RITA Intelligent Transportation Systems
Joint Program Office

Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V)

Subtask 3.3 Interim Report

Test of Alternative Driver-Vehicle Interfaces on the Smart Road

(Appendix A-3)

May 15, 2008

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16. Abstract

The following report documents the work performed in Subtask 3.4 of the Cooperative Intersection Collision Avoidance System for Violations (CICAS-V) project. The basic design objective of the CICAS-V is to create a system that presents a timely and salient in-vehicle warning to those drivers who are predicted, by means of an algorithm, to violate a stop light or a stop sign. The purpose of Subtask 3.4 was to evaluate the CICAS-V and Data Acquisition Systems (DASs) using naive participants in on-road and test-track environments to assess and ensure that all systems are mature enough for a Field Operational Test (FOT).

Data were evaluated from 87 naive drivers who were placed into CICAS-V equipped vehicles to navigate a two-hour prescribed route through equipped intersections in the New River Valley region of Virginia. During the prescribed route, each driver was instructed to cross ten stop-controlled and three signal-controlled intersections making a variety of turn maneuvers through each for a total of 52 intersection crossings (the maximum number of crossings per driver). To ensure sufficient data were obtained to understand drivers' impressions of the warning, 18 drivers followed the on-road study with a test-track study. The test-track study used a ruse that required drivers to perform a variety of in-vehicle tasks while driving. A distraction task was delivered at a carefully controlled point near a signalized intersection so that drivers were not looking at the traffic signal during the phase change. A CICAS-V warning was presented and the drivers' responses to the warning were recorded. The outcome of on-road and test-track driver performance and system data indicate that the CICAS-V and the DASs are ready for an FOT.

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List of Acronyms:

ABS: Anti-Lock Brake System
ANCOVA: Analysis of Covariance
ANOVA: Analysis of Variance
CAMP: Crash Avoidance Metrics Partnership
CI: Confidence Interval
CICAS: Cooperative Intersection Collision Avoidance Systems
CICAS-V: Cooperative Intersection Collision Avoidance Systems - Violation
DART: Data Analysis and Reduction Tool
DAS: Data Acquisition System
DGPS: Differential Global Positioning System
DII: Driver-Infrastructure Interfaces
DSRC: Dedicated Short Range Communications
DVI: Driver-Vehicle Interface
FOT: Field Operation Test
FSE: Front seat experimenter
FV: Following Vehicle
GPS: Global Positioning System
HF: Human Factors
HVAC: Heating, Ventilation, and Air Conditioning
ICAV: Intersection Collision Avoidance – Violation
IDS: Intersection Decision Support
LED: Light-Emitting Diode
MF: Middle Female
MM: Middle Male
MPEG: Motion Picture Experts Group
NTSC: National Television System Committee
OBE: On-Board Equipment
OF: Older Female
OM: Older Male
PBA: Panic Brake Assist
POV: Principle Other Vehicle
RDP: Required Deceleration Parameter
RSE: Roadside Equipment
SD: Standard Deviation
SNK: Student-Newman-Keuls
SV: Subject Vehicle
TCD: Traffic Control Device
TTI: Time to Intersection
UDP: User Datagram Protocols
USDOT: United States Department of Transportation
USDOT/IE: Independent Evaluator
USDOT/ VSC2: Vehicle Safety Communications Consortium
VTTI: Virginia Tech Transportation Institute
WAVE: Wireless Access in Vehicular Environments
YF: Young Female
YM: Young Male

Metric conversions

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Executive Summary

The Cooperative Intersection Collision Avoidance System -Violation (CICAS-V) project aims to develop and field-test a comprehensive system to reduce the number and severity of crashes at intersections due to violations of traffic control devices (TCD; i.e., traffic lights and stop signs). These crashes account for thousands of injuries and fatalities in the United States every year (National Highway Traffic Safety Administration, 2006). The approach selected to reduce these crashes is to present a timely and salient in-vehicle warning to those drivers predicted to violate a TCD. The warning is intended to elicit a behavior from the driver to avoid a potential violation. The means through which the warning information is presented to the potential violator, the Driver-Vehicle Interface (DVI), is one of the CICAS-V subsystems. The importance of this particular subsystem is based on its function: prompting the driver to take the appropriate violation avoidance maneuver. For this reason, a series of Human Factors (HF) test-track studies were planned within Subtask 3.3 of the CICAS-V project for the exploration of the DVI. These studies focused on two primary goals:

- Determine the DVI that would be integrated into the CICAS-V system for a pilot Field Operational Test (FOT, Phase 1, Subtask 3.4) and Objective Tests (Task 11)

- Provide the United States Department of Transportation Independent Evaluator (USDOT/IE) with data for use in the estimation of safety benefits

To this end, experimental scenarios were developed to attain a set of test conditions that simulate "representative" signal violation scenarios. Naive drivers were exposed to these scenarios while being aided by one of several DVI alternatives. In addition, an experimental condition without a CICAS-V alert (i.e., a baseline condition) was also examined. This report describes the effort to determine the characteristics of the DVI associated with the warning given to a driver predicted to violate the TCD for the CICAS-V prototype. The assessment approach and candidate DVIs selected for these studies were based on previous research and consensus of stakeholders within the CICAS-V project, and are summarized within Table ES-1.

Table ES-1 Final list of studies completed as part of CICAS-V Subtask 3.3.

Study #	DVI*	Time to Intersection (TTI, s)	Protocol for testing
1	Collision Avoidance Metrics Partnership (CAMP) Tone	2.24	Occlusion
2	CAMP Tone	2.44	Occlusion
3	CAMP Tone	2.44	Naturalistic distraction
4	Speech	2.44	Naturalistic distraction
5	CAMP Tone and Brake Pulse	2.44	Naturalistic distraction
6	Speech and Brake Pulse	2.44	Naturalistic distraction
7	Beep Tone and Brake Pulse with Panic Brake Assist (PBA)	2.24	Naturalistic distraction
8	Speech and Brake Pulse with PBA	2.24	Naturalistic distraction
9	Speech and Brake Pulse with PBA	2.04	Naturalistic distraction
10	Speech and Brake Pulse with PBA	1.84	Naturalistic distraction
11	Baseline Condition (No warning)	2.44**	Naturalistic distraction

*All of these studies featured a visual display that performed both advisory and warning functions (only the advisory function of this display was used in Study 11).

** The amber light change occurred at 2.44 s

In an effort to determine the best method to evaluate the DVIs, two protocols were developed that employed different methods to distract drivers' attention from the forward roadway. One protocol used visual occlusion, while the other protocol used a naturalistic distraction method. Both protocols for Subtask 3.3 were tailored to maximize the probability that drivers would not be attending to the forward roadway (and, consequently, the intersection signal) upon their first encounter with the intersection TCD violation warning. The naturalistic distraction protocol was determined to better serve the goals of this subtask, and was, therefore, used in the majority of the studies.

Most of the experimental groups used contained 18 participants, counterbalanced for age and gender. However, when it was apparent that the DVI being tested would not yield favorable results, some studies were stopped early in an effort to conserve resources (e.g., subjects) for later experimentation. Participants across three age groups were recruited for all experiments: younger drivers aged 20-30 years, middle-aged drivers aged 40-50 years, and older drivers aged 60-70 years. Altogether, data from 172 participants were used to support the conclusions provided in this report.

Participants drove a 2006 Cadillac STS on the Smart Road for several loops before being exposed to a surprise signal violation trial. The experimental vehicle was instrumented with a visual warning (in the form of a flashing red signal and stop sign icon), with loudspeakers to produce an auditory warning (either the CAMP Tone in Kiefer et al. (1999), a 'Stop Light' speech warning, or a Beep Tone), and with modifications to its braking system to allow for the generation of a single brake pulse (or vehicle jerk cue; pulse duration: 0.6 s, peak deceleration: 0.25 g reached between 0.25 and 0.35 s from pulse onset). Any subset of these warnings could be selected for concurrent presentation. The presence of Panic Brake Assist (PBA) was also tested in conjunction with these warning modalities. In certain studies, PBA could be activated based on the braking behavior of the participant. Unlike the vehicle jerk cue from the brake pulse warning, PBA would heighten the braking level once the participant initiated braking. The experimental vehicle was also outfitted with data acquisition equipment that coordinated the presentation of distractions, triggered the DVIs, and provided automated control of the traffic signal. The data acquisition equipment also collected video and driver performance data, all of which supported the analyses described in this report.

As previously stated, the primary goal of these experiments was to issue a recommendation for the DVI to be used for Subtask 3.4, a pilot test of the CICAS-V system. In support of this goal, Table ES- 2 shows a summary of the compliance results obtained for each of the 11 studies that were completed within Subtask 3.3 of CICAS-V. For the purposes of these studies, compliance occurred if the driver fully stopped the vehicle prior to entering the area of the intersection where cross-traffic could occur (i.e., the intersection collision zone).

Table ES- 2 Summary of results for CICAS-V Subtask 3.3.

Note: Studies in bold investigated the warning recommended based on the results presented in this report.

Study	DVI*	TTI (s)	Protocol	Number of drivers who complied	Number of drivers who did not comply	Compliant drivers who activated PBA
1	CAMP Tone	2.24	Occlusion	9 (50%)	9 (50%)	N.A.
2	CAMP Tone	2.44	Occlusion	13 (72%)	5 (28%)	N.A.
3	CAMP Tone	2.44	Naturalistic distraction	7 (39%)	11 (61%)	N.A.
4	Speech	2.44	Naturalistic distraction	7 (39%)	11 (61%)	N.A.
5	CAMP Tone with Brake Pulse	2.44	Naturalistic distraction	14 (78%)	4 (22%)	N.A.
6	**Speech with Brake Pulse**	**2.44**	**Naturalistic distraction**	**17 (94%)**	**1 (6%)**	N.A.
7	Beep Tone with Brake Pulse and PBA	2.24	Naturalistic distraction	5 (50%)	5 (50%)	0
8	**Speech with Brake Pulse and PBA**	**2.24**	**Naturalistic distraction**	**16 (89%)**	**2 (11%)**	**1**
9	**Speech with Brake Pulse and PBA**	**2.04**	**Naturalistic distraction**	**7 (78%)**	**2 (22%)**	**0**
10	**Speech with Brake Pulse and PBA**	**1.84**	**Naturalistic distraction**	**3 (33%)**	**6 (67%)**	**1**
11	Baseline Condition (No warning)	N.A.	Naturalistic distraction	1 (6%)	17 (94%)	N.A.

*All of these studies featured a visual display that performed both advisory and warning functions (only the advisory function of this display was used in Study 11).
N.A. – Not applicable

Note that studies 6, 8, 9, and 10 are shown in bold. These studies used the Visual icon + Speech (‘Stop Light’) + Brake Pulse warning. Driver behavior, performance, and compliance with the warnings suggest that this particular combination of DVIs has the highest probability of success amongst the warnings tested. Therefore, this warning combination of DVIs is recommended for use as the warning format for the CICAS-V Subtask 3.4 pilot test. This warning format, which contains elements from the visual, auditory, and haptic modalities, also performed relatively well across a number of relatively late presentation timings, which may have positive implications for the Subtask 3.2 algorithm development.

The results suggest a number of potential recommendations for the design and implementation of DVIs for intersection violation avoidance systems. These are:

- The brake pulse warning appears to play the primary, dominant role in the observed effectiveness of this warning format, and therefore should be strongly considered for inclusion as part of the DVI warning approach for intersection violation avoidance systems.

- The speech warning (which should accompany the brake pulse warning) appears to play a secondary role in the effectiveness of this warning format, and is preferred over a non-speech warning for inclusion as part of the DVI warning approach for this warning format. The speech warning provides specific information with respect to the context of the warning.

- A visual warning, which it could be argued has had limited utility as a primary warning modality in this case, should be provided as a tool for the driver to confirm the type of multi-modal warning that he/she just received. This visual warning was included in all the studies, with no observation of 'capture' effects.

- Amongst the warning formats tested, a Visual icon + Speech ('Stop Light') + Brake Pulse warning yielded the best TCD compliance results.

When combined with some of the warning modalities tested, PBA did not have any measurable effects on the outcome of the evaluations. No incompatibilities or issues were identified when PBA was active in combination with one or more other warnings tested in these studies. Instances of PBA activation in response to the different intersection violation warnings were rare under these experimental conditions. However, it should be stressed that the threat levels experienced by test participants in these test-track studies may not be representative of those experienced by drivers during real-world, intersection crash threat conditions (where there may be a higher incidence of PBA system activations). Furthermore, the results in no way support discounting PBA as ineffective in other driving situations where it may be activated.

The main goal of this series of studies was to inform the selection of a DVI for the CICAS-V system. In the process of accomplishing that goal, data were obtained that describe relative compliance levels and performance measures for these systems under a small sample of warning timings. While these compliance levels and performance measures (as a function of timing and warning) may inform the activation algorithm for CICAS-V, finalization of such algorithm should be based on data from real-world exposure to these systems. Input from Subtask 3.2 (which is examining naturalistic intersection approach data) could serve as an initial step in this algorithm development process. In particular, Subtask 3.2 will be able to provide guidance as to anticipated alert rates with various timing approaches, which can be used to help ensure the timing approach does not result in an unacceptable number of alerts perceived as "too early" or unnecessary.

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1 Introduction

The Cooperative Intersection Collision Avoidance Systems-Violation (CICAS-V) project aims to develop and field-test a comprehensive system to reduce the number and severity of crashes at intersections due to violations of traffic control devices (TCD; i.e., traffic lights and stop signs). These crashes account for thousands of injuries and fatalities in the United States every year (National Highway Traffic Safety Administration, 2006). The approach selected to reduce these crashes is to present a timely and salient in-vehicle warning to those drivers predicted to violate a TCD. The warning is intended to elicit a behavior from the driver to avoid a potential violation (and possible crash). Supporting the warning are several subsystems that exchange, process, and present the required information from both the vehicle and the intersection.

