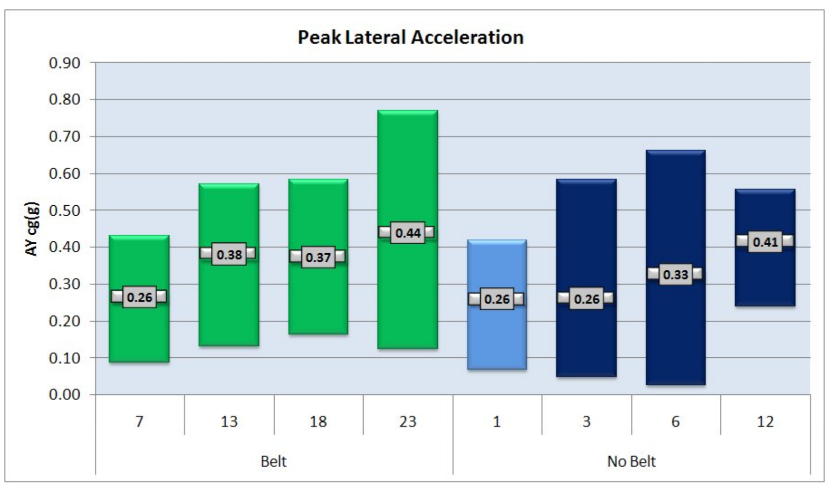

Figure 8.3. Peak lateral acceleration magnitude, presented as a function of FCW modality.

The mean peak lateral accelerations associated with the seat belt pretensioner-based FCW modalities, ranged from 0.264 g to 0.44 g, for conditions 7 and 23, respectively. The range of these values almost entirely overlapped the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 0.261 to 0.41 g for conditions 3 and 12, respectively, as well as the mean value of the trials performed with no FCW alert (0.259 g).

Figure 8.4 presents the distribution of peak lateral accelerations, presented as a function of FCW modality and crash outcome. The overall peak means of the trials where the participants collided with the SLV (0.267 g) was less than that observed when the crash was avoided (0.473 g), differing by 43.5 percent.

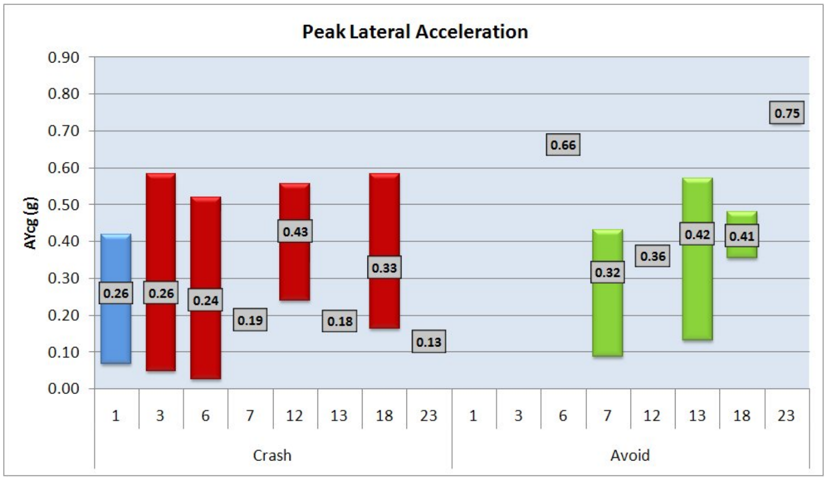

Figure 8.4. Peak lateral acceleration magnitude, presented as a function of FCW modality and crash outcome.

9.0 CRASH AVOIDANCE AND MITIGATION SUMMARY

9.1 Crash Avoidance

Although it is not the intent of this study to identify the "best" FCW alert modality (i.e., the objective of the work was to develop a protocol suitable for evaluating FCW DVI effectiveness), the protocol indicates a potential for good discriminatory capability, and its output can be used for high-level crash avoidance comparisons. Table 9.1 provides an overall summary of how many participants were able to avoid crashing into the SLV as a function of FCW modality.

Table 9.1. Overall Crash Avoidance Summary.

Condition	FCW Alert Modality	# of Participants			
		Belt		No Belt	
		Crash	Avoid	Crash	Avoid
1	No alert	--	--	8	0
3	Visual Only (Volvo HUD)	--	--	8	0
6	Auditory Only (Mercedes Beep)	--	--	7	1
7	Haptic Seat Belt Only (Acura Belt)	5	3	--	--
12	Auditory + Visual	--	--	7	1
13	Visual + Haptic Seat Belt	3	5	--	--
18	Auditory + Haptic Seat Belt	5	3	--	--
23	Visual + Auditory + Haptic Seat Belt	4	4	--	--
Total *(percent of 64 participants)*		**17** *(26.6%)*	**15** *(23.4%)*	**30** *(46.9%)*	**2** *(3.1%)*

A total of 17 participants (26.6 percent) avoided a collision with the SLV. Of these 17 instances, the FCW modality present in 15 included seat belt pretensioning (88.2 percent). For the FCW modalities that supported successful crash avoidance, the success rate is shown in Table 9.2. Table 9.3 presents the data shown in Table 9.2, but collapsed by FCW alert modality.

9.2 Likelihood of an FCW Alert Response

When considering the crash/avoid data previously presented in this report, the authors emphasize that being involved in a crash does not necessarily indicate the participant did not respond to the FCW modality used in their individual trial. Although most participants crashed into the SLV because they failed to respond to the various FCW alerts used in this study (or were not presented with one), some crashed because their avoidance strategy was simply not effective.

Table 9.2. Successful SLV Avoidance Summary.

Condition	FCW Alert Modality	Avoidance Summary	
		Ratio	Percentage
6	Auditory Only	1 of 8	12.5
12	Auditory + Visual	1 of 8	12.5
7	Haptic Seat Belt Only	3 of 8	37.5
18	Haptic Seat Belt + Auditory	3 of 8	37.5
13	Haptic Seat Belt + Visual	5 of 8	62.5
23	Haptic Seat Belt + Visual + Auditory	4 of 8	50.0
7, 13, 18, 23	*All Haptic Seat Belt-Based*	*15 of 32*	*46.9*

Table 9.3. Successful SLV Avoidance Summary, Collapsed.

Condition	FCW Alert Modality	Avoidance Summary	
		Ratio	Percentage
6, 12	Auditory	2 of 16	12.5
18, 23	Auditory-Haptic	7 of 16	43.8
7, 13	Haptic	8 of 16	50.0

To quantify this phenomenon, the authors reviewed video recorded during each trial. Facial expressions, the manner in which the participant re-established their forward-looking view, throttle release, brake application, steering inputs, etc. were all considered in this assessment. Ultimately, each subject was categorized in one of three ways:

1. FCW alert response likely, crash avoided s46_c18_0.270s.wmv
2. FCW alert response likely, crash <u>not</u> avoided s1_c23_0.740s.wmv
3. FCW alert response <u>not</u> likely, crash <u>not</u> avoided s56_c7_1.740s.wmv

Results of this categorization were used in conjunction with FCW⇨VC_{end} duration to further dissect response time. As shown in Figure 9.1, the range of response times where FCW alert responses were likely and the crash avoided was 270 to 870 ms. For the cases where FCW alert responses were likely but the crash still occurred, response times were between 330 ms to 1.0 second. Finally, for the instances where FCW alert responses were not likely response times were between 870 ms to 1.74 seconds. As previously stated, if there was no FCW response, a crash always occurred. Note that Figure 9.1 presents data from 63 valid trials. Although this study had 64 valid participants, video data was not available for one.

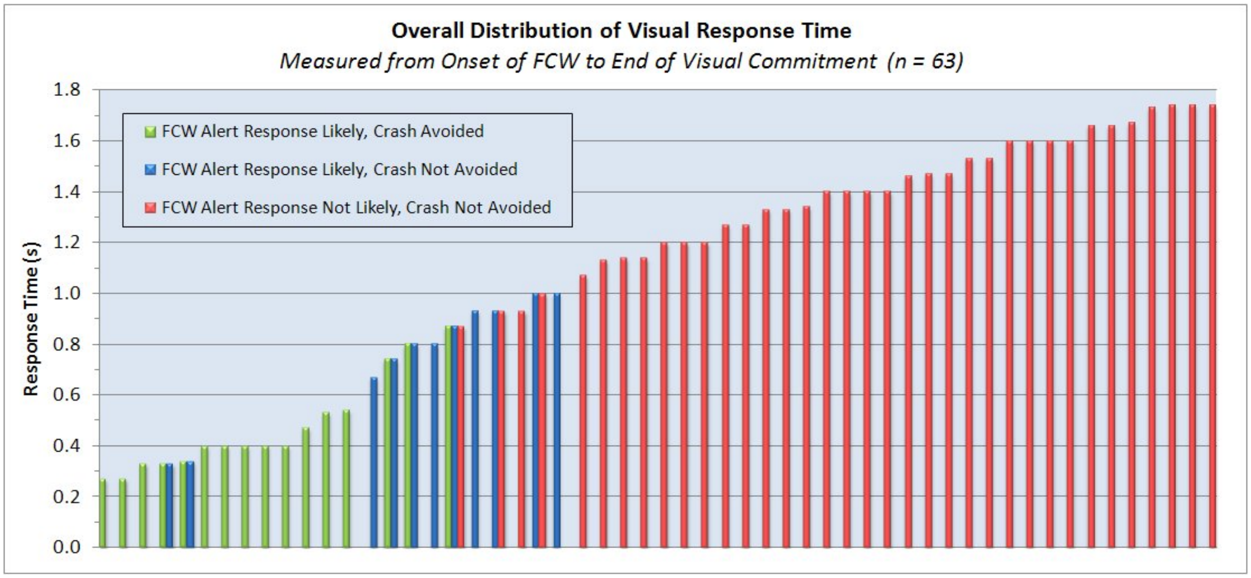

Figure 9.1. FCW⇨VC_{end} duration as a function of alert response likelihood and crash outcome.

Table 9.4 provides an FCW alert response likelihood summary for each alert modality. Overall, a total of 27 participants (42.9 percent) acknowledged the FCW alert. In response to the alert, 16 participants avoided a collision with the SLV, 11 did not. Twenty-one of these 27 participants responded to an FCW modality that included seat belt pretensioning (74.1 percent). Table 9.5 presents the data shown in Table 9.4, but collapsed by FCW alert modality.

Table 9.4. FCW Alert Response Summary.

Condition	FCW Alert Modality	# of Participants		
		Response Likely, Crash Avoided	Response Likely, Crash Not Avoided	Response Not Likely, Crash Not Avoided
1	No alert	--	--	8
3	Visual Only (Volvo HUD)	--	--	8
6	Auditory Only (Mercedes Beep)	1	3	4
7	Haptic Seat Belt Only (Acura Belt)	3	--	5
12	Auditory + Visual	1	2	5
13	Visual + Haptic Seat Belt	5	1	2
18	Auditory + Haptic Seat Belt	3	2	3
23	Visual + Auditory + Haptic Seat Belt	3[1]	3	1
Total *(percent of 63 participants[1])*		**16[1]** *(25.4%)*	**11** *(17.5%)*	**36** *(57.1%)*

[1]*VC_{end} video data not available for one of the 64 participants.*

Table 9.5. FCW Alert Response Summary, Collapsed.

Condition	FCW Alert Modality	# of Participants					
		Response Likely, Crash Avoided		Response Likely, Crash <u>Not</u> Avoided		Response <u>Not</u> Likely, Crash <u>Not</u> Avoided	
		Ratio	%	Ratio	%	Ratio	%
6, 12	Auditory	2 of 16	12.5	5 of 16	31.3	9 of 16	56.3
18, 23	Auditory-Haptic	6[1] of 16	37.5	5 of 16	31.3	4 of 16	25.0
7, 13	Haptic Seat Belt	8 of 16	50.0	1 of 16	6.3	7 of 16	43.8
1, 3	None	0 of 16	0.0	0 of 16	0.0	16 of 16	100.0

[1]*VC_{end} video data not available for one of the 64 participants.*

Table 9.6 further examines crashes classified as "FCW response likely, crash not avoided." Using video data reduction, this table provides the authors' best explanation as to why the crash occurred, despite the participant actually acknowledging the respective FCW alerts. For reference purposes, the FCW⇨VC_{end} duration and peak decelerations observed up to the point of impact with the SLV are shown.

In each trial shown in Table 9.6, the participants used insufficient braking[16] to avoid the crash, despite achieving moderate-to-high pre-crash peak decelerations. In 9 of the 11 cases (81.8 percent), there was an apparent lag from the time the alert was presented to the time the participant appeared to respond to it. The combination of these two factors is believed to be largely responsible for the respective trials ultimately concluding with a collision.

In the case of Participant 28, the FCW alert was clearly detected and responded to (330 ms reaction time). However shortly after initiating the crash avoidance maneuver (67.5 lbf peak brake force, 39.2 degree peak left steer angle), the participant realized the SLV was artificial, and relaxed brake force before impact. Note: All data to this point of ruse recognition were unquestionably valid for this participant.

In the case of Participant 14, the FCW alert was also clearly detected and acted upon (340 ms reaction time). However, the brake input was simply insufficient. Although a peak deceleration of 0.89g was produced, it was realized 1.72 seconds from the onset of the brake application.

[16] Depending on the TTC when the participants applied force to the brake pedal, and how much brake force was used, it may have been physically impossible to actually avoid the crash by braking alone.

Table 9.6. FCW Response Likely, But Crash Not Avoided Summary.

Participant	FCW⇨VC_{end} (seconds)	FCW Modality	Plausible Explanation for Collision	Peak Pre-Crash Deceleration (g)	Brake Apply to Peak Decel (seconds)
28	0.330	Acura Belt, Mercedes Beep	Insufficient braking/steering	0.71	0.700
14	0.340	Acura Belt, Mercedes Beep	Insufficient braking	0.89	1.720
21	0.670	Mercedes Beep, Volvo HUD	Brief FCW response delay; insufficient steering/braking; reported 5 numbers from the recall task, however the experimenter did not verify they were correct.	0.61	0.275
1	0.740	Acura Belt, Mercedes Beep, Volvo HUD	Brief FCW response delay; insufficient braking; reported 3 numbers from the recall task, however the experimenter did not verify they were correct.	1.13	0.455
54	0.800	Acura Belt, Mercedes Beep, Volvo HUD	Brief FCW response delay; insufficient braking	1.04	0.475
23	0.800	Mercedes Beep	FCW response delay; insufficient braking; noticed alert after two numbers were presented	0.73	0.380
42	0.870	Acura Belt, Mercedes Beep, Volvo HUD	FCW response delay; insufficient braking; noticed beep after two numbers were presented	0.91	0.490
32	0.930	Mercedes Beep, Volvo HUD	FCW response delay; insufficient braking/steering; abandon the random number recall task after hearing auditory alert	0.85	0.375
47	0.930	Mercedes Beep	FCW response delay; insufficient braking	0.72	0.355
38	1.000	Mercedes Beep	Brief FCW response delay; insufficient braking	1.01	0.450
35	1.000	Acura Belt, Volvo HUD	FCW response delay; insufficient braking; "I didn't get any of those numbers"	0.59	0.300

9.3 SV Speed Reduction

9.3.1 General SV Speed Reduction Observations

The magnitude of SV speed reductions presented in this section were obtained by considering the same time interval used to assess peak inputs (steering angle and brake pedal force) and accelerations (longitudinal and lateral).

One participant avoided a collision with the SLV by straight line braking only; no attempt to steer was made (FCW configuration 23; final range was 5.8 inches). For two other participants, the avoidance maneuver was nearly all braking; minor dithering of the steering wheel was used, but not as part of an avoidance strategy (FCW configurations 7 and 13; final ranges were 10.7 and 4.9 ft, respectively).

Figure 9.2 presents a distribution of the speed reductions realized by the 64 study participants. Overall, these values ranged from -0.9 mph (observed during a trial that did not include any avoidance maneuver, braking or steering) to 35.0 mph (SV was braked to a complete stop ahead of the SLV). The mean values for each FCW modality ranged from 1.1 to 13.6 mph overall, for configurations 3 and 23, respectively.

The mean speed reductions associated with the seat belt pretensioner-based FCW modalities ranged from 7.5 to 13.6 mph, for conditions 7 and 23, respectively. The range of these values was outside (i.e., higher) than the comparable range of means recorded during tests performed without seat belt pretensioner-based FCW modalities, from 1.1 to 5.9 mph for conditions 3 and 6, respectively, and the mean value of the trials performed with no FCW alert (5.9 mph).

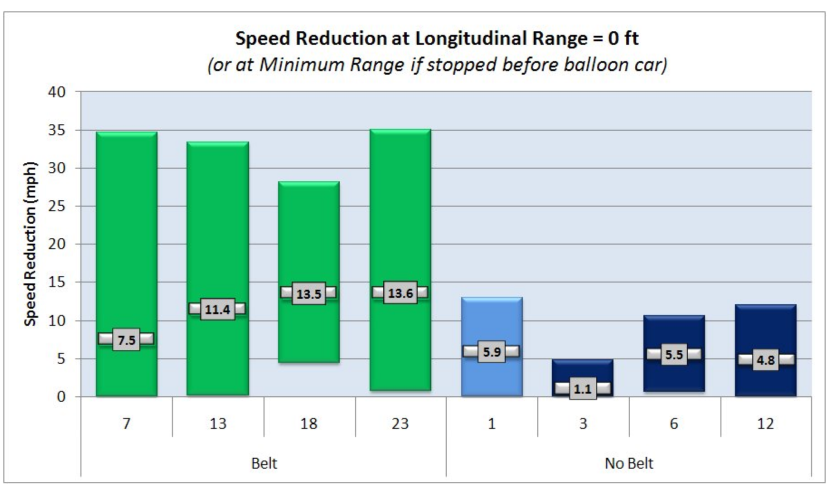

Figure 9.2. Speed reduction from onset of FCW alert, presented as a function of FCW modality.

Figure 9.3 presents the distribution of SV speed reductions, presented as a function of FCW modality and crash outcome. The overall peak means of the trials where the participants collided with the SLV (5.7 mph) was less than that observed when the crash was avoided (14.1

mph), differing by 59.6 percent. In agreement with the trend shown in Figure 9.2, the mean speed reductions of the successful pretensioner-based FCW trials were each greater than those where a pretensioner-based alert was not presented.

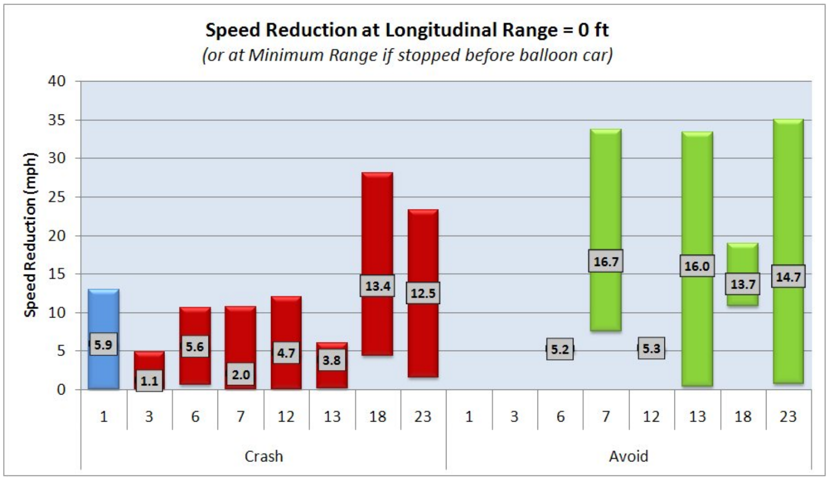

Figure 9.3. Speed reduction from onset of FCW alert, presented as a function of FCW modality and crash outcome.

9.3.2 Statistical Assessment of FCW Modality on SV Speed Reductions

In this section, two analyses of how FCW modality can affect SV speed reduction were performed. First, an overall evaluation was performed; data from each participant were considered regardless of whether they ultimately collided with the SLV. The second analysis considers only tests that ultimately resulted in a crash. As previously discussed in Section 9.2, being involved in a crash does not necessarily indicate the participant did not respond to the FCW modality used in their individual trial.

9.3.2.1 Overall SV Speed Reductions; Crash and Avoid

Table 9.7 provides a summary of the data used to statistically compare the mean SV speed reductions shown in Figure 9.2. In this case, the means for the eight FCW modalities had marginally significant differences.

Pair-wise comparisons were made between the four FCW configurations that did not include a HUD-based alert, with the corresponding configuration that did. The results, shown in Table 9.8, indicate the mean SV speed reductions of comparable alerts were not significantly different.

Table 9.7. SV Speed Reduction Comparison By Modality.

Subject Vehicle Speed Reduction (mph)							
Condition	Modality	N	Mean	Std Dev	Minimum	Maximum	Pr > F
23	All	8	13.575	11.442	0.800	35.000	0.0404
3	Beep	8	5.525	4.342	0.600	10.700	
12	BeepHUD	8	4.813	4.348	-0.100	11.900	
7	Belt	8	7.475	11.495	-0.900	33.800	
18	BeltBeep	8	13.500	7.502	4.400	28.100	
13	BeltHUD	8	11.450	13.645	0.100	33.400	
6	HUD	8	1.075	1.579	-0.300	4.600	
1	None	8	5.863	4.834	0.000	13.000	

Table 9.8. Testing the Effect of HUD on SV Speed Reduction.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Beep vs. BeepHUD	1	2.03062500	2.03062500	0.03	0.8664
Compare BeltBeep vs. All	1	0.02250000	0.02250000	0.00	0.9859
Compare Belt vs. BeltHUD	1	63.20250000	63.20250000	0.89	0.3500
Compare None vs. HUD	1	91.68062500	91.68062500	1.29	0.2611

Table 9.9 provides a summary of the paired data used to statistically compare the mean SV speed reductions associated with the four combined FCW configurations. The results show the means were significantly different, which is consistent with the first analysis discussed in this section.