The means through which the warning information is presented to the potential violator, the Driver-Vehicle Interface (DVI), is one of these CICAS-V subsystems. The importance of this particular subsystem is based on its function: prompting the driver to take the appropriate violation avoidance maneuver. For this reason, a series of Human Factors (HF) test track studies were planned within Subtask 3.3 of the CICAS-V project for the exploration of the DVI. These studies focused on two primary goals:

- Determine the DVI that would be integrated into the CICAS-V system for a pilot Field Operational Test (FOT, Phase 1, Subtask 3.4) and Objective Tests (Task 11)

- Provide the United States Department of Transportation Independent Evaluator (USDOT/IE) with data for use in the estimation of safety benefits

To this end, experimental scenarios were developed to attain a set of test conditions that simulated "representative" signal violation scenarios. Naive drivers were exposed to these scenarios while being aided by one of several DVI alternatives. Based on knowledge gaps remaining after past research efforts, these test scenarios were designed to address the following research questions:

- Are there differences in the outcome of experiments employing occlusion versus naturalistic distraction techniques that would make either more useful for evaluation of the different DVIs?

- Within the auditory modality, how does the effectiveness of speech warnings compare to non-speech warnings?

- Is scenario outcome improved by the addition of a brake pulse warning?

- Does the availability of Panic Brake Assist (PBA) functionality improve the scenario outcomes?

- Within the context of the experimental scenario, what is the effectiveness of each different DVI warning relative to when a warning was not presented?

Although interesting data were obtained during this research addressing signal violation alert timing, this timing issue was a secondary goal of this investigation. The range of alert timings examined in the current research (as they coupled with the examined DVI approaches) was initially based upon previous research and then was later modified based on the scenario outcomes as the studies progressed. It should be noted that the current research did not directly examine potential false alarm (annoyance) issues associated with the alert timings examined. The alert rate and false alarm issue will be addressed via CICAS-V Subtask 3.2 efforts.

This report describes the effort to select a DVI that can be used to warn a driver that is predicted to violate a TCD. The approach and candidate DVIs selected for these experiments were based on previous research and consensus of stakeholders within the CICAS-V project.

1.1 Description of Past Research

The magnitude and prevalence of intersection crashes have prompted a variety of research efforts in recent years. Within the context of crashes resulting from intersection TCD violations, most of these efforts have examined the effect of infrastructure-based systems in mitigating this problem. This limitation has mainly been due to constraints in technology, especially that which allows the vehicle and intersection to communicate and share information. However, new wireless communications technologies (e.g., Dedicated Short Range Communications - DSRC) have bridged some of these gaps and prompted research into vehicle-based countermeasures for addressing the intersection crash problem.

The most comprehensive examination of vehicle-based intersection TCD violation collision avoidance systems to date was the Intersection Collision Avoidance-Violation (ICAV) project (Lee et al., 2005). This effort examined auditory, visual, and haptic (in the form of brake pulses and soft braking) DVIs in the context of a surprise scenario presented to naive drivers, using a visual occlusion approach. Some of the key findings from the ICAV study with respect to an intersection TCD violation scenario include:

- The effectiveness of a particular DVI is dependent upon its timing; that is, the optimal warning presentation timing for one DVI is not necessarily the optimal timing for another DVI.

- Visual warnings should be accompanied by warnings in other modalities and, in the intersection TCD violation context, mainly function as confirmation of the warning meaning.

- Speech-based ("Red Light") auditory warnings may elicit faster and more effective driver responses than non-speech (context-free) tones.

- Brake pulses and automated soft braking appear to be effective warning methods in the intersection TCD violation context.

- Nuisance alarms are a key consideration in defining the warning type and timing to be used in these systems.

The ICAV project results were complemented by the Intersection Decision Support (IDS) project (Neale et al., 2006), which examined a wide range of infrastructure-based countermeasures in the context of similar intersection TCD violation scenarios. The IDS effort allowed for further development and refinement of the experimental protocols used in ICAV. Lessons from both of these projects provide a strong foundation of knowledge for the studies conducted as part of CICAS-V Subtask 3.3, as described in this report. The current investigation builds upon these two efforts in two distinct ways. First, it introduces a naturalistic testing approach that will aid in the estimation of safety benefits from the countermeasures tested. Second, the warnings that are considered are the result of government and industry consensus. As such, it is likely that the final systems implemented (assuming a positive result is achieved) will be based on the general characteristics of these warnings.

The literature examined to determine the collection of DVIs tested as part of this effort was not limited to these two projects. The types of warnings tested in this investigation have been examined, often with encouraging results, in other crash contexts. The literature examined described these previous tests and presented guidelines for the design of haptic, auditory, and visual warning systems in automotive applications (e.g., Campbell, 2004; Kiefer et al., 1999; Lee, McGehee, Brown, & Nakamoto, 2007; Lloyd, Wilson, Nowak, & Bittner, 1999; Noyes, Hellier, & Edworthy, 2006). The results of these efforts, along with the project team's experience and the opinions of automotive manufacturers and the USDOT, enabled developing multi-modality approaches that were production-representative and technologically-feasible.

1.2 Overview of CICAS-V Studies

The original proposal for CICAS-V Subtask 3.3 described five studies designed to provide answers to the previously stated research questions. However, as results for initial tests became available, it was evident that modifications to this experimental scheme would be needed. CICAS-V stakeholders were involved in these modifications, which resulted in an increase in the number of studies (from 5 to 11) and the re-specification of some study characteristics (see Table 1).

Table 1 Final list of studies completed as part of CICAS-V Subtask 3.3.

Study #	DVI*	Time to Intersection (TTI, s)	Protocol for testing
1	Collision Avoidance Metrics Partnership (CAMP) Tone	2.24	Occlusion
2	CAMP Tone	2.44	Occlusion
3	CAMP Tone	2.44	Naturalistic distraction
4	Speech	2.44	Naturalistic distraction
5	CAMP Tone and Brake Pulse	2.44	Naturalistic distraction
6	Speech and Brake Pulse	2.44	Naturalistic distraction
7	Beep Tone and Brake Pulse with PBA	2.24	Naturalistic distraction
8	Speech and Brake Pulse with PBA	2.24	Naturalistic distraction
9	Speech and Brake Pulse with PBA	2.04	Naturalistic distraction
10	Speech and Brake Pulse with PBA	1.84	Naturalistic distraction
11	Baseline Condition (No warning)	2.44**	Naturalistic distraction

*All of these studies featured a visual display that performed both advisory and warning functions (only the advisory function of this display was used in Study 11).
** The amber light change occurred at 2.44 s

There are three assumptions implicit in the results and discussion contained in this report. First, it is expected that the surprise signal violation scenarios used in the experiments provide DVI effectiveness estimates that may approximate those that may be obtained in the real world. Furthermore, the assumption is made here that the relationship between experimental and real-world environments when comparing DVIs is ordinal, which is deemed sufficient to support the DVI selection process for the FOT. Second, it was assumed that DVI rankings obtained for signalized intersection scenarios would be applicable to stop sign scenarios (stop signs were not tested as part of the experiments described in this report). This assumption was supported by the findings of the ICAV and IDS studies, which showed equivalencies in driver stopping behaviors for surprise traffic signal and stop sign scenarios. Third, all studies used nominal intersection approach speeds of 35 mph (56.3 km/h) and one or more TTIs (time-to-intersection) at which warnings were presented (the warning presentation algorithm was based on TTI). The performance measures discussed herein are expected to be applicable to speeds that are close to the 35 mph nominal speed used, and might be expected to change at higher and lower approach speeds. These performance measures were collected in these studies as a means of evaluating various DVIs, not to characterize typical driver behavior across a range of intersection types. However, the DVI rankings obtained, which were the primary focus of the study, are expected to remain largely consistent across intersection approach speeds.

Finally, it is important to stress that the key goal of this subtask is to support a joint USDOT/Vehicle Safety Communications Consortium (VSC2) decision on the DVIs to be used in accomplishing Subtask 3.4 (Pilot FOT). The information provided in this report is tailored to support that decision-making process.

2 Method

In an effort to determine the best method to evaluate the DVIs, two protocols were developed that employed different methods to distract drivers' attention from the forward roadway. One protocol used visual occlusion, while the other protocol used a naturalistic distraction method. Both protocols for Subtask 3.3 were tailored to maximize the probability that drivers would not be looking out toward the forward roadway (and, consequently, the intersection signal) upon their first encounter with an intersection TCD violation warning. Note that traffic lights were the only traffic control device tested in the experiments described in this report. Therefore, the effectiveness of the various DVIs was not directly tested on stop signs. As described in the protocol sections below, this approach was intended to simulate a worst-case scenario in which a driver may experience these warnings. These protocols, along with the performance measures collected, participant characteristics, instrumentation, and analysis approach, are described in this section.

2.1 Participants

Participants were recruited through the newspaper, broadcast media, word of mouth, and the Virginia Tech Transportation Institute's (VTTI) database of people who had expressed an interest in participating in studies. On initial contact (usually over the phone), individuals were screened to ensure their eligibility for the study (Appendix A). Eligibility criteria included restrictions to exclude individuals who had previously participated in a surprise-scenario experiment at VTTI (which may have predisposed them to expect a surprise scenario), health conditions or medication intake that may interfere with their ability to operate a motor vehicle, and no more than two moving violations nor any at-fault accidents within the previous three years (for liability and safety reasons). Participants also had to possess a valid driver's license.

As is shown in detail in Table 2, most experimental groups contained 18 participants, counterbalanced for age and gender. However, when it was apparent that the DVI being tested would not yield favorable results, the study was stopped early in an effort to conserve resources. Participants across three age groups were recruited for all experiments: younger drivers aged 20-30 years, middle-aged drivers aged 40-50 years, and older drivers aged 60-70 years. Altogether, 244 participants were run for the studies in Subtask 3.3, of which 172 provided valid data points (resulting in an invalid response rate of 29.5%). Invalid data points were caused by different factors, depending on the protocol used. For the occlusion protocol, invalid data points were caused by drivers removing their foot from the gas pedal as they approached the intersection and/or as the goggles were occluded. For the naturalistic protocol, invalid data points resulted from drivers looking directly at the forward roadway at the time of warning or yellow light onset.

Table 2 Number and characteristics of participants per conditions tested.

Condition Tested	Participants with Usable Data	Age/Gender Distribution	Participants with Unusable Data	Total Participants
CAMP Tone, 2.24 s TTI, occlusion protocol	18	3 OM 3 OF 3 MM 3 MF 3 YM 3 YF	3	21 (21 total)
CAMP Tone, 2.44 s TTI, occlusion protocol	18	3 OM 3 OF 3 MM 3 MF 3 YM 3 YF	10	28 (49 total)
CAMP Tone, 2.44 s TTI, naturalistic distraction protocol	18	3 OM 3 OF 3 MM 3 MF 3 YM 3 YF	13	31 (80 total)
Speech warning, 2.44 s TTI, naturalistic distraction protocol	18	3 OM 3 OF 3 MM 3 MF 3 YM 3 YF	8	26 (106 total)
CAMP Tone, Brake Pulse, 2.44 s TTI, naturalistic distraction protocol	18	3 OM 3 OF 3 MM 3 MF 3 YM 3 YF	4	22 (128 total)
Speech warning, Brake Pulse, 2.44 s TTI, naturalistic distraction protocol	18	3 OM 3 OF 3 MM 3 MF 3 YM 3 YF	5	23 (151 total)
Beep Tone, Brake Pulse, PBA, 2.24 s TTI, naturalistic distraction protocol	10	2 OM 1 OF 3 MM 2 MF 1 YM 1 YF	2	12 (163 total)
Speech warning, Brake Pulse, PBA, 2.24 s TTI, naturalistic distraction protocol	18	3 OM 3 OF 3 MM 3 MF 3 YM 3 YF	8	26 (189 total)
Speech warning, Brake Pulse, PBA, 2.04 s TTI, naturalistic distraction protocol	9	1 OM 2 OF 1 MM 2 MF 2 YM 1 YF	5	14 (203 total)
Speech warning, Brake Pulse, PBA, 1.84 s TTI, naturalistic distraction protocol	9	1 OM 2 OF 1 MM 0 MF 2 YM 3 YF	5	14 (217 total)
Baseline Condition (No warning)	18	3 OM 3 OF 3 MM 3 MF 3 YM 3 YF	9	27 (244 total)
Total	172	28 OM 29 OF 29 MM 28 MF 29 YM 29 YF	72 (29.5% unusable)	244

Note: OM=older male, OF=older female, MM=middle-age male, MF= middle-age female, YM=young male, YF=young female

2.2 Testing Facility

The experiments were completed on the Virginia Smart Road, a 2.2 mile controlled-access research facility. The designated path driven by participants during the Subtask 3.3 studies spanned the upper and third turnaround areas on the two lane test-bed. The path included a pass through one signalized intersection (Figure 1). At this intersection, the Smart Road intersects with an additional access road, which then connects to a road that runs parallel to the upper portion of the Smart Road.