Table 9.9. SV Speed Reduction Comparison By Modality, Collapsed.

Subject Vehicle Speed Reduction (mph) – Alerts With and Without HUD Combined						
Modality	N	Mean	Std Dev	Minimum	Maximum	Pr > F
Auditory	16	5.169	4.214	-0.100	11.900	0.0049
Auditory-Haptic	16	13.538	9.347	0.800	35.000	
Haptic	16	9.463	12.359	-0.900	33.800	
None	16	3.469	4.264	-0.300	13.000	

Six possible pair-wise comparisons between the four FCW alert combinations were examined and the FCW alert modalities ranked. Family-wise error rate was controlled at alpha = 0.05, meaning significant main effects would be less than alpha = 0.05/6, or 0.00833. The results show that two of these comparisons were significantly different; they are marked with an (*) in Table 9.10.

Table 9.10. SV Speed Reduction Pair-Wise Comparisons.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Auditory vs. Auditory-Haptic	1	560.2878125	560.2878125	8.12	0.0060*
Compare Auditory vs. Haptic	1	147.4903125	147.4903125	2.14	0.1490
Compare Auditory vs. None	1	23.1200000	23.1200000	0.34	0.5649
Compare Auditory-Haptic vs. Haptic	1	132.8450000	132.8450000	1.92	0.1704
Compare Auditory-Haptic vs. None	1	811.0378125	811.0378125	11.75	0.0011*
Compare Haptic vs. None	1	287.4003125	287.4003125	4.16	0.0457

*Significant at the alpha = 0.00833 level.

Table 9.11 presents the mean SV speed reductions previously shown in Table 9.9, sorted from highest (best) to lowest (worse), and an indication of where significant differences between configurations occurred.

Table 9.11. Objective Ranking of SV Speed Reductions.

Rank of Subject Vehicle Speed Reduction (mph)			
Relative Rank	**Modality**	**Mean**	**Significant Differences***
1	Auditory-Haptic	13.538	A
2	Haptic	9.463	A B
3	Auditory	5.169	B
4	None	3.469	B

*Alert modalities with the same letter were not significantly different.

The analysis presented in Table 9.12 indicates that on average, the female participants reduced SV speed 4.4 mph more than the males; this was a marginally significant difference.

Table 9.12. SV Speed Reduction by Gender.

Subject Vehicle Speed Reduction (mph) – by Gender						
Gender	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
F	32	10.119	9.622	-0.100	35.000	0.0491
M	32	5.700	7.910	-0.900	32.800	

Since both of the main effects evaluated in this section were significantly different, the interaction term was examined for information-purposes only. Using a gender by FCW configuration model, a significant interaction between gender and alert type was shown to exist. The means from each gender by modality combination are shown in Table 9.13.

Table 9.13. SV Speed Reduction and Gender Interaction.

Subject Vehicle Speed Reduction (mph) – Modality by Gender							
Modality	**Gender**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	F	8	5.800	3.721	-0.100	10.700	0.0078
	M	8	4.538	4.827	0.000	11.900	
Auditory-Haptic	F	8	15.750	10.640	4.400	35.000	
	M	8	11.325	7.926	0.800	23.300	
Haptic	F	8	14.013	12.187	5.300	33.800	
	M	8	4.913	11.467	-0.900	32.800	
None	F	8	4.913	5.342	0.300	13.000	
	M	8	2.025	2.377	-0.300	6.100	

Two additional analyses were conducted to demonstrate the overall influence seat belt pretensioner-based FCW configurations had on SV speed reduction (i.e., to demonstrate that this protocol had reasonable discriminatory capability). The analysis presented in Table 9.14 indicates that on average, the SV speed reductions recorded during tests performed with a pretensioner-based alert were 7.2 mph greater than those without seat belt pretensioning, and that this was a significant influence.

Table 9.14. SV Speed Reduction With and Without Seat Belt Pretensioning.

Subject Vehicle Speed Reduction (mph)						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Belt	32	11.500	10.976	-0.900	35.000	0.0010
No Belt	32	4.319	4.258	-0.300	13.000	

Since the main effect shown in Table 9.14 was significantly different, and gender was already shown to have a marginally significant difference, the interaction term was examined for information-purposes only (and to remain consistent). Using a gender by pretensioner-based FCW configuration model, a significant interaction between gender and modality was shown to exist. The means from each gender by modality combination are shown in Table 9.15.

Table 9.15. SV Speed Reduction With and Without Seat Belt Pretensioning and Gender Interaction.

Subject Vehicle Speed Reduction (mph) – Modality by Gender							
Modality	**Gender**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Belt	F	16	14.881	11.088	4.400	35.000	0.0009
	M	16	8.119	10.082	-0.900	32.800	
No Belt	F	16	5.356	4.471	-0.100	13.000	
	M	16	3.281	3.898	-0.300	11.900	

9.3.2.2 SV Impact Speed Reductions (for Trials Resulting in a Crash)

Table 9.16 provides a summary of the data used to statistically compare the mean SV speed reductions shown in "Crash" grouping shown of Figure 9.3. For this grouping, "SV speed reduction" refers to "impact speed reduction;" the SV speed reduction measured from the onset of the FCW alert to the instant the SV collided with the SLV. The mean impact speed reductions means for the eight FCW modalities were significantly different.

Table 9.16. SV Impact Speed Reduction Comparison By Modality.

Impact Speed Reduction (mph)						
Condition	**Modality**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
23	All	12.475	8.959	1.500	23.300	0.0043
3	Beep	5.571	4.688	0.600	10.700	
12	BeepHUD	4.743	4.691	-0.100	11.900	
7	Belt	1.960	4.424	-0.900	9.800	
18	BeltBeep	13.400	9.389	4.400	28.100	
13	BeltHUD	3.800	3.223	0.100	6.000	
6	HUD	1.075	1.579	-0.300	4.600	
1	None	5.863	4.834	0.000	13.000	

Pair-wise comparisons were made between the four FCW configurations that did not include a HUD-based alert, with the corresponding configuration that did. As shown in Table 9.17, the mean SV speed reductions of comparable alerts were not significantly different.

Table 9.17. Testing the Effect of HUD on SV Impact Speed Reduction.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Beep vs. BeepHUD	1	2.40285714	2.40285714	0.08	0.7756
Compare BeltBeep vs. All	1	1.90138889	1.90138889	0.07	0.7998
Compare Belt vs. BeltHUD	1	6.34800000	6.34800000	0.22	0.6434
Compare None vs. HUD	1	91.6806250	91.6806250	3.14	0.0840

Table 9.18 provides a summary of the paired data used to statistically compare the mean SV impact speed reductions associated with the four combined FCW configurations. The results show the means were significantly different, which is consistent with the first analysis discussed in this section.

Table 9.18. SV Impact Speed Reduction Comparison By Modality, Collapsed.

Impact Speed Reduction (mph) – Alerts With and Without HUD Combined						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	14	5.157	4.526	-0.100	11.900	0.0004
Auditory-Haptic	9	12.989	8.626	1.500	28.100	
Haptic	8	2.650	3.881	-0.900	9.800	
None	16	3.469	4.264	-0.300	13.000	

Six possible pair-wise comparisons between the four FCW-alert combinations were examined and the FCW alert modalities ranked. Family-wise error rate was controlled at alpha = 0.05, meaning significant main effects would be less than alpha = 0.05/6, or 0.00833. The results show that three of these comparisons were significantly different; they are marked with an (*) in Table 9.19.

Table 9.19. SV Impact Speed Reduction Pair-Wise Comparisons.

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
Compare Auditory vs. Auditory-Haptic	1	336.0159558	336.0159558	11.65	0.0014*
Compare Auditory vs. Haptic	1	32.0002597	32.0002597	1.11	0.2980
Compare Auditory vs. None	1	21.2850060	21.2850060	0.74	0.3950
Compare Auditory-Haptic vs. Haptic	1	452.7216993	452.7216993	15.70	0.0003*
Compare Auditory-Haptic vs. None	1	522.0463361	522.0463361	18.11	0.0001*
Compare Haptic vs. None	1	3.5752083	3.5752083	0.12	0.7265

*Significant at the alpha = 0.00833 level.

Table 9.20 presents the mean SV impact speed reductions previously shown in Table 9.18, sorted from highest (best) to lowest (worse), and an indication of where significant differences between configurations occurred.

Table 9.20. Objective Ranking of SV Impact Speed Reductions.

Rank of Subject Vehicle Impact Speed Reduction (mph)			
Relative Rank	**Modality**	**Mean**	**Significant Differences***
1	Auditory-Haptic	12.989	
2	Auditory	5.157	A
3	None	3.469	A
4	Haptic	2.650	A

*Alert modalities with the same letter were not significantly different.

When compared to the results in Table 9.11 (where data from all trials were used, not just those concluding with a SLV impact), the rank order of the modalities shown in Table 9.20 differs somewhat. When considering this point, it is important to recognize the Auditory-Haptic configuration still promoted the greatest speed reduction, and the mean speed reductions of the other three FCW alerts were not significantly different.

The analysis presented in Table 9.21 indicates that on average, the female participants reduced SV speed 4.3 mph more than the males; this was a marginally significant difference.

Table 9.21. SV Impact Speed Reduction by Gender.

Impact Speed Reduction (mph) – by Gender						
Gender	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
F	22	7.923	6.726	-0.100	28.100	0.0207
M	25	3.660	5.452	-0.900	23.300	

Since both of the main effects evaluated in this section were significantly different, the interaction term was examined for information-purposes only. Using a gender by FCW configuration model, a significant interaction between gender and alert type was shown to exist. The means from each gender by modality combination are shown in Table 9.22.

Table 9.22. SV Impact Speed Reduction and Gender Interaction.

Impact Speed Reduction (mph) – Modality by Gender							
Modality	**Gender**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Auditory	F	6	5.983	4.384	-0.100	10.700	0.0032
	M	8	4.538	4.827	0.000	11.900	
Auditory-Haptic	F	6	14.000	8.087	4.400	28.100	
	M	3	10.967	11.179	1.500	23.300	
Haptic	F	2	7.550	3.182	5.300	9.800	
	M	6	1.017	2.501	-0.900	6.000	
None	F	8	4.913	5.342	0.300	13.000	
	M	8	2.025	2.377	-0.300	6.100	

Two additional analyses were conducted to demonstrate the overall influence seat belt pretensioner-based FCW configurations on SV impact speed reduction. The analysis presented in Table 9.23 indicates that on average, the SV speed reductions recorded during tests performed with a pretensioner-based alert were 3.9 mph greater than those without seat belt pretensioning, and that this was a marginally significant influence.

Table 9.23. SV Impact Speed Reduction With and Without Seat Belt Pretensioning.

Impact Speed Reduction (mph) – Crash Only						
Modality	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Belt	17	8.124	8.491	-0.900	28.100	0.0448
No Belt	30	4.257	4.396	-0.300	13.000	

Since both main effects (i.e., FCW modality and gender) had marginally significant differences, the interaction term was examined for information-purposes only (and to remain consistent). Using a gender by pretensioner-based FCW configuration model, a significant interaction between gender and modality was shown to exist. The means from each gender by modality combination are shown in Table 9.24.

Table 9.24. SV Impact Speed Reduction With and Without Seat Belt Pretensioning and Gender Interaction.

Impact Speed Reduction (mph) – Modality by Gender (Crash Only)							
Modality	**gender**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**Pr > F**
Belt	F	8	12.388	7.554	4.400	28.100	0.0058
	M	9	4.333	7.740	-0.900	23.300	
No Belt	F	14	5.371	4.802	-0.100	13.000	
	M	16	3.281	3.898	-0.300	11.900	

10.0 CONCLUSIONS

10.1 Test Protocol

The protocol developed for use in this study provides a robust way to assess the driver vehicle interface (DVI) effectiveness of a forward collision warning system (FCW). Presentation of task instructions and FCW alerts was accurately controlled and repeatable. With very few exceptions, participants recruited from the general public maintained an acceptable headway, began the random number recall task when instructed to do so, and were fully distracted when presented with an FCW alert. Acceptable subject vehicle to moving lead vehicle (SV-to-MLV) headway maintenance task performance was achieved by 85.9, 98.4, and 96.9 percent of the participants for the first, second, and third passes of their experimental test drive, respectively. The fact that 26.6 percent of the participants were able to successfully perform the random number recall task without any errors indicates the task was a reasonably demanding one.

A total of 71 tests were performed with the protocol, producing 64 valid trials. Of the seven non-valid trials, three were non-valid simply because the participants failed to participate in the random number recall task when instructed to do so. Review of these participants' video data and post-test interviews indicated inattentiveness was the most probable explanation for this behavior. One participant deliberately postponed beginning the number recall task until the number presentation began (i.e., they realized, and adapted to, the 1.0 second pause between the end of the task instructions and presentation of the first number).

Insuring the participants remained visually committed to the random number recall task when the FCW alert was presented (i.e., they were fully distracted) was an essential component of the protocol. Generally speaking, this goal was achieved. Data collected from two participants were discarded because they briefly returned to their forward-looking viewing position before the FCW alert was presented.

The timing of the critical events contained within the protocol appears to be repeatable, appropriate, and effective. The pre-crash scenario depicted by the protocol was a very challenging one; having enough time available to avoid a collision with the stationary lead vehicle (SLV) required the participant to abandon the random number recall task before its completion despite an expected loss of incentive pay. Collisions always occurred during trials where the fully distracted participants did not receive (baseline condition) or did not perceive (visual-only configuration) presentation of an FCW alert.

10.2 Evaluation Metrics

With respect to evaluation metrics, the data produced during this study indicate that reaction time and crash outcome provide good measures of FCW alert effectiveness. Many variants of reaction time were explored in this study, however the interval defined by the onset of the FCW alert to the end of visual commitment (i.e., VC_{end}, the instant the driver returned their attention to a forward-facing viewing position) is the most appropriate. While reaction time from VC_{end} to throttle release, brake application, and/or steering input also provides good indications of FCW alert effectiveness, it is important to consider that not all drivers use the same techniques to arrive at a successful crash avoidance outcome. The mean FCW⇨VC_{end} duration of the trials where SV-to-SLV crashes occurred was 163.2 percent longer than that observed when the crash was avoided (1.24 seconds versus 470 ms).

The timing of when VC_{end} occurred directly affected the TTC at VC_{end}, a metric used to quantify how much time the participant had to comprehend the presence of the unexpected SLV, commit to a counter-measure, and execute their crash avoidance response. The overall mean TTC at VC_{end} of the trials resulting in a collision with the SLV was 90.8 percent shorter than that observed when the crash was avoided (837 ms versus 1.60 seconds). These findings help quantify how the additional time provided to the participants by the FCW alert increased the likelihood that their crash avoidance response would produce a successful avoidance outcome.

10.3 Crash Avoidance Maneuvers

In 59 of the 64 trials (92.2 percent), participants fully released the throttle as part of their crash avoidance response.

In 56 of the 64 trials (87.5 percent), participants applied force to the brake pedal as part of their crash avoidance response. In the 40 of these 56 instances (71.4 percent), the participants also used steering during their respective avoidance responses. In 11 of 40 trials (27.5 percent), participants began braking before steering. Steering preceded braking during 28 of 40 trials (70.0 percent). A simultaneous input of braking and steering was observed during one trial (2.5 percent). Peak brake pedal force magnitude did not appear to be affected by FCW alert modality.

In 42 of the 64 trials (65.6 percent), participants used steering inputs as part of their crash avoidance response. During 40 of 42 trials (95.2 percent), these responses also included braking. In the 33 of the 42 trials with steering (78.6 percent), the participants' primary avoidance attempt was to the left of the SLV. Peak steering wheel angle magnitude did not appear to be affected by FCW alert modality.

Overall, differences in the participants' mean FCW⇨VC_{end} reaction times were statistically significant for the alert configurations used in this study. Similarly, differences in mean throttle release, brake application, avoidance steer reaction times measured from FCW onset were each significant. However, the mean brake application and avoidance steer magnitudes associated with each modality were not significantly different. Differences in driver response times from VC_{end} to throttle release, brake application, and avoidance steer were also not significant. These findings provide an indication that while FCW modality can affect the driver's response time from FCW onset, it does not appear to affect the manner in which they execute their avoidance maneuver.

With respect to gender, overall mean FCW⇨VC_{end} reaction times of the female participants was 254 ms quicker than that of the male participants, a statistically significant outcome. This contributed to a significantly longer (287 ms) TTC at VC_{end} for the female participants. Differences in overall brake application response time were also statistically significant (male participants applied force an average of 50 ms quicker), however the difference was small and not believed to be of practical significance.

10.4 Forward Collision Warning Modality Assessment

Use of the protocol described in this report provided a way for the authors to perform a DVI assessment of eight FCW configurations (seven alerts plus a baseline condition). Each alert modality was intended to emulate one or more elements from those presently available in contemporary vehicles. In this study, the various alerts were each presented at TTC = 2.1s nominally, a value believed to be representative of that used in production FCW algorithms.

Overall, 17 of the 64 participants avoided collisions with the SLV (26.6 percent). Fifteen of the successfully-avoided crashes (88.2 percent) occurred during trials performed with a seat belt pretensioner-based haptic alert. One crash (1.6 percent) was avoided during a trial performed with the beep-based auditory-only alert, one with the combination of the auditory beep plus visual HUD alert. These results clearly indicate the seat belt pretensioner-based FCW alert used in this study offered better crash avoidance effectiveness than the other individual modalities on the test track. However, the authors emphasize that of the 32 trials performed with some form of seat belt pretensioner-based FCW alert, 53.1 percent of them still resulted in a crash.

Since being involved in a crash does not necessarily indicate the participant did not respond to the FCW modality used in their individual trial, evaluating FCW effectiveness should not be limited to successful crash avoidance. Although it is certainly an important consideration, some participants crashed because their avoidance strategy was simply not effective. For this reason, consideration of FCW⇨VC_{end} duration and TTC at VC_{end} are important factors when assessing overall FCW effectiveness.

In the cases where crashes did occur, consideration of vehicle speed reductions (i.e., from onset of the FCW alert to impact) observed in this study may provide some insight into FCW crash mitigation effectiveness. Differences in the participants' mean SV-to-SLV impact speeds were statistically significant for the alert configurations used in this study. The mean impact speed reduction facilitated by FCW alerts inclusive of seat belt pretensioning was significantly greater (3.9 mph) than that realized without pretensioning. With respect to gender, the overall mean impact speed reduction achieved by the female participants was 4.3 mph greater than that of the male participants, a statistically significant outcome.

Although there was considerable response variability present for each FCW configuration used in this study, there was a completing trend indicating the FCW⇨VC_{end} duration (and thus TTC at VC_{end}, and throttle release/brake application/avoidance steer response times) input were more influenced by the presence of seat belt pretensioning than any other modality.

11.0 FUTURE CONSIDERATIONS

Overall, the protocol used in this study successfully satisfied the objectives of the project. That said, lessons learned during test conduct suggest there is an opportunity for additional follow-on research. Specific areas of interest include minor configuration changes at the test track, an evaluation of how FCW education prior to test conduct may affect test outcome, an assessment of alternative incentive schedules, and an analysis of how equipping the SV with crash avoidance technologies capable of directly mitigating or preventing rear-end crashes (i.e., not just warning they are imminent).

11.1 Protocol Refinement (Time-to-Collision Based Triggering)

In this study, the random number recall task instructions, the random number recall task, and the FCW alert were each automatically initiated at fixed points on the test course. While these triggers were accurate and repeatable, and the overall mean TTC at FCW onset was only 36 ms (1.7 percent) less than the respective target value, the TTC variability about the mean could potentially be reduced if it were directly controlled. Since the participants were fully responsible for indirectly maintaining vehicle speed via a constant SV-to-MLV headway, and TTC is based on speed and headway, SV speed variability at the time of the FCW alert is a concern; it directly affects the immediacy of the rear-end crash scenario used in the study (i.e., TTC at VC_{end}). Activating the FCW alert, as well as the other triggered events, as a function of TTC should directly address this concern.

While this improvement would not be expected to alter the FCW⇨VC_{end} performance metric, it is conceivable that a participant's crash avoidance response, and the likelihood of a crash into the SLV, may be affected by small variations in TTC at VC_{end}. Tightening control of the choreography on the test track should improve the consistency of protocol's pre-crash severity.

11.2 Protocol Validation

Due to limited sample population availability and a desire to preserve the greatest number of samples per cell, FCW alert modality was the only dependent variable evaluated with the protocol described in this report. Unfortunately, while this improved the power of the conclusions described in this report, an in-depth evaluation of potentially confounding factors was not possible. Examples of such factors may include the choreography of when the surprise event occurred, the compensation schedule, and participant education.

11.2.1 Alternative Stationary Lead Vehicle Presentation Schedule

Using the current protocol, each participant was presented with a suddenly appearing SLV on the fourth of a four-pass drive. This was because the authors sought to make the participants as comfortable as possible with the testing environment (i.e., the SV, the test track, and the two tasks they were asked to perform) before the surprise event. The reasons for this were threefold:

1. Concerns that the participants may be "on guard" during their first view passes. If they were functioning with a heightened sense of awareness, alertness, or attentiveness the participants' sensitivity to the various FCW modalities might be artificially enhanced, resulting in non-representative FCW⇨VC_{end} response times.
2. The elevated risk of a mistrial. Early in their drive, the participants had received little exposure to the headway maintenance and random number recall tasks. Since the limited task exposure would coincide with an unfamiliarity of the test course (e.g., uncertainty as to how much other traffic would be present, orientation of their travel lane, etc.), the authors were very concerned that the risk of participants indulging in a quick forward-looking glance during the random number recall task would be greatest early in the drive.
3. Maximizing the likelihood of the participants driving at the proper SV speed, at the proper SV-to-MLV headway, at the time the FCW was presented, was an essential for consistent pre-crash scenario severity. Presenting the participants with the suddenly appearing SLV at the end of their drive provided the greatest opportunity for the effects of practice to be realized, allowing the participants to be groomed for achieving driving performance closest to the desired parameters.