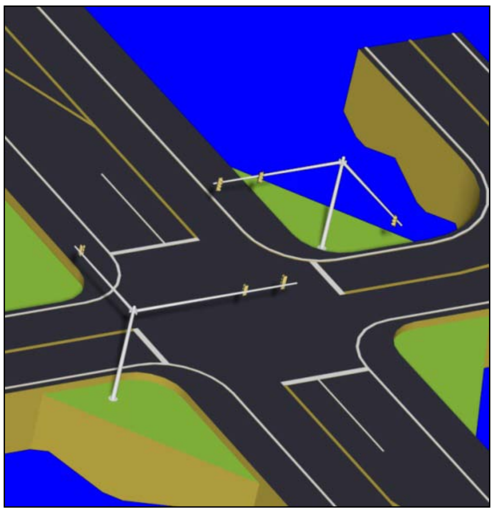

Figure 1 Smart Road intersection diagram.

2.3 Occlusion Protocol

The original protocol, summarized in this section, involved the activation of occlusion goggles (Figure 2) for 2 s at pre-determined intervals as the participant was driving on the Smart Road. The participant experienced 10 trials, each trial representing one length of the Smart Road. During several trials, cross traffic was staged at the intersection, although never at the same time as an occlusion. For the surprise presentation of the DVI, occurring on the last trial, a confederate vehicle followed behind the participant vehicle at a safe distance. Upon approaching the intersection, the participant's vision was occluded and the signal cycled from green to yellow. The DVI (both auditory and visual) was then presented at the same time that the goggles cleared. At this point, the participant needed to decide whether to stop or cross through the intersection.

Figure 2 Occlusion goggles in closed state.

The trials preceding the surprise trials were scripted to build the expectation of possible cross traffic at the intersection, in hopes of creating a more urgent response to the yellow light than may otherwise have been the case. The confederate vehicle following behind the participant added another layer of complexity and realism to the intersection scenario. This protocol was successfully used in relative comparison of different DVIs and Driver-Infrastructure Interfaces (DIIs) during the ICAV and IDS studies (Lee et al., 2005; Neale et al., 2006). The surprise scenario was designed to represent a scenario in which the driver needed to make a split-second decision about the potential consequences of a rear-end collision (i.e., being struck by the following vehicle) versus the potential consequences of an intersection collision if cross-traffic was present (as they had experienced during earlier test runs). A system that showed promise in making a driver stop under these somewhat worst-case scenario conditions is fully expected to also be effective for less complex events. The remainder of this section provides a detailed description of the occlusion protocol.

Upon arriving at the Institute, participants were asked to read an informed consent form (Appendix B) which provided specific information about the study, including the procedures, risks involved, and measures for confidentiality. The participants were initially not told the true purpose of the study in order to gain information on how naive participants react to an intersection warning. The purpose stated in the form described the study as an evaluation of the effectiveness of occlusion goggles for studying driver distraction. After agreeing to the study and signing the informed consent, a health screening questionnaire (Appendix D) was administered to ensure that participants did not have any conditions that would impair their ability to safely operate the test vehicle. A Snellen vision test was conducted to ensure the participants' visual abilities were within Virginia-legal limits of 20/40 or better. In addition, a color vision test was conducted using the Ishihara Test for Color Blindness, though this test was not used for screening purposes. If it was found that participants were not in good health or if vision results fell outside the acceptable limits, they would be excused from the study and paid for their participation time.

Participants were then led to the vehicle where they were given time to make the necessary adjustments to the seat, mirrors, and climate control. They were then instructed to drive towards the Smart Road, where the study was conducted. Once on the Smart Road, participants were asked to stop for further instructions concerning the purpose of the study. Participants were initially told that the experiment concerned the use of occlusion goggles to simulate distracted driving. During the pre-drive vehicle orientation, different safety systems available in the experimental vehicle, including the CICAS-V system, were briefly mentioned (e.g., forward collision warning, backing aid). Participants were told to follow all the normal traffic rules and that maintenance vehicles would occasionally be entering and leaving the road at the crossing intersection. Unbeknownst to the participant, these maintenance vehicles were staged confederate vehicles driven by VTTI on-road crew personnel as part of the study. At this time, participants experienced the occlusion goggles while the car was still parked. They were told that the goggles would occlude (or close) their vision for 2 s at random intervals, during which time speed maintenance and lane position accuracy information would be recorded. They were asked to place the car in third gear (to aid in speed maintenance in graded road sections) and maintain 35 mph throughout the study. Throughout the experiment, the front seat experimenter (FSE) occluded the participant at predetermined landmarks. The on-board computer also triggered automatic occlusions on the third, fifth, and eighth intersection approaches, at approximately 7 s TTI (i.e., 7 s before crossing the intersection given the driver's current speed). Each 2-3 minute drive (trial) up or down the Smart Road contained four or five occlusions in total. On the first trial down the Smart Road, there was a "maintenance" vehicle (Principal Other Vehicle - POV) parked on a road parallel to the Smart Road. The POV driver appeared to be performing maintenance activities on the road. After the Subject Vehicle (SV) circled through the lower turn-around and approached the intersection for the second trial, the POV drove to the adjacent stop bar at the intersection. The signal, though triggered by the on-board computer in the SV, appeared to the participant to be triggered by the waiting POV. The participant then received a common yellow-red light sequence, during which the POV crossed and exited the road.

On the sixth intersection approach, the POV re-entered the road, crossing through the intersection towards the parallel road. Again, the light sequence was triggered by the on-board computer in the SV, though appearing to change because of the presence of the POV. When the SV continued to the lower turn-around during the seventh trial and was no longer in view of the POV, the POV inconspicuously exited the road. At the start of the SV's tenth intersection approach, a second confederate vehicle (Following Vehicle- FV) followed with approximately 1.5 to 2 s headway behind the SV up the road. As the participant reached the intersection, his/her vision was occluded. During the occlusion, the light cycled from green to the yellow phase. Once the participant's vision was un-occluded, the violation warning was initiated. Although participants might have believed that the maintenance vehicle was again entering or leaving the road, the confederate vehicle was not near the intersection at this time.

For this tenth intersection approach (the surprise scenario), two different sets of timings were used in separate experiments. For the first experiment, the occlusion was triggered at 4.4 s TTI, the yellow phase was triggered at 4.2 s TTI, and the participant's vision was un-occluded (i.e., opened) as they received the violation warning at 2.24 s TTI. For the second experiment, the occlusion was triggered at 4.6 s TTI, the yellow phase was triggered at 4.4 s TTI, and the participant's vision was un-occluded as they received the violation warning at 2.44 s TTI. After the surprise trial was complete and participants either stopped or crossed through the intersection, a brief questionnaire (Appendix F or G) was administered concerning the warning. Participants were then asked to read and sign a new informed consent form (Appendix E) that explained the true purpose of the study. The experiment was then concluded and participants returned to the VTTI main building for payment.

The experiment took approximately 45 minutes per participant and required a staff of three experimenters:

- A front seat experimenter to read scripts, start and monitor data collection, monitor speed, silently signal the confederate vehicle when to approach the intersection, and use the experimenter brake pedal if required

- A confederate vehicle driver to drive both confederate vehicles in an elaborate choreography involving precise timing and the ability to keep the confederate vehicle hidden as needed

- An in-building experimenter to screen and schedule participants, prepare paperwork, and enter questionnaire and demographic data into the database

Up to nine participants could be run per day, depending on weather and amount of daylight. The study was run only when the road was dry, since the experiment involved the potential for hard braking and risk of skidding on wet pavement.

Altogether, 45 participants were run using the occlusion protocol, of which 36 provided valid data points (resulting in an invalid response rate of 20%). Invalid data points were due to drivers who removed their foot from the gas pedal as they approached the intersection or as the goggles were occluded. Most of the dependent variables could not be calculated for these cases. This is more thoroughly discussed in the data analysis and reduction section.

2.4 Naturalistic Distraction Protocol

Nine out of the eleven groups of participants experienced a naturalistic distraction protocol. Rather than occlusions, this protocol used pre-recorded in-vehicle tasks to distract participants at pre-specified intervals as they were driving up and down the Smart Road. Tasks the participants were asked to complete included changing the radio station, changing tracks on a CD, changing properties of the heating, ventilation, and air conditioning (HVAC) system, and turning on the vehicle's hazard lights. Participants were given a brief in-vehicle tutorial of these systems prior to beginning the experiment. Similar to the occlusion protocol, the participant occasionally encountered cross traffic at the intersection, although never at the same time as an in-vehicle task.

For the surprise presentation of the DVI, a confederate vehicle followed the participant vehicle at a safe distance (as with the occlusion protocol) and a distracting task was performed as the participant approached the intersection. The DVI (auditory, visual, brake pulse, or some combination of these) was presented a set time after the participant was instructed to start the in-vehicle task. Once again, the trials preceding the surprise trials were scripted to build the expectation of possible cross traffic at the intersection, and the confederate vehicle following behind the participant added another layer of complexity and realism to the intersection scenario. As with the occlusion protocol, the surprise scenario was designed to represent a worst-case scenario in which the driver may not be willing to brake hard because of the following vehicle and the threat of a rear-end collision, while at the same time being cautious of a violation due to the potential for cross-traffic presence. The remainder of this section provides a detailed description of the naturalistic protocol.

The experimental protocol prior to driving on the test road was identical to that employed with the occlusion protocol, with the exception that the informed consent form (see Appendix C) indicated that the research was aimed at evaluating the effect of in-vehicle tasks on driving behavior. During the pre-drive vehicle orientation, different safety systems available in the experimental vehicle, including the CICAS-V system, were briefly mentioned (e.g., forward collision warning, backing aid). The availability of PBA (when it was active) was never mentioned. Once again, participants were told to follow all the normal traffic rules throughout the experiment and that maintenance vehicles would occasionally be entering and leaving the road at the intersection. Unbeknownst to the participant, these maintenance vehicles were staged confederate vehicles driven by VTTI on-road crew as part of the study. At this time, the participants were given a brief tutorial and demonstration of the in-vehicle systems they would be using to perform various tasks. These tasks included changing a radio station, manipulating the HVAC system, and turning the hazard lights on. Participants were also provided with the opportunity to practice one of these distraction task sequences while parked. They were told that information about their speed maintenance and lane position accuracy would be recorded, including during the execution of any in-vehicle tasks. They were asked to place the car in third gear and maintain 35 mph throughout the study.

During the experiment, at predetermined landmarks on the Smart Road, the FSE triggered a pre-recorded message, which instructed the participant to complete a certain task. Each message ended with the word “Now.” The protocol was updated after a few participants to include the instruction for participants to keep both hands on the steering wheel prior to hearing the word “Now.” Upon hearing the word “Now,” participants were to complete the task as quickly and as accurately as possible. Once the participant finished the task, they were to say “Done,” as an indication to the FSE that they had completed the task. The procedure of keeping both hands on the steering wheel prior to hearing the word “Now” helped to minimize the frequency of early glances to the HVAC system or quick return glances to the forward roadway. The participant had the option to quit or skip any task, or to ask the FSE to play the instructions again. Additionally, for safety reasons, the FSE could instruct the participant to stop or skip any task.

The experimental script for the naturalistic study was nearly identical to that of the occlusion study in that the stoplight changes on the second and sixth trials remained intact and the positioning of the POV and FV remained the same. Every effort was made to ensure that the timings of all occlusions triggered by the FSE and the on-board computer in the previous experiment roughly correlated with the timings of manually triggered messages in the naturalistic protocol. On the tenth intersection approach (the surprise trial), a recorded set of instructions was automatically triggered by the on-board computer at 24 s TTI. A separate audio file stating “Now” was triggered at 4 s TTI. This consistent timing of events helped to maximize the probability that participants would not be glancing at the forward roadway as the light turned yellow, before the warning was presented. The light turned yellow about 0.1 s before the warning onset, which occurred at 2.44, 2.24, 2.04, or 1.84 s TTI (depending on the study).

Due to the increased time taken to briefly educate participants on the in-vehicle systems they would be using and the procedure to complete the in-vehicle tasks, the naturalistic protocol took slightly longer to complete than the occlusion protocol. Each participant took approximately 75 minutes to complete the experiment, and up to six participants could be run per day, depending on weather and amount of daylight.

Altogether, 195 participants were run using the naturalistic protocol, of which 136 provided valid data points (resulting in an invalid response rate of 30%). Invalid data points were due to drivers who looked directly at the forward roadway at time of warning or yellow light onset. This exclusion criterion is discussed in the data analysis and reduction section.

2.5 Additional Trials

In order to obtain additional information on braking behavior and PBA activation thresholds, several participants in Studies 7 through 10 completed up to two additional trials using different PBA activation settings following the surprise trial. After the surprise trial questionnaires had been administered, and with the participant's consent, the participant completed one or two additional approaches to the intersection. The availability of PBA, or the fact that PBA activation was the main measure of interest from the additional trials, was not discussed during the orientation for these trials. As the SV approached the stop bar, the CAMP Tone warning (as used and described in Kiefer et al., 1999) was presented at 2.0 s TTI. Upon hearing the warning tone, the participant was asked to apply the vehicle brakes as if trying to avoid an intersection crash. The FSE instructed the participant on this procedure after the surprise trial and prior to asking for their consent to participate in these additional trials.

Altogether, 53 participants were run through at least one additional trial, and 88 trials were collected.

2.6 Instrumentation

Details concerning the instrumentation of the equipment used in the Subtask 3.3 studies are discussed in this section. The vehicles, on-board equipment, and roadside equipment are described and illustrated.

2.6.1 Vehicles

Two 2006 Cadillac STSs were equipped as the SV in this set of studies (one is pictured in Figure 3). The vehicles were outfitted with anti-lock brakes, dual front and side airbags, and traction control. To minimize risk for participants and experimenters, an emergency passenger-side brake was mounted such that the experimenter (seated in the front passenger seat) could take control of braking the vehicle if needed.

Figure 3 Experimental vehicle, 2006 Cadillac STS.