To assess whether the protocol may have introduced an artificial state of complacency, it may be of interest to perform tests where the suddenly appearing SLV is presented earlier in the drive. Although the authors believe this to be unlikely, it is possible the participants became too comfortable during their drive (i.e., since the first three passes were unremarkable and there was no expectation of anything dangerous happening to them), which is a behavior capable of affecting how they respond to the various FCW modalities. Should such follow-on tests be performed, the authors caution that careful consideration of the concerns expressed above be respected.

11.2.2 Alternative Compensation Schedule

As stated throughout this report, successfully achieving the desired SV-to-SLV TTC at the time of FCW alert presentation required the participants maintain the proper SV-to-MLV headway while being fully engaged with the random number recall task. To encourage good performance in these tasks, an incentive-based compensation schedule was used. To evaluate whether the amount of the compensation may have imposed an artificially high reluctance to abandon participation in the random number recall task when presented with an FCW, tests performed with different compensation schedules (i.e., incentive pay) may be of interest. However, should such work be performed, it is essential that the participants remain fully engaged with the random number recall task at the onset of the FCW alert.

Note: The authors do not believe the compensation schedule used in this study provided an unrealistically high motivation for the participants to remain committed to the random number recall task. Although the protocol used in this study required that participants refrain from using a forward-facing viewing position from just after the random number recall task instruction to the onset of the FCW alert, the authors do not consider the total task duration of 2.36 seconds to be excessive (an observation supported by the absence of forward-looking glances during random number recall task participation). The overall VC durations actually used by the participants ranged from 1.27 to 4.33 seconds; the mean values for each FCW modality ranged from 2.35 to 3.51 seconds. While it was challenging, most participants were quite capable of completing it. Therefore, the authors suspect most participants did not effectively respond to the auditory or visual alerts during the random number recall task because they simply did not find the alerts compelling enough, not because they were ignored for the sake of maximizing task compensation.

11.2.3 Education and Training

Due to limited sample population availability and a desire to preserve the greatest number of samples per cell, the authors had to decide whether all participants would, or would not, receive some form of FCW education in this study. When considering this point, there were serious concerns about whether providing participants with information or descriptions of an unfamiliar technology less than an hour before receiving the alert during their experimental drive was appropriate. Therefore, in the interest of being able to observe the most genuine, untrained responses to the various FCW modalities, none of the participants used in this study received education explaining what FCW was, what modalities are presently installed in production vehicles, or whether the SV was so-equipped.

Establishing a better understanding of how education and/or practice may affect the manner in which drivers perceive, interpret, and respond to FCW alerts is of unquestionable importance. However, the authors have strong reservations about trying to quantify these affects with the protocol used in this study. That said, should evaluation of this variable be of interest, a provision to incorporate some form of FCW education into the protocol pre-brief could be easily introduced. Presenting a sample alert in a relevant driving scenario, on the test track, is also possible, but will be more involved. Simply maintaining a close headway will not activate an FCW; a critical closure (i.e., range rate-of-change) threshold must also be exceeded. Satisfying these activation criteria may be quite uncomfortable for many drivers, and the driving situation in which they receive their practice will be a memorable one. This point should be carefully considered given the high risk for pre-test FCW exposure to artificially (and temporarily) enhance the participants' sensitivity to an FCW alert, regardless of the modality.

11.3 Consideration of Additional FCW Modalities

11.3.1 Alternative Seat Belt Pretensioner Magnitudes and Timing

The seat belt pretensioner used in this study was the most effective FCW modality evaluated by the test protocol. However, the authors concede that the magnitude and timing of a seat belt pretensioner-based FCW are certain to affect effectiveness. While the origins of the seat belt pretensioner-based FCW alert used in this study were from a production vehicle, the pre-crash timing was not. Vehicle manufacturers must balance "ideal" performance with how the driver would respond to the alert in a false activation situation. While resolution of this issue was certainly outside the scope of the CWIM program, additional tests performed with different retractment strategies may be worthy of consideration.

11.3.2 Low-Magnitude Brake Pulse

At the time the tests were performed, the SV was equipped with alerts representative of each modality presently installed in model year 2010 production vehicles. For model year 2011, the FCW alerts installed in the Audi A8 include seat belt pretensioning, a low magnitude brake pulse (peak deceleration of ≈0.25 g, 100 ms pulse duration), and low level (≈0.3 g) braking. After the work described in this report was complete, VRTC performed a suite of braking-related tests on a 2011 Audi A8, and have sufficient data to characterize these brake interventions.

The protocol used in this study is intended to be modality-independent. Using this protocol, in conjunction with characterization data collected during the VRTC tests, evaluating an alternate haptic alert should be possible.

11.4 Interactions with Other Advanced Technologies

11.4.1 Crash-Imminent Braking

Many vehicles presently equipped with FCW are also equipped with crash-imminent braking (CIB), a technology intended to mitigate crashes by automatically applying the vehicle's brakes just prior to impact. Understanding how CIB interventions may affect the protocol output may be an area for future research. Given the TTCs at VC_{end} observed in this study, particularly for those produced during trials that ultimately resulted in a collision with the SLV, it is probable that many participants would have experienced a CIB intervention very near the time of their VC_{end}.[17]

Note: Given the surprise nature of the suddenly appearing SLV, it is possible that the combination of short target acquisition time, sensor limitations (e.g., target identification), and system response time (e.g., for algorithm processing and brake system activation), may adversely affect the CIB intervention timing, should production algorithms be retained during conduct of the current protocol. To address this issue, a means of activating CIB via an external trigger may need to be incorporated into the test protocol. Cooperation with the respective vehicle manufacturers and/or CIB system supplier will be necessary for this modification.

11.4.2 Dynamic Brake Support (DBS)

Brake assist (BA) is a technology that increases the gain of the vehicle's foundation brake system if a "panic" application is detected. Conventional BA typically relies on the rate of a

[17] Strong CIB interventions generally occur when TTC ≤ 600 ms. However, depending on factors such as vehicle, pre-crash scenario, etc., milder interventions may occur earlier (e.g., when TTC = 1.6 seconds).

brake application to assess whether an activation threshold has been satisfied. However, studies have indicated these thresholds are high enough (i.e., to prevent unintended assist) that many drivers may not be able to achieve them, even when motivated by crash-imminent driving scenarios.

Dynamic brake support (DBS) attempts to address the shortcomings of conventional BA by using forward-looking sensors to provide pre-crash range and range-rate data to supplement brake pedal position information. If the driver has applied force to the brake pedal (typically after the FCW alert is presented), and the vehicle estimates the application will not be enough to avoid a crash, the DBS will automatically increase the foundation brake system output in a way that endeavors to prevent a crash. If a crash cannot be avoided, the DBS intervention will have at least reduced the impact speed.

Unlike CIB, DBS requires that drivers actively participate in the driving task to receive any benefit (i.e., they must apply the brakes). Furthermore, the likelihood of DBS actually preventing a crash depends to a great extent on when the brakes are applied. For this reason, DBS system effectiveness is expected to be closely intertwined with the ability of an FCW to bring a distracted or inattentive driver back to the driving task. In other words, an effective FCW increases the amount of time available for DBS to prevent a crash. Evaluating a vehicle equipped with DBS and FCW, using the protocol described in this report, may provide a way to quantify DBS effectiveness.

Note: For the reasons previously stated in the CIB discussion above, a means of enabling[18] DBS via an external trigger may need to be incorporated into the test protocol to facilitate test conduct.

[18] Once enabled, DBS activation is triggered by the driver's brake application.

12.0 REFERENCES

[1] Najm, W.G., Stearns, M.D., and Yanagisawa, M.,“Pre-Crash Scenario Typology for Crash Avoidance Research,” DOT HS 810 767, April 2007.

[2] Miller, George, A, “The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information,” Harvard Psycho-Acoustic Laboratory under Contract N5ori-76 between Harvard University and the Office of Naval Research, U.S. Navy (Project NR 142-201, Report PNR-174), April 15, 1955.

13.0 APPENDICES

Appendix A. Phase I Post-Test Questionnaire

Appendix B. CWIM FCW Phase I Static Study Analysis

Appendix C. RT / RT-Range System Description

Appendix D. Participant Recruitment Advertisement

Appendix E. Participant Health and Eligibility Screen

Appendix F. Informed Consent Form

Appendix G. Transportation Research Center, Inc. Confidentiality Form

Appendix H. In-vehicle Experimenter Task Performance Logsheet

Appendix I. Debrief Statement

Appendix J. Post-Test Questionnaire

Appendix A. Phase I Post-Test Questionnaire and Response Summary

Phase I Post Test Questions, asked by the in-vehicle experimenter

1. Of the three visual alerts, which did you find to be the most noticeable?
2. Did you find any of the three visual alerts to be offensive in any way? If so, please describe.
3. One word to describe the HUD visual alert?
4. One word to describe the triangle-based visual alert on the instrument cluster?
5. One word to describe the alert that had the word “BRAKE” in the instrument cluster?
6. Of the three visual alerts, which did you prefer?
7. Of the two auditory alerts, which did you find to be the most noticeable?
8. Did you find either of the two auditory alerts to be offensive in any way? If so, please describe.
9. One word to describe the “beep-based” auditory alert?
10. One word to describe the “tone-based” auditory alert?
11. Of the two auditory alerts, which did you prefer?
12. Was the seat belt pretensioner activation more or less apparent than the most noticeable visual alert?
13. Was the seat belt pretensioner activation more or less apparent than the most noticeable auditory alert?
14. One word to describe the seat belt pretensioner activation?
15. Overall, what alert or combination of alerts did you prefer?
16. Did the position of the throttle relative to the brake pedal seem natural (i.e., as the throttle was released and the brakes applied)

Appendix A. Phase I Post-Test Questionnaire and Response Summary (continued)

Table A1. Phase I Static Pilot Post-Test Questionnaire Responses.

	Subject Response							
Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	HUD	MDC	HUD	MDC	IC	MDC	HUD	MDC
2	n/a	n/a	No	No	No	No	No	No
3			Different	Flash	Unnoticeable	Hard to see	Flashing	Dim
4			Vague	Small	Noticeable	Visible	Confusing	Small
5			Dim	Bold	Noticeable	Clear	Billboard	Large
6			HUD	MDC	IC	MDC	HUD	MDC
7	Same	Beep	Beep	Beep	Beep	Beep	Beep	Same
8	n/a	n/a	No	No	No	No	No	No
9			Attention getting	Noticeable	Attention getting	Urgent	Elevator	Obvious
10			OK	Quiet	Noticeable	Vague	Zero	Obvious
11			Beep	Beep	Beep	Beep	Beep	No preference
12			Yes	More	More	More	More	More
13			Yes	More	More	More	More	Equally apparent
14			Maddening	Alerting	Annoying	Startling	Sudden	Sudden
15	HUD+Tone	Belt+Beep	HUD+Beep	Belt+Beep	Beep+IC	Belt+Beep	HUD	Belt+either auditory alert+MDC help explain what was happening
16	n/a	n/a	Yes	Yes	Yes	Yes	Missing or getting a corner of the brake pedal	Natural

Appendix B. CWIM FCW Phase I Static Study Analysis

CWIM FCW Phase I Static Study Analysis

The following analysis was performed to assess the whether there was a significant difference in participant reaction times to the auditory and visual based FCW alerts presented in the Phase I static study.

The first step taken was to determine whether or not there was a learning effect (i.e.: whether reaction time performance systematically improved over the 4 test blocks. A repeated-measures design was used with the specified error term. As the output below shows, there was no overall learning effect (p-value of 0.26) and that the absence of a learning effect was consistent across all 23 treatments (p-value of 0.98). This meant that the data could be treated equally across blocks in latter analyses.

Tests of Hypotheses Using the Type III MS for subject*block as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
block	3	1.35635849	0.45211950	1.43	0.2624

Tests of Hypotheses Using the Type III MS for subject*block*treatment as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
block*treatment	66	8.57709800	0.12995603	0.63	0.9882

The next three repeated-measures analyses examined whether there were differences among the visual stimuli. The first analysis examined the subjects' reaction time to the visual stimuli. On trials where the subject did not respond after 5 seconds, the trial was ended and the reaction time set at 5 seconds, even though the subject had not yet responded. Family-wise error was controlled by setting alpha = 0.01667. As the output below shows, there was no effect due to type of visual stimuli used.

Tests of Hypotheses Using the Type III MS for subject*alert as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
visual alert	2	1.27297552	0.63648776	0.36	0.7022

The second analysis used the same basic dataset and approach, but trials where subjects had not responded within 5 seconds of stimuli presentation were removed. As with the previous output, there was no effect due to type of visual stimuli used.

Tests of Hypotheses Using the Type III MS for subject*alert as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
visual alert	2	0.14621372	0.07310686	0.27	0.7670

In addition to the reaction time, a third analysis examined the effects of different visual alerts on the number of trials where the alert successfully elicited a response from the driver. A one-way within-subjects ANOVA was computed with alert as the independent variable. Visual alert had three levels: a message displayed on the instrument cluster (Message), an icon on the instrument cluster (Icon), and a HUD. Alert by subject responses were given an aggregate value of between 0 and 4 reflecting the number of successful detections out of 4 trials. To accommodate the three

Appendix C. A GPS-Enhanced Inertial Data System With Real-Time Range Capability

System Overview

An Oxford Technical Solutions (OXTS) RT Range system was used to provide inertial data and highly accurate real-time GPS positioning of the subject vehicle (SV) and moving lead vehicle (MLV). Additionally, this system the provided relative position of the SV with respect to the MLV, fixed points on the test course, and ultimately to the stationary lead vehicle (SLV).

This system included two RT3002 inertial measuring units (IMUs), each containing an integrated GPS configured to receive differential corrections from a local base station at VRTC to provide real time kinematic (RTK) resolution. When operating in this mode, OXTS specifies that each IMU the system achieves a vehicle position accuracy of 2 cm (dynamic), and a relative position accuracy of 3 cm between two vehicles.

Each IMU contained a six degree of freedom inertial sensing unit used to directly measure the state of SV and MLV about each vehicle's roll, pitch, and yaw axes. These measurements were augmented with the differentially corrected RTK-GPS data at a 100Hz sample rate. The resulting data channels were recorded on a laptop computer using OXTS software. While a majority of the available data channels reported by this system were output directly from the IMUs via Ethernet, some were calculated by the software. Table C.1 provides a list of key channels provided by the RT3002s, and their respective accuracy specifications.

Table C.1. RT3002 Channels and Accuracy Specifications.

Channels	Range	Accuracy	Sensory Mode
X, Y, Z Accelerations	10.2g (100 m/s^2)	0.001g (0.01 m/s^2)	IMU
X,Y, Z Angular Rates	100 deg/s	0.01 deg/s	IMU
Pitch and Roll (calculated)	0-90 deg	0.03 deg	IMU
Vehicle Heading (calculated)	0-360 deg	0.1 deg	IMU / GPS
GPS Position (Lat, Long, Alt)	Extensive[1]	0.08 in (2 cm); 0.12 in (3cm) SV-to-MLV	IMU / GPS
Velocities (North, East, Down)	≥0.03 mph (0.05km/h)	0.03 mph (0.05km/h)	IMU / GPS

[1] Anywhere on or near the Earth with an unobstructed view of four or more GPS satellites.

To report real-time SV-to-MLV headway, the OXTS software uses measurements based in local coordinate system established by SV. The measurements of the MLV are transmitted via high-speed wireless LAN back to the SV to facilitate these calculations. For this study, the system was configured to report SV-to-MLV headway from the center of the SV front bumper to the center of the MLV rear bumper.

With respect to the effect of radio delay on position accuracy, OXTS states that "because of radio delays, the RT-Range will predict the position of the [MLV] so that the measurements can be output in real-time with a low latency…Typically the radio delay is 10ms and there is no degradation in performance with this delay. Even when the radio delay is up to 50ms, the error in range is very small (less than 1cm).[19]" When considering this point, it is important to recognize that any position error resulting from latency of the wireless LAN is only expected to occur in real time under highly dynamic situations; it was eliminated during data post processing of the core data recorded by the RT3002s installed in the SV and MLV.

Installation Overview

Following IMU installation into the SV and POV, precise measurements of their locations were made, and the respective values entered into an OXTS software configuration file. Locations of the GPS antennas, the centers of the front and rear bumpers also measured and included in the configuration utility. All measurements were obtained using a Faro Arm Fusion portable measuring arm, accurate to ±0.049 in (±0.124 mm).

Data produced by the RT Range system were recorded using a laptop computer secured in the trunk of the SV. A separate data acquisition system, also mounted in the trunk, recorded the analog channels from the SV at a rate of 200 Hz (described in Section 3.4.1). A digital link between the two systems provided a common "trigger" channel to insure accurate synchronization of the RT Range and analog data during post-processing. During this data merging process, the RT Range system data were interpolated from 100 to 200 Hz to match the sample rate used to record the analog data channels.

[19] http://www.oxts.com/downloads/rtrangeman.pdf

Appendix D. Participant Recruitment Advertisement

Receive up to $100 for approximately 1 hour of participation

($35 plus a Performance Bonus of up to $65)

We are seeking participants for a research study of driving performance

The study will be conducted by:

The National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation on the grounds of Transportation Research Center Inc. (TRC) in East Liberty, Ohio

Sessions conducted on weekdays and Saturdays during daylight hours.

<u>MUST BE:</u>
25-55 years old
In good general health
Licensed driver without restrictions
Have driven 7,000+ miles per year in the last 2 years

If you would like to participate, and you meet these requirements,

PLEASE CALL: 1-800-262-8309 to inquire about the "Headway Maintenance Assessment" study from 7:30 am – 4:00 pm weekdays (leave a message at extension 251 after hours) or Email name, phone number, and best time to contact you to VRTCWEBMASTER@dot.gov, add subject "Headway Maintenance Assessment" study.

Appendix D. Participant Recruitment Advertisement (continued)

Seeking participants for a research study of driving performance (East Liberty, Ohio in Logan Co.)

Date: 2010-09-03, 8:01AM EDT
Reply to: VRTC.Webmaster@dot.gov [Errors when replying to ads?]

Receive up to $100 for approximately 1 hour of participation
($35 plus a Performance Bonus of up to $65)

We are seeking participants for a research study of driving performance

The study will be conducted by:
The National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation on the grounds of Transportation Research Center Inc. (TRC) in East Liberty, Ohio

Sessions conducted on weekdays and Saturdays during daylight hours.

MUST BE:
25-55 years old
In good general health
Licensed driver without restrictions
Have driven 7,000+ miles per year in the last 2 years

If you would like to participate, and you meet these requirements,

PLEASE CALL: 1-800-262-8309 to inquire about the "Headway Maintenance Assessment" study from 7:30 am – 4:00 pm weekdays (leave a message at extension 251 after hours) or Email name, phone number, and best time to contact you to VRTCWEBMASTER@dot.gov, add subject "Headway Maintenance Assessment" study.

- Location: East Liberty, Ohio in Logan Co.
- Compensation: Listed in Ad
- This is a contract job.
- Principals only. Recruiters, please don't contact this job poster.
- Phone calls about this job are ok.
- Please do not contact job poster about other services, products or commercial interests.

Appendix E. Participant Health and Eligibility Screen

Introduction	Thanks for expressing interest in participating in our research study.
Research Study Purpose	The study is being conducted by the United States Department of Transportation's National Highway Traffic Safety Administration (NHTSA) to assess your ability to use a windshield-mounted headway measurement display to maintain a consistent distance between a vehicle being driven by you, and one being driven directly in front of you. NHTSA is interested in better understanding how interfacing with an electronic display in the rear passenger compartment may affect this ability.
Purpose of Phone Screening	I'd like to describe the study to you briefly and gather information that can be used by the principal investigator to determine if you qualify for participation. This call may take up to 15 minutes. Is now a good time?
Participation Commitment	Participation involves approximately one hour at our research laboratory located in East Liberty, Ohio. For a portion of the hour, participants will drive a government-owned vehicle on a test course.
Participation Compensation	You will be paid $35 for participating in the study. This study also includes two performance-based incentives providing you with an opportunity to receive additional payments of up to $65. You will also be paid for mileage driven between your residence and the laboratory.
Information Being Requested & Confidentiality	I would now like to ask you a series of questions to determine your eligibility. Questions will cover: (1) personal information, (2) driving experience, (3) vehicle information, and (4) medical history. NHTSA will not release any personal identifying information that you provide during this call. Responses to health related questions will not be retained, they are merely being asked to determine your eligibility for participation. At this time, are you willing to proceed with the questions? You do not have to answer any question that you do not want to answer. (If yes, then proceed. If NO, then ask if person would like us to keep his/her contact information in our database and contact him/her for consideration for participation in future studies? If NO, then make note to delete information.)
NOTE: (Office Use Only)	Exclusion Criteria are on Subject Info sheet

Appendix E. Participant Health and Eligibility Screen (continued)