The confederate vehicles used for these studies included a 1999 Ford Contour, posing as cross traffic, and a 2000 Ford Explorer as the following vehicle.

2.6.2 On-Board Equipment (OBE)

The subject vehicles were equipped with visual, auditory, and haptic warning displays. The visual display consisted of a non-reprogrammable single-icon light-emitting diode (LED) screen located in a high head-down (top of dashboard) position on the vehicle centerline near the center speaker and oriented towards the driver (Figure 4). Detailed specifications for the display follow:

- Size: 0.68° X 0.68° visual angle
- Independently addressable high-intensity blue and red LEDs
- Shaded by hooded enclosure
- Low-reflection diffusion glass panel

As implemented in the vehicle, the visual icon was 11.6 mm (0.46 inches) high and 11.6 mm (0.46 inches) wide. Including the additional 1 mm background on all sides, the total icon size was 13.6 mm (0.54 inches) high and 13.6 mm (0.54 inches) wide.

Figure 4 High-heads-down visual display LED screen.

In addition, the vehicles had an integrated loudspeaker (located in the dashboard above the instrument cluster) used to present the auditory warnings independently of the vehicle's sound system. The sound was directed toward the driver from the location of interest (i.e., forward windshield). The loudspeaker was powered by a 3.1 W Mono Class AB amplifier attached to the experimenter laptop.

2.6.2.1 Visual Icon

The visual icon consisted of an outlined traffic signal and stop sign (Figure 5), which was developed via open-ended icon comprehension and rank order testing (Campbell, Kludt, & Kiefer, 2007). At a pre-established TTI, the figures would become blue and steady. On warning activation, the figures would become red, and flash at 4 Hz with a 50% duty cycle (125 ms on, 125 ms off).

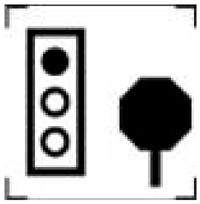

Figure 5 Visual icon of traffic signal and stop sign.

2.6.2.2 Auditory Warnings

Three different auditory warnings were tested. The initial warning tested in studies 1, 2, 3, and 5 was the CAMP Tone (Kiefer et al., 1999). The CAMP Tone was presented at 74.6 dBA, measured at the location of the driver's head. Studies 4, 6, 8, 9, and 10 tested a speech warning consisting of a female voice stating the word "Stop Light," presented at 72.6 dBA, measured at the location of the driver's head. Study 7 tested a Beep Tone, which consisted of three high-pitched beeps. The Beep Tone was presented at 75.0 dBA, measured at the location of the driver's head.

2.6.2.3 Haptic Brake Pulse Warning

Several studies tested the effectiveness of a single brake pulse, presented in conjunction with the visual icon and an auditory warning. A brake pulse warning was employed with positive results in the ICAV study (Lee et al., 2005). The Brake Pulse was triggered immediately before the onset of the visual and auditory warnings, such that deceleration would reach ~0.10 g and the participant would experience the brake pulse warning at approximately the same time as the visual and auditory warning onset, which occurred at the nominal TTI for the warning condition (e.g. 2.44 sec). Had the brake pulse warning been triggered at the same TTI as the visual and auditory warning, the participant would have experienced a delay between the visual/auditory warnings and the brake pulse warning. Total pulse duration was approximately 0.6 s. Deceleration produced by the pulse peaked around 0.25 g, and was reached between 0.25 and 0.35 s after the onset of the visual and auditory warnings (Figure 6). The brake pulse command was not issued if deceleration over 0.1 g was detected by the on-board processing unit.

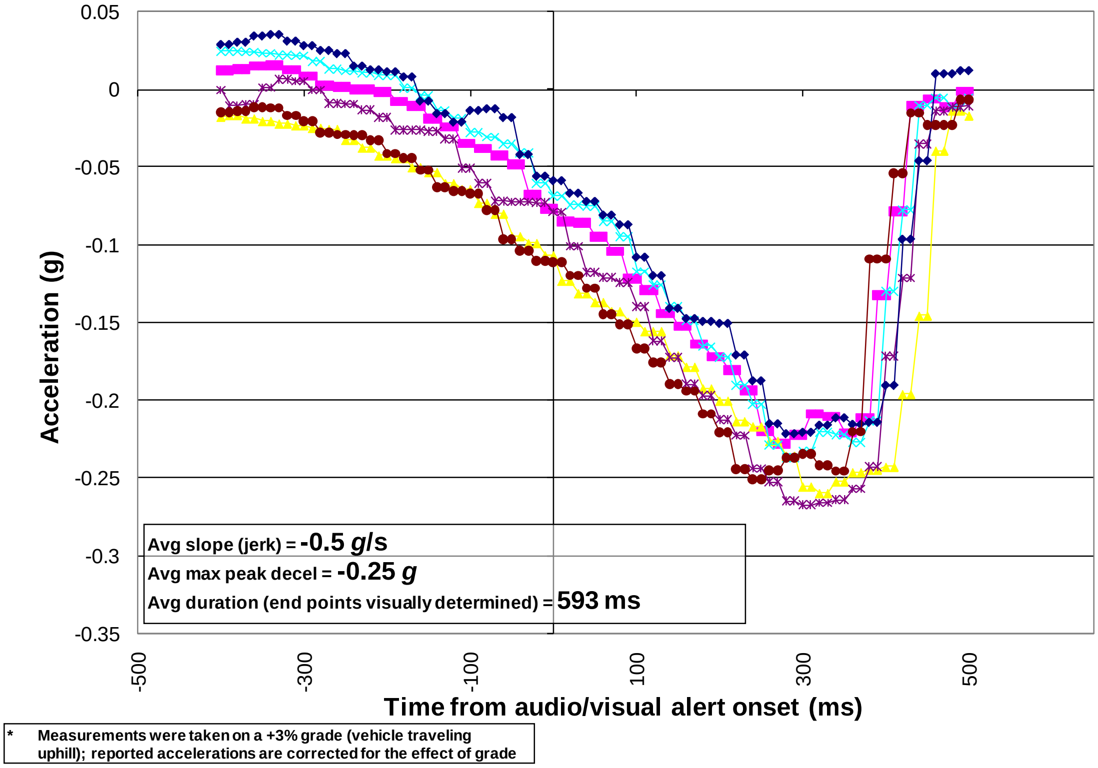

Figure 6 Actual Brake Pulse profiles for five different participants.

Note: Summary pulse descriptors are provided in the inset box.

The brake pulse warning system permitted computer-controlled vehicle deceleration on demand. This system was constructed entirely within the brake controller using the existing Anti-Lock Braking System (ABS) pump. The system was capable of matching a specified deceleration or pressure profile while supporting exceptions in the warning algorithm (e.g., the brake pulse command not being issued if deceleration over 0.1 g was detected).

2.6.2.4 Experimenter Interface

The experimenter interface (Figure 7) was presented on an in-vehicle screen and controlled through a standard keyboard with a trackball. The interface allowed the experimenter to control any aspect of the intersection approach (e.g., distance at which to change the light, visual occlusion, type of warning that was presented) and the warning parameters. It also provided the experimenter with information on the intersection status and vehicle kinematics.

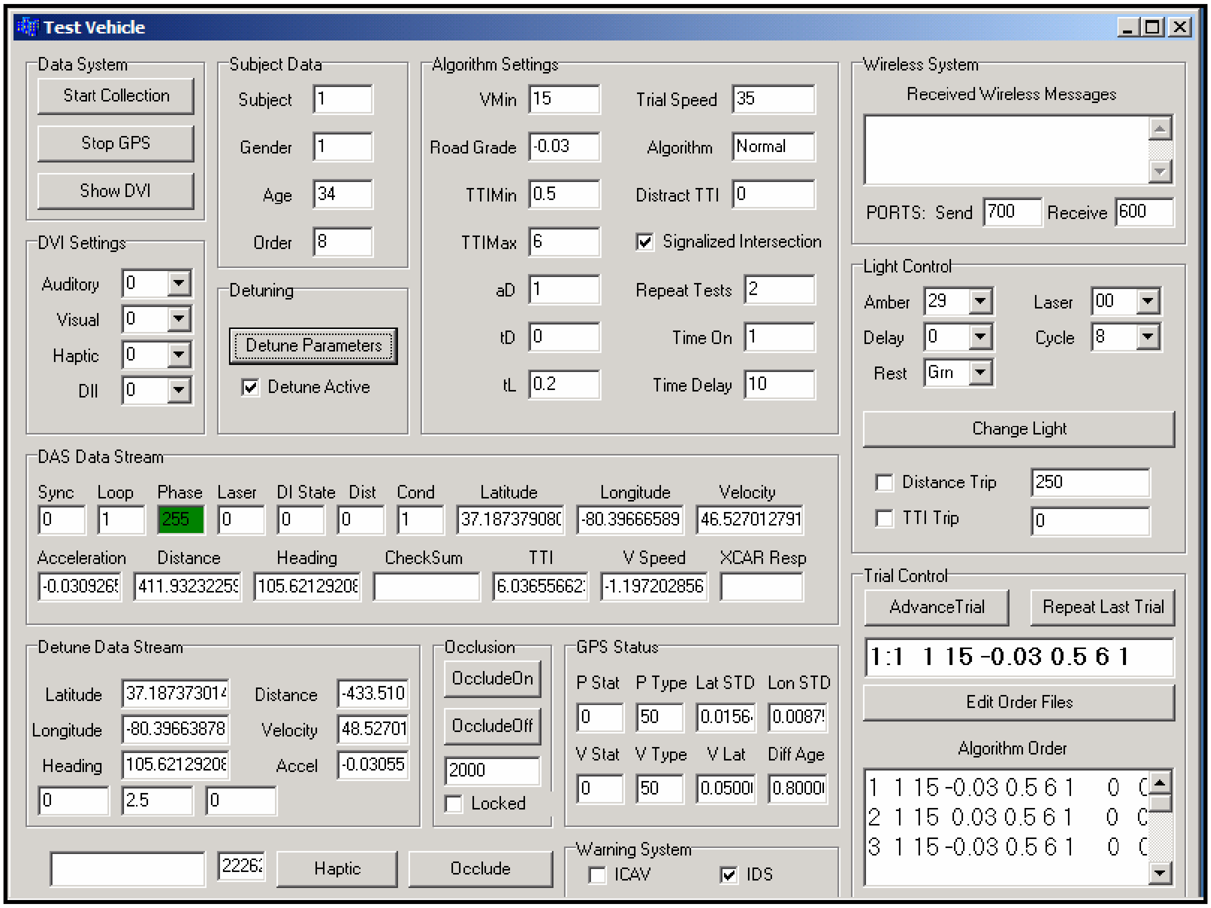

Figure 7 Experimenter interface.

A trial order file was created for each set of experimental conditions and loaded into the interface at the beginning of each test. The experimenter manually advanced to the next trial at each test bed turnaround. Once in wireless range, the interface would automatically transmit trial information to the infrastructure as appropriate. In case of a system malfunction, the experimenter did maintain override control on occlusions and signal phase changes. Finally, the interface provided information regarding the loaded algorithm timing and real-time data from the sensing equipment. This allowed the experimenter to verify data collection accuracy and trial characteristics.

2.6.2.5 Data Acquisition System (DAS)

The Data Acquisition System (DAS) contained within the vehicle was custom-built by VTTI. The DAS was located inside the trunk and out of the participant's view (Figure 8). Attached to the system bus was a series of custom-designed circuit boards that controlled the various functions of the acquisition device. This system included video grabbers, accelerometer/gyroscope, a vehicle network sniffer (to pull variables from vehicle network), and power management boards. The alignment and time stamping data retrieved from these boards was choreographed by a customized VTTI proprietary software package, which collected non-video data at 100 Hz. Hardware was contained in a custom-mounting case designed to affix instrumentation in orientations necessary for accurate measurement and durability.

Figure 8 Data Acquisition System, installed in the vehicle trunk, underneath the rear shelf.

The video grabbers installed in the DAS converted the National Television System Committee (NTSC) signal from the cameras into Motion Picture Experts Group 4 (MPEG-4) compressed video, which was recorded to the hard drive in real time. Small cameras (1" square by ¼" deep, seeing through a 1/32" aperture) were mounted inconspicuously within the vehicle and collected the video data. For the current study, four cameras were installed. The camera views included:

1. Driver's face – to allow for the recording of eye glances
2. Forward view – to provide a visual reference of the current vehicle location
3. Driver-side B-pillar camera – to capture the steering wheel, instrument panel, and the driver's hands from the rear
4. Driver's feet – to show accelerator and brake activation (due to the low-light conditions, this camera also required an infra-red light source).

Video data were recorded on the DAS computer at 30 Hz. For analysis, video data were multiplexed in a four-quadrant, split-screen display (Figure 9).

Figure 9 Four-quadrant, split-screen video data display.

Wireless communications needs were addressed via a second computer connected to the distributed DAS network. In addition to coordinating wireless communications, this computer provided the experimenter interface, computed the algorithm, and supplied algorithm data to the DAS for synchronization with the video and driver performance data.

The distributed DAS network consisted of three primary components: 1) three-axis accelerometer and network box; 2) Differential Global Positioning System (DGPS); and 3) DSRC (wireless communications). Each component of the DAS network provided information to the DAS for recording. The accelerometer box was located near the vehicle pitch-center to minimize pitch-induced acceleration noise. The vehicle network was used to collect information on pedal and steering wheel positions. The DGPS subsystem provided vehicle position and speed. The DSRC equipment provided signal phase and timing information to the DAS and sent control commands to the intersection.

The DAS was independent of the CICAS-V test-bed system but remained linked as necessary to record and time-stamp key events (e.g., warning onsets). The entire DAS was unobtrusive and did not limit visibility or create a distraction.