Admin	***Questions for Subject Recruitment Phone Interview***
	Subject Number (selection by principal investigator)
	Caller Number
	Date Interviewed
	Interviewers initials
	Date Scheduled
	Call Log (Track the time and date of each call attempt made):
	Condition
Demographics	NAME (first M.I. last)
	PHONE - DAY
	PHONE - EVENING
	GENDER (M / F)
	BIRTHDATE (mm/dd/yyyy)
	AGE (office note: must be 25 - 55 years old to participate) **25 - 55**
	OCCUPATION:
Driving Information	Does your job involve any type of driving?
	Do you have a valid US driver's license? (Y / N) Are there any restrictions on that license? Are you able to drive without the use of assistive devices?
	Number of years of driving experience (office note: need at least 2 years)?
	How many miles do you drive per year (office note: > 7,000)?
	What kind of vehicle do you normally drive (year, make, model)?
	End call here if: driver's license not valid, there are license restrictions other than corrective eyewear, driving experience is less than 2 yrs, the # of miles driven per year is less than 7,000.
	Do you use a cellular phone while driving (Y / N)?
	Do you use a navigation system, computer, or any other similar devices in your car? If yes, what are they specifically?
	ANY CRASHES IN LAST 5 YEARS? (If YES to crash) Briefly, what was the cause?
	ANY OTHER RECENT TRAFFIC VIOLATIONS? (IF YES to traffic violations) WHAT TYPE(S) OF VIOLATIONS?
Medical	**I am now going to ask you some confidential questions about your medical history and present condition. You can refuse to answer any question. Please answer yes or no to the following.**
	DO YOU HAVE ANY HEALTH PROBLEMS THAT AFFECT DRIVING ABILITY?
	DO YOU SUFFER FROM ANY HEART CONDITIONS SUCH AS: DISTURBANCE OF HEART RHYTHM? HAD A HEART ATTACK WITHIN THE LAST 6 MONTHS? HAD A PACEMAKER IMPLANT WITHIN THE LAST 6 MONTHS? (IF YES, DESCRIBE.)
	DO YOU HAVE HIGH BLOOD PRESSURE?

Appendix F. Informed Consent Form

STUDY: Headway Measurement Display
STERLING IRB ID: 3566-001
DATE OF IRB REVIEW:

PARTICIPANT INFORMED CONSENT AND CONFIDENTIAL INFORMATION FORM

STUDY TITLE: Headway Maintenance Assessment

STUDY INVESTIGATOR: Garrick J. Forkenbrock, BSME

STUDY SITE: NHTSA Vehicle Research and Test Center
10820 SR 347; Bldg 60
East Liberty, OH 43319

TELEPHONE: 937-666-4511

SPONSOR: U.S. Department of Transportation
National Highway Traffic Safety Administration

You are being asked to participate in a research study. Your participation is strictly voluntary, meaning that you may or may not choose to take part. To decide whether or not you want to be part of this research, you should understand the study risks and benefits in order to make an informed decision. This process is known as informed consent. This consent form describes the purpose, procedures, possible benefits, and risks of the study. This form also explains how your information will be used and who may see it. You are being asked to take part in this study because the study investigator feels that you meet the required qualifications.

The study investigator or research staff will answer any questions you may have about this form or the study. Please read this document carefully and do not hesitate to ask anything about this information. This form may contain words that you do not understand. Please ask the investigator or staff to explain the words or information that you do not understand. After reading the consent form, if you would like to participate, you will be asked to sign and date this consent form. You may have a copy of this form to review at your leisure and keep for your records.

PURPOSE

In this study, the investigators will assess your ability to use a windshield-mounted headway display to maintain a consistent distance between a vehicle being driven by you, and one being driven directly in front of you. To better understand how interfacing with a small electronic display may affect this ability, you will be presented with a series of secondary tasks during your drive. Each of these secondary tasks will require you view and recall a series of five random numbers presented on the display. After the fifth number has been presented, you will be asked to tell the in-vehicle study staff member what the five numbers were, in the order they were displayed.

To make these tasks challenging, the display will be placed in the right rear passenger compartment. Although you may adjust the orientation of the display to make the completion of

Participant's Initials ____________

Appendix F. Informed Consent Form

STUDY: Headway Measurement Display
STERLING IRB ID: 3566-001
DATE OF IRB REVIEW:

PARTICIPANT INFORMED CONSENT AND CONFIDENTIAL INFORMATION FORM

STUDY TITLE: Headway Maintenance Assessment

STUDY INVESTIGATOR: Garrick J. Forkenbrock, BSME

STUDY SITE: NHTSA Vehicle Research and Test Center
10820 SR 347; Bldg 60
East Liberty, OH 43319

TELEPHONE: 937-666-4511

SPONSOR: U.S. Department of Transportation
National Highway Traffic Safety Administration

You are being asked to participate in a research study. Your participation is strictly voluntary, meaning that you may or may not choose to take part. To decide whether or not you want to be part of this research, you should understand the study risks and benefits in order to make an informed decision. This process is known as informed consent. This consent form describes the purpose, procedures, possible benefits, and risks of the study. This form also explains how your information will be used and who may see it. You are being asked to take part in this study because the study investigator feels that you meet the required qualifications.

The study investigator or research staff will answer any questions you may have about this form or the study. Please read this document carefully and do not hesitate to ask anything about this information. This form may contain words that you do not understand. Please ask the investigator or staff to explain the words or information that you do not understand. After reading the consent form, if you would like to participate, you will be asked to sign and date this consent form. You may have a copy of this form to review at your leisure and keep for your records.

PURPOSE

In this study, the investigators will assess your ability to use a windshield-mounted headway display to maintain a consistent distance between a vehicle being driven by you, and one being driven directly in front of you. To better understand how interfacing with a small electronic display may affect this ability, you will be presented with a series of secondary tasks during your drive. Each of these secondary tasks will require you view and recall a series of five random numbers presented on the display. After the fifth number has been presented, you will be asked to tell the in-vehicle study staff member what the five numbers were, in the order they were displayed.

To make these tasks challenging, the display will be placed in the right rear passenger compartment. Although you may adjust the orientation of the display to make the completion of

Participant's Initials ____________

the secondary tasks more comfortable, the display must not be physically removed from the mounting bracket. During your drive, you will be asked to complete four secondary tasks, approximately one per mile.

STUDY REQUIREMENTS

You are being asked to participate in this research study because you:

- Are 25 - 55 years of age
- Have a valid U.S. driver's license with no restrictions (excluding corrective eyewear)
- Have a minimum of 2 years driving experience
- Drive at least 7,000 miles per year
- Are in good general health

NUMBER OF STUDY SITES AND PARTICIPANTS

This study will take place at one research site (NHTSA's Vehicle Research and Test Center) and will include up to 64 men and women.

STUDY PROCEDURES

Before participating in this research study, you will be asked to read this Participant Informed Consent and Confidential Information Form in its entirety. After all of your questions have been answered, you will be asked to sign this form to show that you voluntarily consent to participate in this research study.

During all driving taking place on the grounds of the Vehicle Research and Test Center, you will be required to wear the vehicle's seat belt. In addition, a member of the research staff will accompany you when driving a government-owned vehicle and give you detailed instructions regarding where to drive. Although a member of the study staff will be with you at all times, he or she is not able to ensure complete safety. Therefore, it is important to remember that you, as the driver, are in control of the vehicle and you must be the final judge as to when to complete the tasks during this study.

By signing this form, you agree to participate in one visit to the study site lasting approximately 60 minutes. The visit will include a brief period of vehicle and equipment familiarization followed by a test drive and a short survey. Procedure steps include:

- You will be asked to read and sign this consent form before you start any part of the study.
- Prior to the test drive, you will have an opportunity to familiarize yourself with the test vehicle, the windshield-mounted headway measurement display and how to access the display-based secondary tasks you will be asked to use during the test drive.
- While driving from the laboratory to where the test drive will take place, you will have an opportunity to familiarize yourself with the government-owned test vehicles and use of

Participant's Initials ____________

Appendix F. Informed Consent Form (continued)

- the headway measurement display. During this warm-up you will perform various basic driving maneuvers.
- When you arrive at the test location, you will perform a test drive in a government-owned vehicle. In addition to the windshield-mounted headway measurement display, this vehicle will be equipped with video cameras and sensors to record information such as vehicle speed, distance between your vehicle and the lead vehicle, and your steering, braking, and gas pedal use. The data collected allows the researchers to accurately and objectively quantify your driving performance. Some of your actions may be videotaped while you are taking part in the study.
- Following the test drive, you will complete a brief, written survey.

NEW INFORMATION

No changes to procedures are anticipated to take place during this study. However, any new information that may affect your willingness to participate will be provided to you.

RISKS

During the test drive, participants will be subject to all risks and uncertainties normally associated with driving on the test track, access roads (two-lane rural roads), and in parking lots. A number of controls exist to reduce the risk of crashing. Specifically, test track traffic is generally light and the number of vehicles occupying the same travel lane will be limited. Access to the test track is controlled.

The test drive will be performed only in daylight and in favorable driving conditions. In the event of bad weather, your test drive may be delayed until conditions for driving improve. For these reasons, the risks are considered to be less than might be expected when performing comparable driving tasks while traveling on a controlled access freeway and two-lane roads under light to moderate traffic conditions. You will not be asked to perform any unsafe acts. If you want to stop the test drive at any time, you should tell the investigator. You may stop the study at any time.

There are no known physical or psychological risks associated with participation in this study beyond those described above.

BENEFITS

There is no personal benefit to you from participating in this study. You are not expected to receive direct benefit from you participating in this research study.

The research study will provide data on driver behavior and performance that may be used by researchers to develop recommendations or standards for increasing vehicle and driving safety.

Participant's Initials ____________

STUDY: Headway Measurement Display
STERLING IRB ID: 3566-001
DATE OF IRB REVIEW:

ALTERNATIVES

This study is for research purposes only. Your alternative is to not participate.

CONDITIONS OF PARTICIPATION, WITHDRAWAL, AND TERMINATION

Participation in this research is voluntary. By agreeing to participate, you agree to cooperate in accordance with all instructions provided by the study staff. If you fail to follow instructions, or if you behave in a dangerous manner, you may be terminated from the study and forfeit your compensation. You may withdraw your consent and discontinue participation at any time without penalty. If you decide to withdraw from the research study, you should notify the study investigator.

COSTS TO YOU

Other than the time you contribute, there will be no costs to you.

COMPENSATION

You will receive a nominal compensation of $35.00 upon completion of the study. If you are able to maintain a distance of 95 – 125 feet between your vehicle and the lead vehicle when instructed to do so, you will receive an additional $20.00. If you are able to successfully complete the secondary tasks when instructed to do so, you will receive an additional $45.00.

If you do not complete the entire study, you will receive a pro-rated portion of this amount. In addition, you will be compensated 50 cents per mile (up to a maximum of $200.00) for driving from your residence to our facility. In the event that severe weather causes a delay in your completion of required driving, you will receive $30.00 per hour for up to 2 hours spent at the research facility in excess of 3 hours.

COMPENSATION FOR RESEARCH RELATED INJURY

The contractor assisting with the conduct of this study, Transportation Research Center, Inc. (TRC), will maintain insurance that will cover you in the event of a crash occurring on TRC facilities while driving a government-owned vehicle. This insurance will provide coverage if you are injured up to a limit of $10,000.00. You should contact your insurance company to check on additional coverage.