2.6.2.6 Vehicle Sensors

A Novatel OEM4-G2L DGPS unit was used to provide position and speed for data collection and algorithm computations. This unit received differential corrections from a base unit with an antenna on the roof of the VTTI building. The corrections were transmitted via a Pacific Crest RFM96W radio unit operating at 35 Watts. Specifications for this DGPS system (Figure 10) were as follows:

- Update rate: 20 Hz maximum
- Latency: 0.05 s
- Reliability: 99%
- Accuracy:
    - Longitudinal: Position – 1 cm, Speed – 0.03 m/s
    - Lateral: Position – 1 cm, Speed – 0.03m/s
    - Heading: Not available
- Power requirement: 2 W

Figure 10 Novatel DGPS unit and Pacific Crest radio unit.

Since the system was mounted on the vehicle, it required an internal vehicle map to allow the determination of position relative to the intersection. Stop bar locations were used to fulfill this role.

A Crossbow VG400 was used to provide acceleration data. Specifications for this device follow:

- Update rate: 70 Hz
- Latency: 0.01 s
- Reliability: 99%
- Accuracy:
  - Longitudinal: 0.6 mg @ 70 Hz
  - Lateral: 0.6 mg @ 70 Hz
- Power requirement: 9V @ <250 mA

2.6.3 Roadside Equipment (RSE)

2.6.3.1 Controller

For research purposes, the signal controller needed capabilities such as on-demand rapid signal timing and phase changes as well as high-speed wireless communications. A 700 MHz PC104 computer was used to support this level of performance, unattainable by traditional signal controllers. This computer managed the signal configuration and wireless data transfer tasks. The PC104 received commands over the wireless communication system with regard to signal change sequence, timing, and phase change initiation. The computer physically controlled the signal state through a 110 V interface built in-house at VTTI (Figure 11). Commands sent by the computer were received by a microcontroller on the interface which managed a bank of solid state relays, each of which was attached to an individual signal head.

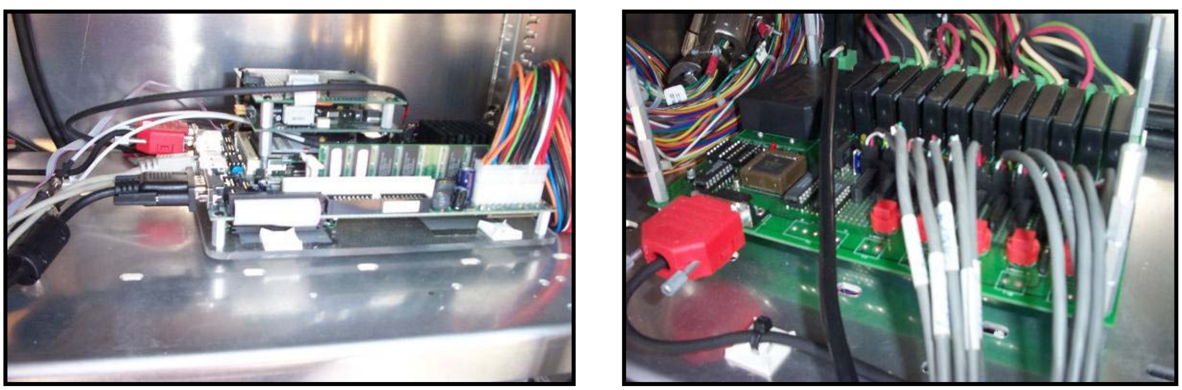

Figure 11 Single-board signal management computer and signal control interface.

2.6.4 Wireless Communications

Off-the-shelf DSRC was not available at the time the test bed was under development. Therefore, the in-vehicle communications laptop was linked to a Denso WAVE Radio to interface with a similar DSRC radio at the intersection. The radios operated in the 5.8-GHz frequency band with two sets of external antennas that were mounted underneath the front vehicle bumper and on top of the controller cabinet (Figure 12). This setup allowed for two-way communication of digital information packets between the intersection controller and the vehicle when it was within approximately 305 m (1000 ft) of the intersection. The communications link used User Datagram Protocols (UDP--one of the two standard transport protocols for the Internet Protocol traffic) to receive signal information from the infrastructure controller. VTTI developed platform-specific software to address all communication packet needs.

Figure 12 Wireless communications antennas (surrounded by circle).

Note: GPS antenna is also visible towards the left of the wireless antennas.

Time-synced signal phase and timing was continuously transmitted from the infrastructure to the vehicle while it was in range. Information transmitted from the vehicle to the infrastructure included the desired signal setup for the current experimental trial (including signal change characteristics and the onset of phase change).

2.7 Independent Variables

Within a study, participant Age and Gender were treated as blocking factors, and their effects were analyzed under cases where there was sufficient statistical power. When outcomes were compared across studies, the primary independent variable was DVI Type. In cases where multiple timings were tested for the same DVI, Warning Timing (i.e., TTI) was also used as a factor.

2.8 Dependent Variables

A substantial number of dependent variables were collected across the studies. The majority of these variables were objective measures, but some subjective data were also collected through questionnaires. The following dependent variables were selected or derived from the raw data available from the vehicle DAS:

- Stopping Zone: Four different zones were defined, depending on the vehicle's distance with respect to the stop bar, measured from the front of the vehicle. These zones are specific to the Smart Road intersection and its approach configurations (although they could be defined for any intersection). The zones were defined below and illustrated in Figure 13.

    - Collision Zone – Vehicles that stopped at or more than 9.1 m (30.0 ft) beyond the stop bar. For the Smart Road intersection, this distance represented the location at which crossing traffic could first be encountered.

    - Intrusion Zone – Vehicles that stopped between 4.6 m (15.0 ft) and 9.1 m (30.0 ft) beyond the stop bar. (The test bed vehicles measured close to 4.6 m in length, so at this distance the rear end of the vehicle would be completely over the stop bar.)

    - Violation Zone – Vehicles that stopped within 4.6 m (15.0 ft) beyond the stop bar.

    - No Violation Zone – Vehicles that stopped at or before the stop bar.

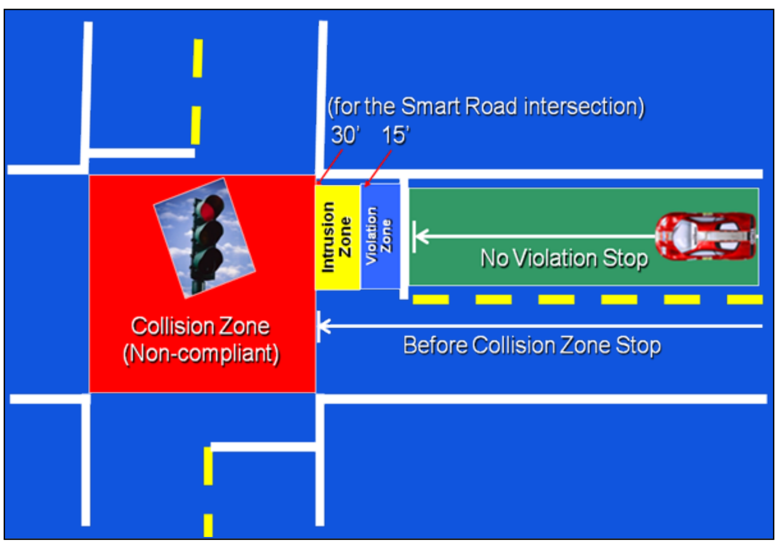

Figure 13 Illustration of the four stopping zones on the Smart Road.

- Compliance: Whether the trial resulted in a participant stopping prior to entering the collision zone (which was defined as compliance) or not (either because the vehicle stopped in the collision zone or did not stop at all). Areas prior to the collision zone included the 'No Violation', 'Violation', and 'Intrusion' zones.

- Distance Before the Stop Bar (ft): Vehicle distance to intersection once its speed was less than 0.2 ft/s (0.4 mph). The threshold was selected to eliminate incorrect triggers due to noise in the speed data.

- Peak Deceleration (g): Raw (i.e., non-smoothed) maximum driver-induced deceleration during the intersection stop.

- Constant Deceleration (g): Required constant deceleration to yield the observed stopping distance based on the observed brake onset distance, as calculated in Equation 1:

$$a = \frac{V^2}{2 \times g \times (D_i - D_f)} \qquad \textbf{(Eq. 1)}$$

Where:
a = constant deceleration as a proportion of g
V = vehicle speed at the point when the driver initiated braking (m/s)
g = gravitational acceleration constant (9.81 m/s^2)
D_i = distance to intersection when the driver initiated braking (m)
D_f = distance to intersection at which the vehicle stopped (m)

- Required Deceleration Parameter (RDP) from Warning Onset to Stop Bar (g): Required constant deceleration to come to a stop at the stop bar based on the observed warning onset distance, as calculated in Equation 2:

$$a = \frac{V^2}{2 \times g \times D_j} \qquad \textbf{(Eq. 2)}$$

Where:
a = constant deceleration as a proportion of g
V = vehicle speed at the point when the driver received a warning (m/s)
g = gravitational acceleration constant (9.81 m/s^2)
D_j = distance to intersection stop bar at warning onset (m)

- RDP from Braking Onset to Stop Bar (g): Required constant deceleration to come to a stop at the stop bar based on the observed brake onset distance, as calculated in Equation 3.

$$a = \frac{V^2}{2 \times g \times D_j} \qquad \textbf{(Eq. 3)}$$

Where:
a = constant deceleration as a proportion of g
V = vehicle speed at the point when driver initiated braking (m/s)
g = gravitational acceleration constant (9.81 m/s^2)
D_j = distance to intersection stop bar at braking onset (m)

- RDP from Warning Onset to Collision Zone (g): Required constant deceleration to come to a stop at the entrance point of collision zone based on the observed warning onset distance, as calculated in Equation 4.

$$a = \frac{V^2}{2 \times g \times (D_i - D_f)} \qquad \textbf{(Eq. 4)}$$

Where:
a = constant deceleration as a proportion of g
V = vehicle speed at the point when the driver received a warning (m/s)
g = gravitational acceleration constant (9.81 m/s^2)
D_i = distance to intersection stop bar at warning onset (m)
D_f = distance from the collision zone to the stop bar (m, negative since the collision zone is located beyond the stop bar)

- RDP from Braking Onset to Collision Zone (g): Required constant deceleration to come to a stop at the entrance point of collision zone based on the observed brake onset distance, as calculated in Equation 5.

$$a = \frac{V^2}{2 \times g \times (D_i - D_f)} \qquad \textbf{(Eq. 5)}$$

Where:
a = constant deceleration as a proportion of g
V = vehicle speed at the point when the driver initiated braking (m/s)
g = gravitational acceleration constant (9.81 m/s^2)
D_i = distance to intersection stop bar at braking onset (m)
D_f = distance from the collision zone to the stop bar (m, negative since the collision zone is located beyond the stop bar)

- Time to Accelerator Release (s): Time from the onset of the stimulus to the onset of accelerator pedal release (operationally defined as the first decrease in accelerator position, after stimulus onset, of more than 2.5% in 0.1 s). For the warning conditions, the stimulus was the warning onset. For no-warning conditions, the stimulus was the presentation of the yellow light.
- Time to Brake (s): Time from the onset of the stimulus to the onset of brake application (operationally defined as the first increase in brake position, after stimulus onset, of more than 5% in 0.1 s). For the warning conditions, the stimulus was the warning onset. For no-warning conditions, the stimulus was the presentation of the yellow light.
- Time from Accelerator to Brake (s): Time from the onset of accelerator pedal release (operationally defined as the first decrease in accelerator position, after stimulus onset, of more than 2.5% in 0.1 s) to the onset of brake application (operationally defined as the first increase in brake position, after stimulus onset, of more than 5% in 0.1 s).
- Time to Peak Deceleration (s): Time from the onset of the stimulus to maximum driver-induced deceleration. For the warning conditions, the stimulus was the warning onset. For no-warning conditions, the stimulus was the presentation of the yellow light.
- Time from Brake to Peak Deceleration (s): Time from the onset of brake application (operationally defined as the first increase in brake position, after stimulus onset, of more than 5% in 0.1 s) to maximum driver-induced deceleration.
- Maximum Brake Velocity (%/s): Maximum increase in brake position per unit time. Calculated based on successive brake position samples down-sampled to 10 Hz (from the original 100 Hz rate). The calculation is based on the division of change in percentage total pedal travel (e.g., 50% would indicate half of the possible pedal travel) over a pre-selected time period.

For experiments using the naturalistic distraction protocol, a few additional dependent variables were collected using the video from the SV's DAS:

- Time to First Glance (s): Time from the "Now" command to the initiation of the participant's first glance to the HVAC console (which was used in the distraction task for the surprise trial).
- Last Glance Duration (s): The duration of the participant's final glance to the HVAC console, within which the warning onset (or yellow light onset for baseline experiments) usually occurred.
- Time from Stimulus to Forward Fixation (s): Time from the onset of the warning (if warning trial) or the yellow light (if baseline trial) to the end of the participant's final glance to the HVAC console (which immediately preceded a forward fixation).
- Number of Glances: A count of the glances that were directed towards the HVAC console from the issuance of the "Now" command until the last glance taken after the warning (if warning trial) or the yellow light (if baseline trial) was presented. A glance towards the HVAC console beginning prior to the issuance of the "Now" command was included in the count if it was still occurring when the "Now" command was issued.

2.9 Data Reduction and Analysis Techniques

The dependent variables for the study were examined for consistency prior to the analysis process. Custom software was created in the Matlab environment (Mathworks, Natick, MA) to identify the surprise trial within the data, calculate the dependent variables of interest, and produce plots (Figure 14) that aided in data integrity verification and the identification of data that should be excluded. The figures created in Matlab illustrated all essential aspects of the intersection approach, and allowed the identification of incorrectly processed, incomplete, or corrupt data.

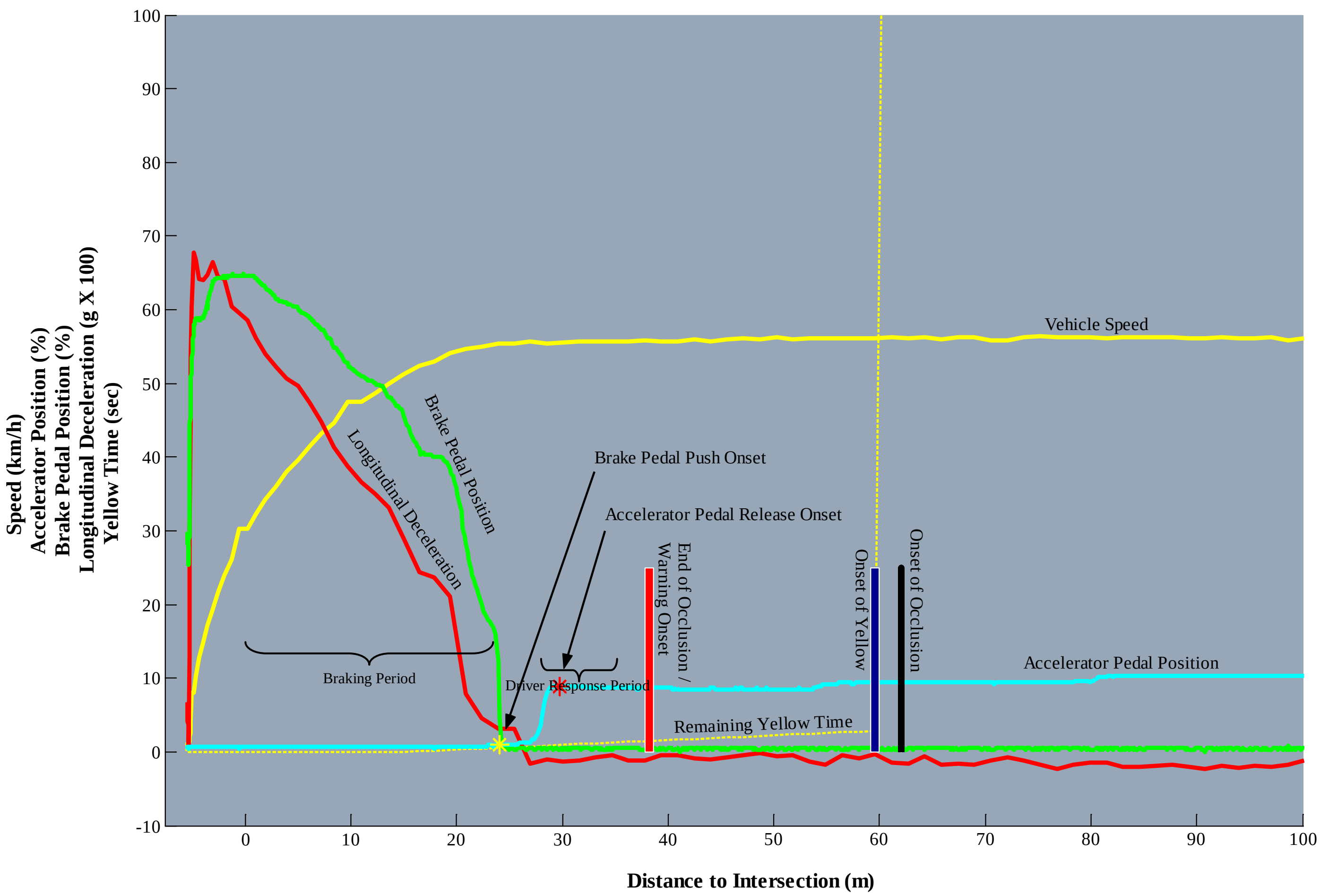

Figure 14 Sample intersection approach plot used to aid in data integrity verification.

Note: The graph represents an occlusion trial.

For experiments using the naturalistic protocol, behavior, rather than gas pedal activity, was used to determine whether data collected were valid and would be included in the analyses. Participants were excluded from data analysis of the naturalistic study if their eyes were primarily focused on the forward roadway at warning onset or the yellow light onset in the baseline study. Upon completing each naturalistic experiment, video collected by the on-board DAS was analyzed using VTTI's data analysis and reduction tool (DART). Participants who were not glancing down or otherwise obviously distracted were excluded from data analysis. Participants were also excluded from the study if they were traveling, at warning or yellow light onset, more than 7.9 km/h (5 mph) over or under the nominal speed for the warning condition (56.3 km/h, or 35 mph).

After data collection was complete, all dependent variables were further examined for consistency and the presence of outliers. Any outliers whose occurrence could be attributed to a particular flaw in data collection or data processing were either corrected or removed (e.g., the software had selected incorrect brake-onset or accelerator-release thresholds, or a sensor required calibration).

‘Clean’ data were then analyzed based on their dependence with the construct of driver response time. Conceptually, there are two steps required for a successful intersection stop. These aspects are: (Step 1) analyze, formulate, and initiate a response plan to the stimulus requiring the stop, and (Step 2) adapt and complete the execution of the plan based on any sensory feedback. Put in another way, assuming a driver decides to stop, Step 1 characterizes pre-braking behavior and Step 2 characterizes the braking behavior.

Both steps can be quantified using different dependent variables; however, the dependent variables that characterize the second step might not be independent of those that characterize the first step. For example, it is possible that a driver that takes longer to react to the warning stimulus (Step 1) would brake harder (Step 2) in order to compensate and stop at the same point as a driver with a faster reaction time. All of the dependent variables described above can be classified according to the step that they quantify:

- Analysis, formulation, and initiation of the response plan (Step 1, plan initiation)
    - Time to accelerator release
    - Time to brake
    - Time from accelerator to brake
    - Time to first glance (naturalistic distraction protocol only)
    - Last glance duration (naturalistic distraction protocol only)
    - Time from warning or yellow light to forward fixation (naturalistic distraction protocol only)
    - Number of glances (naturalistic distraction protocol only)
- Adaptation and completion of the response plan (Step 2, plan execution)
    - Time to peak deceleration
    - Time from brake to peak deceleration
    - Distance before the stop bar
    - Peak deceleration
    - Constant deceleration
    - RDP from Warning Onset to Stop Bar
    - RDP from Braking Onset to Stop Bar
    - RDP from Warning Onset to Collision Zone
    - RDP from Braking Onset to Collision Zone
    - Maximum brake velocity (%/s)

In order to determine the need for correction factors, a correlation analysis was performed between the Step 1 and Step 2 variables. Given that correlation analysis quantifies the degree of linear relationship between variables, transformation of variables was also examined in this process, as a means of maximizing the correlations.

Once the correlations were completed and any relationships between Step 1 and Step 2 variables established, statistical analysis of variance was performed. Dependent variables for which correction was not needed (i.e., all Step 1 variables and Step 2 variables that did not exhibit correlation with Step 1 variables) were analyzed using traditional Analysis of Variance (ANOVA) techniques. Dependent variables that required a correction were analyzed using Analysis of Covariance (ANCOVA).

When significant main effects were found, Student-Newman-Keuls (SNK) tests were performed to further determine the source of those differences. Significant interaction effects were examined with *post hoc* t-tests using the Tukey correction for multiple comparisons. A Type I error level of 0.05 was assumed for all tests. Finally, the “Trial Outcome” and “Stopping Zone” variables were considered and analyzed separately since they were discrete variables which did not require correction. These variables were analyzed based on proportion of occurrence for each trial. Confidence intervals (95%) were established to determine overlap between different experimental groups and infer statistically significant differences. These confidence intervals were based on the binomial distribution, which describes the probability of discrete outcomes when observations are independent.

3 Results and Discussion

The primary goal of these experiments was to issue a recommendation for the DVI to be used for Subtask 3.4, a pilot test of the CICAS-V system. In support of this goal, Table 3 shows a summary of the compliance results obtained for each of the 11 studies that were completed within Subtask 3.3 of CICAS-V. Note that studies 6, 8, 9, and 10 are shown in bold. These studies used the Visual icon + Speech (‘Stop Light’) + Brake Pulse warning, which, based on the results reported here, is recommended for use in future subtasks of the CICAS-V project. As discussed within this Results section, this recommendation was based on the observed patterns of driving behavior in reaction to this warning. The measures considered in making these recommendations included all dependent variables, including stopping zone, compliance, deceleration levels (e.g. peak, constant, RDP), response times (time to accelerator release, time to brake), and glance-related measures (e.g., time from stimulus to forward fixation).

Table 3 Summary of results for CICAS-V Subtask 3.3.

Note: Studies in bold investigated the warning recommended based on the results presented in this report.

Study	DVI*	TTI (s)	Protocol	Number of drivers who complied	Number of drivers who did not comply	Compliant drivers who activated PBA
1	CAMP Tone	2.24	Occlusion	9 (50%)	9 (50%)	--
2	CAMP Tone	2.44	Occlusion	13 (72%)	5 (28%)	--
3	CAMP Tone	2.44	Naturalistic distraction	7 (39%)	11 (61%)	--
4	Speech	2.44	Naturalistic distraction	7 (39%)	11 (61%)	--
5	CAMP Tone with Brake Pulse	2.44	Naturalistic distraction	14 (78%)	4 (22%)	--
6	**Speech with Brake Pulse**	**2.44**	**Naturalistic distraction**	**17 (94%)**	**1 (6%)**	**--**
7	Beep Tone with Brake Pulse and PBA	2.24	Naturalistic distraction	5 (50%)	5 (50%)	0
8	**Speech with Brake Pulse and PBA**	**2.24**	**Naturalistic distraction**	**16 (89%)**	**2 (11%)**	**1**
9	**Speech with Brake Pulse and PBA**	**2.04**	**Naturalistic distraction**	**7 (78%)**	**2 (22%)**	**0**
10	**Speech with Brake Pulse and PBA**	**1.84**	**Naturalistic distraction**	**3 (33%)**	**6 (67%)**	**1**
11	Baseline Condition (No warning)	N/A	Naturalistic distraction	1 (6%)	17 (94%)	--

*All of these studies featured a visual display that performed both advisory and warning functions (only the advisory function of this display was used in Study 11).

Results are presented first by study, descriptively indicating the characteristics and behaviors of drivers who complied with each DVI. Then the effect of Age and Gender factors on the results are considered separately. Results are then described for various comparisons between the different warnings and, when applicable, the effects of different timings and PBA availability. Finally, descriptive statistics are provided for the additional PBA trials.

3.1 Descriptive Statistics by Study

This section of the report summarizes the results obtained for each of the 11 studies. Note that Studies 1 and 2 used the occlusion protocol, but Studies 3 through 11 used the naturalistic distraction approach.

3.1.1 Study 1: Visual Icon + CAMP Tone warning at 2.24 s TTI (Occlusion Protocol)

This was the first of two studies that employed the occlusion method. This warning condition produced a 50% compliance rate (95% Confidence Interval [CI]: 26.9%-73.1%) for the 18 participants. One non-compliant participant stopped in the collision zone, while the remaining eight non-compliers failed to stop altogether. The deceleration, reaction/response time, and maximum brake velocity dependent variables were available for the 9 (out of 18) participants who successfully stopped in response to the warning (Table 11, Appendix H). Participants were traveling at an average of 34.7 mph with a standard deviation (SD) of 1.0 mph at warning onset. The warning was presented at an average of 112.0 ft (SD=3.7 ft) prior to the stop bar.

Participant responses to the questionnaire statement indicate that all participants noticed some sort of alert before being prompted to describe the warning. Graphs depicting these subjective responses to the ratings scales are shown in Appendix I, Figure 16 to Figure 20.

3.1.2 Study 2: Visual Icon + CAMP Tone Warning at 2.44 s TTI (Occlusion Protocol)

This was the final study that employed the occlusion method. Relative to Study 1, this study used an earlier TTI (2.44 versus 2.24) warning timing, which resulted in higher compliance rates (see Table 3). This pattern of results led to adopting the 2.44 TTI warning timing approach in the subsequent study.

More specifically, this warning condition produced a 72% compliance rate (95% CI: 51.5%-92.9%) across 18 participants. All five non-compliers failed to stop altogether. The deceleration, reaction/response time, and maximum brake velocity dependent variables were available for the 13 (out of 18) participants who successfully stopped in response to the warning (Table 12, Appendix H). Participants were traveling at an average of 34.4 mph (SD=1.9 mph) at warning onset. The warning was presented at an average of 121.7 ft (SD=6.9 ft) prior to the stop bar.

Participant responses to the questionnaire statement indicate that a majority (94%) noticed some sort of alert before being prompted to describe the warning. One non-compliant participant did not report noticing any alert prior to additional prompting from the experimenter. Graphs depicting these subjective responses to the ratings scales are shown in Appendix I, Figure 21 to Figure 25.

3.1.3 Study 3: Visual Icon + CAMP Tone Warning at 2.44 s TTI

This was the first study that employed the naturalistic distraction method. Relative to Study 2, this study differs only in terms of the distraction method (occlusion versus naturalistic), which resulted in lower compliance rates (see Table 3). This pattern of results led to adopting the naturalistic method in all subsequent studies. (This point is discussed further in Section 3.3.2).