Coverage will also be provided for injuries to others, including the driver and any passengers of other vehicles involved in the crash, as well as damages resulting from any crashes occurring during your participation in this study, up to a $1,000,000.00 limit. Except to the extent covered by such insurance policy, neither the TRC nor NHTSA will be responsible for your actions during this study, nor will they indemnify you or otherwise compensate you for any problems arising out of your actions or the normal risks associated with driving. However, you will not be liable for loss or damage to the vehicle instrumentation, the government-owned research vehicle, or other equipment during your participation unless there is gross negligence on your part.

Page 4 of 7
Version Date: 22 July 2010

Participant's Initials ____________

Appendix F. Informed Consent Form (continued)

If you are injured in a crash while on TRC facilities, emergency personnel will be dispatched to treat you. The nearest hospital is about 15 miles away. If you are injured while driving off-site during your participation in the study, either you or your insurance company will be responsible for the costs associated with your medical treatment and your vehicle repairs.

USE OF INFORMATION COLLECTED

In the course of this study, the following data will be collected:

- Video/audio data (such as the information recorded by video cameras)
- Driver-based sensor data (such as your steering, braking, and gas pedal use)
- Vehicle-based sensor data (such as speed, distance between your vehicle and the lead vehicle)

Information NHTSA may release:

- The video data recorded in this study includes your video-recorded likeness. Video data will be used to assess your driving performance. NHTSA may publicly release video image data (in continuous video or still formats) either separately or in association with the driver and vehicle-based sensor data for scientific, educational, research, or outreach purposes.

Information NHTSA may not release:

- Any release of video data will not include release of your name. However, in the event of court action, NHTSA may not be able to prevent release of your name or other personal identifying information. NHTSA will not release any information collected regarding your health and driving record.

QUESTIONS

Any questions you have about the study can be answered by Garrick J. Forkenbrock or the study staff by calling 1-800-262-8309.

If you have questions regarding your rights as a research participant, or if you have questions, concerns, complaints about the research, would like information, or would like to offer input, you may contact: Rev. Paul E. Gamber, J.D., Chairman of Sterling Institutional Review Board, 6300 Powers Ferry Road, Suite 600-351, Atlanta, Georgia 30339 (mailing address) at telephone number 1-888-636-1062 (toll free).

Participant's Initials ____________

Appendix F. Informed Consent Form (continued)

STUDY: Headway Measurement Display
STERLING IRB ID: 3566-001
DATE OF IRB REVIEW:

INFORMED CONSENT

By signing the informed consent statement contained in this document, you agree that your participation is voluntary and that all terms of this agreement have been explained to you. Also by signing the informed consent statement, you agree to operate the study vehicle in accordance with all instructions provided by the study staff. You may withdraw your consent and discontinue your participation in the study at any time without penalty.

NHTSA will retain a signed copy of this Informed Consent and Confidential Information Form. A copy of this form will also be provided to you.

Informed Consent Statement:

I certify that:

- I have a valid, U.S. driver's license with no restrictions (excluding corrective lenses).
- I am the primary driver of the following vehicle: ________________________________.
- All personal information as well as information regarding my normal daily driving habits provided by me to NHTSA, and/or the Transportation Research Center, Inc. (TRC) employees associated with this study during the pre-participation phone interview and the introductory briefing was true and accurate to the best of my knowledge.
- I have been informed about the study in which I am about to participate.
- I have been told how much time and compensation is involved.
- I have been told the purpose of this study and the nature of the protocol involved.

I have been told that:

- The study involves a period of observation of my driving a government-owned vehicle on the TRC test courses and private roads, and that the risk of injury due to a motor vehicle collision is less than in real world driving due to the closed environment and safety precautions which include an on-board member of the study staff ready to intervene if necessary.
- For scientific, educational, research, or outreach purposes, video images of my driving which will contain views of my face may be used or disclosed by NHTSA, but my name and any health data or driving record information will not be used or disclosed by NHTSA.
- My participation is voluntary and I may refuse to participate or withdraw my consent and stop taking part at any time without penalty or loss of benefits to which I may be entitled.
- I have the right to ask questions at any time and I may contact the study investigator, Garrick J. Forkenbrock, at 800-262-8309 for information about the study and my rights.

Page 6 of 7
Version Date: 22 July 2010 Participant's Initials ____________

Appendix F. Informed Consent Form (continued)

STUDY: Headway Measurement Display
STERLING IRB ID: 3566-001
DATE OF IRB REVIEW:

I have been given adequate time to read this informed consent form. I do not give up any of my legal rights by signing this form. I hereby consent to take part in this research study.

I, ____, voluntarily consent to participate.
(*Printed Name of Participant*)

____

Signature of Participant Date

____

Printed Name of Person Obtaining Consent

____

Signature of Person Obtaining Consent Date

INFORMATION DISCLOSURE

By signing this document, you agree that NHTSA and its authorized contractors and agents will have the right to use the video data collected during your participation for scientific, educational, research, or outreach purposes. This includes wide distribution or publication of your likeness in video or still photo format. Neither NHTSA nor its authorized contractors or agents shall release your name. You have been told that, in the event of court action, NHTSA may not be able to prevent release of names or other personal identifying information. NHTSA will not release any information collected regarding your health and driving record, either by questionnaire or medical examination. Your permission to disclose this information will not expire on a specific date.

Information Disclosure Statement:

I, ____, (Printed Name of Participant) grant permission to the National Highway Traffic Safety Administration (NHTSA) to use, publish, or otherwise distribute NHTSA video image data of my likeness (including continuous video and still photo formats) collected in this study, either separately or in association with the appropriate engineering data for scientific, educational, research, or outreach purposes. I have been informed that such use may involve widespread distribution to the public and may involve distribution of my likeness in video or still photo formats, but will not result in release of my name or other identifying personal information by NHTSA or its authorized contractors or agents. I have been told that my permission to disclose this information will not expire on a specific date.

____

Signature of Participant Date

Page 7 of 7
Version Date: 22 July 2010

Participant's Initials ____________

Appendix G. Transportation Research Center, Inc. Confidentiality Form

Transportation Research Center Inc.
POLICY & PROCEDURE

CONFIDENTIAL INFORMATION		P&P NO.	153
Volume:	I, General Information	Issue Date:	11/30/2007
Function:	Security	Effective Date:	11/30/2007
Replaces:	Safeguarding Proprietary Info Issued 10/20/03	Code:	B, D

1. Purpose

To establish standards for the protection of confidential information and a proprietary atmosphere for TRC Inc. and its customers.

2. Scope

This policy applies to all customers and other visitors who have access to testing or other confidential information.

3. Policy

It is the policy of TRC Inc. to protect the identity, objectives, and presence of our customers, their test results, and/or other confidential information by the enforcement of the rules that are outlined herein. These rules are applicable to all personnel at/or within the facilities of TRC Inc.

3.1 You will not be allowed to witness any test or access other confidential information that you are not directly associated with unless prior approval has been given by facility management. This same restriction applies to the photographing of any test or test article.

3.2 In any activity that you are not directly associated with that you do witness, you agree not to disclose any information that you may have obtained.

3.3 Any violation of this policy may result in censure by TRC Inc. and possible punitive legal action through the courts.

I have read and understand the above P&P #153, Confidential Information, and accept my responsibilities in complying with this policy.

____________________ ____________________
Printed Name Signature

____
Company Name

____________________ ____________________
Witness Signature Date

Appendix H. In-vehicle Experimenter Task Performance Logsheet

Date: **DAS16:**

Subject #: **RCOM:**

Test Configuration:

Primary Task Payment Schedule (Car Following Task)

Pass #	Within Range (yes/no)	Range Compensation	Payment	Comments
1		$5.00		
2		$5.00		
3		$5.00		
4		$5.00	$5.00	
Primary Task Total				

Secondary Task Payment Schedule (Random Number Generator Task)

Sequence	Display	#s Correct	Correct # Compenation ($1.50 or $2.50 per #)	Incorrect Order Deduction (-$1)	Payment
1	8 – 3 – 6 – 5 - 6				
2	4 – 5 – 9 – 6 – 7				
3	1 – 6 – 0 – 2 – 1				
4	8 – 2 – 4 – 1 – 2				
5	5 – 8 – 6 – 3 – 6				
6	5 – 3 – 8 – 5 – 8				
7	4 – 9 – 3 – 4 – 8				
8	9 – 1 – 9 – 5 – 1				
9	2 – 7 – 9 – 3 – 1				
10	0 – 5 – 1 – 2 – 9				
Secondary Task Total					

TOTAL PERFORMANCE COMPENSATION:

Appendix I. Debrief Statement

PARTICIPANT DEBRIEF SCRIPT

"We apologize that we staged this event. We deliberately created a situation where the vehicle you were asked to follow was actually intended to conceal a balloon car placed directly in your path. We did this because we are performing driver distraction research. The presence of the balloon car was detected by the test vehicle's forward collision warning (FCW) system. Part of our research is to observe how people respond to different kinds of FCW alerts while being distracted. There were no real people in the balloon car.

Did you have any idea that this would happen? ___ Yes ___ No

The reason we didn't tell you that this would happen ahead of time is that we wanted to observe your natural reaction. I hope you will understand why we deliberately misled you. Also, I hope you can appreciate that the kind of event you just experienced is similar to real situations that occasionally occur in everyday driving.

This type of surprise won't happen again today. And, since we are testing at least through the end of October, we would be grateful if you did not discuss this surprise event experience with anyone until after October.

We can drive back to the laboratory. When we return, we will walk to the conference room, where we have a brief questionnaire for you to complete. Then, we can take care of your compensation."

Appendix J. Post-Test Questionnaire

POST-TRIAL QUESTIONNAIRE PART 1

DATE: ______ SUBJECT #: ______

TEST #: ______ FCW Mode: ________

As part of this study, it is useful to collect some personal information regarding each participant's background. The following questions will ask about you, your driving patterns, and the vehicle(s) which you drive. Please read each question carefully and mark only one response unless otherwise indicated by the question. If none of the responses are appropriate, leave it blank. If anything is unclear, feel free to ask for help. Remember, your participation is voluntary and you have the right to skip ANY question. Thank you for your participation.

1) What is your birth date? (Month/Day/Year)

2) What is your gender?

☐ Male
☐ Female

3) What is your marital status?

☐ Single
☐ Married
☐ Separated or Divorced
☐ Widowed

4) What is your highest level of education completion?

☐ Primary School
☐ High School Diploma
☐ Technical School
☐ Associates Degree
☐ Bachelors Degree
☐ Some Graduate or Professional School
☐ Graduate or Professional Degree

5) What is your present employment status?

☐ Full-time
☐ Part-time
☐ Unemployed
☐ Retired
☐ None of the above

Page **1** of **10**

DOT HS 811 501
July 2011

U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

NHTSA
www.nhtsa.gov