More specifically, this warning condition produced a 39% compliance rate (95% CI: 16.4%-61.4%) across 18 participants. All eleven non-complying participants failed to stop altogether. The deceleration, reaction/response time, and maximum brake velocity dependent variables were available for the 7 (out of 18) participants who successfully stopped in response to the warning (Table 13, Appendix H); eyeglance measures are presented for all 18 participants, but split by their compliance. No significant differences between compliant and non-compliant drivers were observed for the eyeglance variables. Participants were traveling at an average of 34.3 mph (SD=1.7 mph) at warning onset. The warning was presented at an average of 121.7 ft (SD=6.3 ft) prior to the stop bar.

Participant responses to the questionnaire statement indicate that a majority (89%) noticed some sort of alert before being prompted to describe the warning. Two non-compliant participants did not report noticing any alert prior to additional prompts. Graphs depicting these subjective responses to the ratings scales are shown in Appendix I, Figure 26 to Figure 30.

3.1.4 Study 4: Visual Icon + Speech ('Stop Light') Warning at 2.44 s TTI

This study employed the naturalistic distraction method, and was the first to investigate a speech warning. Relative to Study 3, this study differed only in terms of the auditory warning method (speech versus CAMP tone), which resulted in identical compliance rates (see Table 3).

More specifically, this warning condition produced a 39% compliance rate (95% CI: 16.4%-61.4%) across 18 participants. One non-compliant participant stopped in the collision zone, with the remaining 10 non-compliers failing to stop altogether. The deceleration, reaction/response time, and maximum brake velocity dependent variables were available for the 7 (out of 18) participants who successfully stopped in response to the warning (Table 14, Appendix H); eyeglance measures are presented for all 18 participants, but split by their compliance. No significant differences between compliant and non-compliant drivers were observed for the eyeglance variables. Participants were traveling at an average of 34.6 mph (SD=1.5 mph) at warning onset. The warning was presented at an average of 122.0 ft (SD=5.3 ft) prior to the stop bar.

Participant responses to the questionnaire statement indicate that a majority (78%) noticed some sort of alert before being prompted to describe the warning. Four participants did not report noticing any alert (two compliers and two non-compliers) prior to additional prompting from the experimenter. Graphs depicting these subjective responses to the ratings scales are shown in Appendix I, Figure 31 to Figure 35. The majority of participants who did not stop felt that the warning was timed too late, while most of the stopping participants felt the timing was "just right."

3.1.5 Study 5: Visual Icon + CAMP Tone + Brake Pulse Warning at 2.44 s TTI

This study also employed the naturalistic distraction method, and was the first study to employ a brake pulse warning. Relative to Study 3, this study differed only in terms of the added brake pulse warning, which resulted in substantially higher compliance rates (see Table 3). This pattern of results led to adopting the brake pulse warning in all subsequent studies (except in Study 11, the baseline study).

More specifically, this warning condition produced a 78% compliance rate (95% CI: 58.6%-97.0%) across 18 participants. All four non-complying participants failed to stop altogether. The deceleration, reaction/response time, and maximum brake velocity dependent variables were available for the 14 (out of 18) participants who successfully stopped in response to the warning (Table 15, Appendix H); eyeglance measures are presented for all 18 participants, but split by their compliance. No significant differences between compliant and non-compliant drivers were observed for the eyeglance variables. Participants were traveling at an average of 34.8 mph (SD=1.8 mph) at warning onset. The warning was presented at an average of 124.6 ft (SD=6.1 ft) prior to the stop bar.

Participant responses to the questionnaire statement indicate that all participants noticed some sort of alert before being prompted to describe the warning. Graphs depicting these subjective responses to the ratings scales are shown in Appendix I, Figure 36 to Figure 40.

3.1.6 Study 6: Visual Icon + Speech ('Stop Light') + Brake Pulse Warning at 2.44 s TTI

This study also employed the naturalistic distraction method. Relative to Study 5, this study differs only in terms of the auditory warning method (speech versus CAMP tone), which resulted in higher compliance rates (see Table 3). This pattern of results led to adopting the speech warning as the auditory component of the warning approach in subsequent studies (except in Study 7 and Study 11[the baseline study]).

More specifically, this warning condition produced a 94% compliance rate (95% CI: 83.9%-100%) across 18 participants. One non-compliant participant stopped in the collision zone. The deceleration, reaction/response time, and maximum brake velocity dependent variables were available for the 17 (out of 18) participants who successfully stopped in response to the warning (Table 16, Appendix H); eyeglance measures are presented for all 18 participants, but split by their compliance. No statistical comparisons between compliant and non-compliant drivers could be performed since there were not enough non-compliant drivers to establish a robust sample. Participants were traveling at an average of 34.4 mph (SD=1.6 mph) at warning onset. The warning was presented at an average of 123.2 ft (SD=5.9 ft) prior to the stop bar.

Participant responses to the questionnaire statement indicate that a majority (89%) noticed some sort of alert before being prompted to describe the warning. Two participants did not report noticing any alert prior to additional prompts (one complier and one non-complier). Graphs depicting these subjective responses to the ratings scales are shown in Appendix I, Figure 41 to Figure 45.

3.1.7 Study 7: Visual Icon + Beep Tone + Brake Pulse Warning at 2.24 s TTI with PBA Enabled

This study also employed the naturalistic distraction method along with a less complex auditory warning (Beep Tone). More importantly, it was the first study to have the Panic Brake System enabled (note this system would only become activated if the driver's braking behavior satisfied the criterion for activating the PBA system). PBA augments the braking effort input by the driver if certain braking thresholds (which are proprietary to each PBA system manufacturer) are exceeded. Therefore, drivers who fail to brake to the limit of vehicle traction, even in emergency situations where this may be beneficial, are automatically taken to this high braking level while being provided with override opportunities. The compliance rates observed in this study are similar to the relatively low compliance rates observed in Study 1, and suggested that the DVI and timing combination evaluated in the current study should not be included in further studies. In addition, the lack of any PBA system activations suggested either that this system may not be reliably triggered under these intersection violation conditions (with this particular warning and timing approach) and/or that the PBA system entrance criterion should be altered to enable more frequent system activations.

More specifically, this warning condition produced a 50% compliance rate (95% CI: 26.9%-73.1%) across 10 participants. All five non-compliant participants failed to stop altogether. The deceleration, reaction/response time, and maximum brake velocity dependent variables were available for the 5 (out of 10) participants who successfully stopped in response to the warning (Table 17, Appendix H); eyeglance measures are presented for all 10 participants, but split by their compliance. No significant differences between compliant and non-compliant drivers were observed for the eyeglance variables. Although PBA was enabled during this study, none of the five compliant participants activated this functionality. Participants were traveling at an average of 35.4 mph (SD=1.4 mph) at warning onset. The warning was presented at an average of 113.9 ft (SD=4.5 ft) prior to the stop bar.

Participant responses to the questionnaire statement indicate that all participants noticed some sort of alert before being prompted to describe the warning. Graphs depicting these subjective responses to the ratings scales are shown in Appendix I, Figure 46 to Figure 50.

3.1.8 Study 8: Visual Icon + Speech ('Stop Light') + Brake Pulse Warning at 2.24 s TTI with PBA Enabled

This study also employed the naturalistic distraction method. Relative to Study 7, this study differed only in terms of the auditory warning method (speech versus Beep Tone), which resulted in higher compliance rates (see Table 3). Overall, this pattern of results led to adopting the speech warning as the auditory component of the warning approach and altering the PBA system entrance criterion (since only one driver activated the PBA system) in subsequent studies (except in Study 11, the baseline study).

More specifically, this warning condition produced an 89% compliance rate (95% CI: 74.4%-100%) across 18 participants. One non-compliant participant stopped in the collision zone, while the other failed to stop altogether. The deceleration, reaction/response time, and maximum brake velocity dependent variables were available for the 16 (out of 18) participants who successfully stopped in response to the warning (Table 18, Appendix H); eyeglance measures are presented for all 18 participants, but split by their compliance. No statistical comparisons between compliant and non-compliant drivers could be performed since there were not enough non-compliant drivers to establish a robust sample. Although PBA was enabled during this study, only one of the compliant participants activated this functionality. Participants were traveling at an average of 34.0 mph (SD=1.8 mph) at warning onset. The warning was presented at an average of 112.7 ft (SD=9.6 ft) prior to the stop bar.

Participant responses to the questionnaire statement indicate that a majority (94%) noticed some sort of alert before being prompted to describe the warning. One compliant participant did not report noticing any alert prior to additional prompts from the experimenter. Graphs depicting these subjective responses to the ratings scales are shown in Appendix I, Figure 51 to Figure 55.

3.1.9 Study 9: Visual Icon + Speech ('Stop Light') + Brake Pulse Warning at 2.04 s TTI with PBA Enabled

This study also employed the naturalistic distraction method. Relative to Study 8, this study used a later TTI (2.04 versus 2.24) warning timing, which resulted in slightly lower compliance rates (see Table 3). In addition, although the PBA system entrance criterion was altered to enable more frequency of system activations, no drivers activated the PBA system. Overall, this pattern of results led to further alteration of the PBA system entrance criterion in Study 10.

More specifically, this warning condition produced a 79% compliance rate (95% CI: 58.6%-97.0%) across nine participants. Two non-compliant participants failed to stop altogether. The deceleration, reaction/response time, and maximum brake velocity dependent variables were available for the seven (out of nine) participants who successfully stopped in response to the warning (Table 19, Appendix H); eyeglance measures are presented for all nine participants, but split by their compliance. No statistical comparisons between compliant and non-compliant drivers could be performed since there were not enough non-compliant drivers to establish a robust sample. Although PBA was enabled during this study, none of the compliant participants activated this functionality. Participants were traveling at an average of 34.6 mph (SD=1.1 mph) at warning onset. The warning was presented at an average of 101.8 ft (SD=3.3 ft) prior to the stop bar.

Participant responses to the questionnaire statement indicate that all participants noticed some sort of alert before being prompted to describe the warning. Graphs depicting these subjective responses to the ratings scales are shown in Appendix I, Figure 56 to Figure 60.

3.1.10 Study 10: Visual Icon + Speech (‘Stop Light’) + Brake Pulse Warning at 1.84 s TTI with PBA Enabled

This study employed the naturalistic distraction method, and further lowered the TTI threshold at which the warning was presented. Relative to Study 9, this study used a later TTI (1.84 versus 2.04) warning timing, which resulted in substantially lower compliance rates (see Table 3). In addition, although the PBA system entrance criterion was once again altered to enable more frequent system activations, only one driver activated the PBA system.

More specifically, this warning condition produced a 33% compliance rate (95% CI: 11.6%-55.1%) across nine participants. All six non-complying participants failed to stop altogether. The deceleration, reaction/response time, and maximum brake velocity dependent variables were available for the 3 (out of 9) participants who successfully stopped in response to the warning (Table 20, Appendix H); eyeglance measures are presented for all 9 participants, but split by their compliance. No significant differences between compliant and non-compliant drivers were observed for the eyeglance variables. Although PBA was enabled during this study, only one of the compliant participants activated this functionality. Participants were traveling at an average of 34.2 mph (SD=1.9 mph) at warning onset. The warning was presented at an average of 90.0 ft (SD=5.3 ft) prior to the stop bar.

Participant responses to the questionnaire statement indicate that a majority (78%) noticed some sort of alert before being prompted to describe the warning. Two non-compliant participants did not report noticing any alert prior to additional prompts from the experimenter. Graphs depicting these subjective responses to the ratings scales are shown in Appendix I, Figure 61 to Figure 65.

3.1.11 Study 11: Baseline Condition (No Warning); Light Change Stimulus at 2.44 s TTI

This study employed the naturalistic distraction method, but did not present a warning during the surprise trial. A light change stimulus (common traffic signal sequence) was presented at 2.44 s TTI. Relative to all previous studies which employed a warning, substantially lower compliance rates were observed.

More specifically, this warning condition produced a 6% compliance rate (95% CI: 0%-16.1%) across 18 participants. All non-compliant participants failed to stop altogether. The deceleration, reaction/response time, and maximum brake velocity dependent variables were available for the one (out of 18) participant who successfully stopped in response to the light change stimulus (Table 21, Appendix H); eyeglance measures are presented for all 18 participants, but split by their compliance. No statistical comparisons between compliant and non-compliant drivers could be performed since there were not enough compliant drivers to establish a robust sample. Participants were traveling at an average of 34.4 mph (SD=2.5 mph) at the signal change.

Responses to the questionnaire statement indicate that two participants (11%) noticed some sort of visual alert. One claimed that the traffic light displayed an alert, while the other simply noticed the blue indicator light on the visual DVI. Graphs depicting these subjective responses to the ratings scales are shown in Appendix I, Figure 66 to Figure 68.

3.2 Age and Gender Effects

The small sample sizes (usually 18) within a study for each Age by Gender combination (particularly when considering only participants that performed a successful stop) precluded a formal statistical analysis for age and gender effects for most studies. Table 4 indicates that no trends in compliance behavior were observable based on age or gender classifications.

Table 4 Compliance by Age and Gender.

		Younger		Middle		Older	
Study	N (%)	Male	Female	Male	Female	Male	Female
Study 1: Visual icon + CAMP Tone warning at 2.24 s TTI (Occlusion method)	9/18 (50%)	1 (6%)	2 (11%)	3 (17%)	2 (11%)	0 (0%)	1 (6%)
Study 2: Visual icon + CAMP Tone warning at 2.44 s TTI (Occlusion method)	13/18 (72%)	2 (11%)	3 (17%)	3 (17%)	1 (6%)	1 (6%)	3 (17%)
Study 3: Visual icon + CAMP Tone warning at 2.44 s TTI	7/18 (39%)	1 (6%)	2 (11%)	2 (11%)	0 (0%)	1 (6%)	1 (6%)
Study 4: Visual icon + Speech ('Stop Light') warning at 2.44 s TTI	7/18 (39%)	1 (6%)	1 (6%)	2 (11%)	1 (6%)	1 (6%)	1 (6%)
Study 5: Visual icon + CAMP Tone + Brake Pulse warning at 2.44 s TTI	14/18 (78%)	3 (17%)	1 (6%)	2 (11%)	2 (11%)	3 (17%)	3 (17%)
Study 6: Visual icon + Speech ('Stop Light') + Brake Pulse warning at 2.44 s TTI	17/18 (94%)	3 (17%)	3 (17%)	3 (17%)	2 (11%)	3 (17%)	3 (17%)
Study 7: Visual icon + Beep Tone + Brake Pulse warning at 2.24 s TTI	5/10 (50%)	0 (0%)	0 (0%)	3 (30%)	0 (0%)	1 (10%)	1 (10%)
Study 8: Visual icon + Speech ('Stop Light') + Brake Pulse warning at 2.24 s TTI	16/18 (89%)	3 (17%)	3 (17%)	3 (17%)	2 (11%)	3 (17%)	2 (11%)
Study 9: Visual icon + Speech ('Stop Light') + Brake Pulse warning at 2.04 s TTI	7/9 (78%)	2 (22%)	0 (0%)	1 (11%)	1 (11%)	1 (11%)	2 (22%)

Study	N (%)	Younger Male	Younger Female	Middle Male	Middle Female	Older Male	Older Female
Study 10: Visual icon + Speech ('Stop Light') + Brake Pulse warning at 1.84 s TTI	3/9 (33%)	0 (0%)	2 (22%)	0 (0%)	0 (0%)	1 (11%)	0 (0%)
Study 11: Baseline Condition (No warning); Light change stimulus at 2.44 s TTI	1/18 (6%)	0 (0%)	1 (6%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Across all the studies, only Study 6 and Study 8 (Visual icon + Speech ('Stop Light') + Brake Pulse at 2.44 and 2.24 s TTI, respectively) contained enough compliant drivers to support a formal Age by Gender statistical analysis. In these studies, a significant effect was only observed for the Time to Brake measure (F[5,27]=2.82, *p*=0.0355). As illustrated in Figure 15, this effect was precipitated by an Age X Gender interaction, in which older males exhibited a much slower mean Time to Brake (0.93 s) than older females (0.66 s).

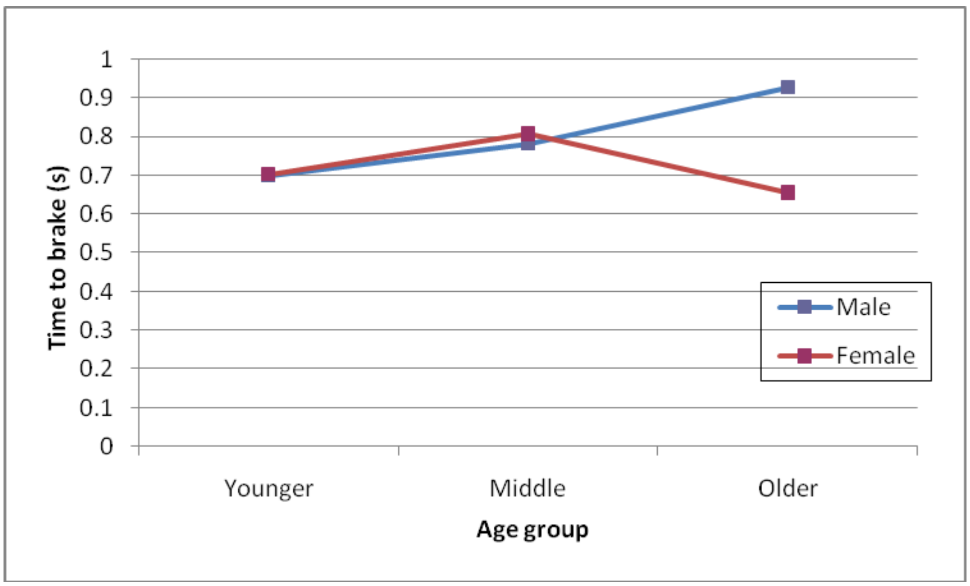

Figure 15 Age by Gender interaction in Studies 6 and 8.

Hence, overall, these results suggest that there was little or no influence of Age or Gender factors on driver behavior and compliance with the warnings. Once again, it should be noted that the statistical determination of this inference is not robustly possible across the remaining studies that were performed due to insufficient sample sizes. Given these results, neither Age nor Gender was considered as a factor in the key study comparisons described in the following section.

3.3 Key Study Comparisons

3.3.1 Differences in Timing with the Occlusion Protocol Methodology

These results compare the data obtained in the studies employing the occlusion protocol methodology (i.e., Study 1 and Study 2), which used the Visual icon + CAMP Tone warning presented at two different warning timings, 2.44 and 2.24 s TTI. Although there is a trend toward lower compliance percentage (50% vs. 75%) in the 2.24 s relative to 2.44 TTI timing, this difference was not statistically significant (p=0.3199). The following statistically significant results are summarized in Table 5.

Analysis of plan initiation (i.e., pre-braking behavior) variables showed only one significant main effect:

- Time to accelerator release ($F[1,20]$= 4.69, p=0.04): The 2.24 s timing induced a quicker accelerator release (by approximately 0.08 s) than did the 2.44 s timing.

Analysis of plan execution (i.e., braking behavior) variables showed significant main effects for all of the Required Deceleration Parameters (RDPs) examined:

- RDP from warning onset to stop bar ($F[2,19]$=20.75, p<0.0001): Analysis showed that this variable significantly correlated with time to accelerator release. After accounting for the effects of this plan initiation variable, this RDP variable was 0.03 g larger in the 2.24 s TTI warning timing condition.

- RDP from braking onset to stop bar ($F[2,19]$=12.42, p=0.0004): This variable correlated with a participant's transition time from the accelerator to the brake. After considering this plan initiation variable's effects, this RDP variable was 0.07 g larger in the 2.24 s TTI warning timing condition.

- RDP from warning onset to collision zone ($F[1,20]$=22.29, p=0.0001): This variable was not significantly correlated with any of the plan initiation variables. The variable was 0.03 g larger for the 2.24 s TTI warning timing condition.

- RDP from braking onset to collision zone ($F[2,19]$=10.97, p=0.0007): Analysis showed that this variable significantly correlated with a participant's transition time from the accelerator to the brake. After accounting for the effects of this plan initiation variable, this RDP was 0.04 g larger in the 2.24 s TTI warning timing condition.

Table 5 Means of significant differences between the occlusion protocols.

Variable (N)	2.24 s TTI (9)	2.44 s TTI (13)
Time to accelerator release (s)	0.35	0.43
RDP from warning to stop bar (g)	0.32	0.29
RDP from brake to stop bar (g)	0.51	0.44
RDP from warning to collision zone (g)	0.25	0.22
RDP from brake to collision zone (g)	0.35	0.31

Overall, these results show that participants in the 2.24 s TTI warning timing condition reacted quicker, had later brake onsets, and braked harder than their counterparts in the 2.44 s timing condition. These timing differences were also investigated using the naturalistic distraction protocol, which is discussed below in Section 3.3.4.

3.3.2 Differences between the Occlusion and Naturalistic Protocols

The Visual icon + CAMP Tone warning (at 2.44 s TTI) was tested using both the occlusion and naturalistic protocols (Study 2 and Study 3, respectively) in order to select the experimental approach for subsequent studies. Although the occlusion protocol has the distinct advantage of providing a higher level of experimental control than the naturalistic protocol, it was important to first ensure that the driver behavior and compliance levels were similar in the occlusion versus naturalistic protocol methodological approaches. Results indicated that the occlusion protocol produced a substantial larger compliance percentage than the naturalistic protocol (72% vs. 39%), a difference that approached statistical significance (p=0.1306). The following statistically significant results are summarized in Table 6.

Analysis of plan initiation variables showed some significant main effects:

- Time to accelerator release (F[1,18]=5.18, p=0.0353): The occlusion protocol induced a quicker accelerator release response (by approximately 0.26 s) than the naturalistic protocol

- Time to brake (F[1,18]=7.87, p=0.0117): The occlusion protocol induced a quicker brake onset time (by approximately 0.31 s) than the naturalistic protocol

Analysis of plan execution variables showed some significant main effects as well:

- Distance before stop bar (F[2,17]=7.67, p=0.0042): Drivers in the occlusion protocol stopped roughly 6 ft closer in front of the stop bar than drivers in the naturalistic protocol.

- Peak deceleration (F[2,17]=11.41, p=0.0007): Drivers in the occlusion protocol exhibited slightly lower (by approximately 0.02 g) peak decelerations than drivers in the naturalistic protocol.

- Constant deceleration (F[2,17]=14.35, p=0.0002): Slightly larger for occlusion protocol drivers, but only by 0.03 g.

- RDP from braking onset to stop bar (F[2,17]=176.9, p<0.0001). Analysis showed that this variable was significantly correlated with the participant's reaction time. After accounting for the effects of this plan initiation variable, this variable was slightly (0.01 g) larger for the occlusion protocol drivers.

- RDP from braking onset to collision zone (F[2,17]=41.99, p<0.0001). Analysis shows that this variable significantly correlated with the participant's reaction time. After accounting for this plan initiation variable, the significant difference was smaller than 0.01 g.

Table 6 Means of significant differences between the occlusion and naturalistic protocols.

Variable (N)	Occlusion Protocol (Study 2) (13)	Naturalistic Distraction Protocol (Study 3) (7)
Time to accelerator release (s)	0.43	0.69

Time to brake (s)	0.8	1.11
Distance before stop bar (ft)	-5.45	-11.74
Peak deceleration (g)	0.67	0.69
Constant deceleration (g)	0.47	0.44
RDP from brake to stop bar (g)	0.49	0.48
RDP from brake to collision zone (g)	0.3397	0.3393

Overall, these results suggest that the occlusion protocol induced quicker reactions and earlier brake onsets than the naturalistic distraction protocol, and that the naturalistic protocol induced higher peak decelerations. Since the primary goal of this project is to determine which DVI should be implemented in an FOT or a real-world scenario, external validity is a major factor in that determination. Consequently, since the naturalistic distraction protocol exhibits greater external validity and there were differences observed in driver behavior across the occlusion and naturalistic protocols, naturalistic distraction protocol was used for the remainder of the Subtask 3.3 experiments.

3.3.3 Differences between CAMP Tone and Speech Warnings and the Influence of a Brake Pulse

This section compares the results of four studies testing four different DVI Types at a 2.44 s TTI and another baseline study where a warning was not provided but a traffic light change occurred at a similar timing:

- Visual icon + CAMP Tone (Study 3)
- Visual icon + 'Stop Light' Speech Warning (Study 4)
- Visual icon + CAMP Tone + Brake Pulse (Study 5)
- Visual icon + 'Stop Light' Speech Warning + Brake Pulse (Study 6)
- Baseline Condition with no warning presented (Study 11)

The Baseline condition compliance percentage (6%) was substantially (and significantly) lower than the compliance observed for any of the other warning conditions (which ranged from 33% to 94%), which provides clear evidence of the merit of providing drivers with CICAS-V warnings. Although no other significant differences in compliance were observed between the remaining groups that experienced warnings, there was a trend for participants who experienced the Brake Pulse as a component of the warning approach to stop more often than participants receiving a warning that did not include a Brake Pulse.

In discussing the following plan initiation and plan execution variable results, it should be noted that only one participant complied with the traffic signal during the Baseline condition. Therefore, although the performance values for this participant are provided, statistical comparisons of these values with those obtained for other conditions with substantially larger compliance percentages was not possible. The following statistically significant results are summarized in Table 7.

Analysis of plan initiation variables showed some significant main effects:

- Time to accelerator release (F[4,42]=11.21, *p*<0.0001): On average, participants who experienced the Brake Pulse released the accelerator roughly 0.4 s faster than those who did not experience the Brake Pulse. This translated to a roughly 0.25 s faster time to brake (F[4,42]=6.28, *p*=0.0005) for participants experiencing a brake pulse.

- Time to brake (F[4,42]=6.28, *p*=0.0005): Participants that experienced the Brake Pulse had faster brake onset times (by approximately 0.25 s).

Analysis of plan execution variables showed several significant main effects as well, which are mainly attributed to the presence of the Brake Pulse (since the effects were not present when auditory warnings were presented in isolation):

Distance before stop bar (F[5,40]=10.94, *p*<0.0001): This variable was significantly correlated with time to brake. After accounting for the effect of this plan initiation variable, results showed that participants who received the Brake Pulse stopped roughly 6 to 7 ft closer in front of the stop bar than those who did not receive a brake pulse.

Peak deceleration (F[5,40]=5.48, *p*=0.0006): Analysis shows that this variable was significantly correlated with time to accelerator release. After accounting for the effects of this plan initiation variable, the significant differences between conditions were small, on the order of 0.01 g.

Constant deceleration (F[5,40]=9.77, *p*<0.0001): This variable was significantly correlated with time to brake. Conditions with a brake pulse resulted in slightly (approximately 0.02 g) lower constant decelerations than other conditions when the influence of Time to Brake was removed.

RDP from warning onset to stop bar (F[5,40]=6.99, *p*<0.0001): After considering the large correlation of this variable with time to accelerator release, small (about 0.01 g) but significant differences between the Brake Pulse and non-brake pulse conditions remained. Similar results were observed for RDP from braking onset to stop bar (F[5,40]=43.78, *p*<0.0001, correlated with time to brake), RDP from warning onset to collision zone (F[5,40]=7.72, *p*<0.0001, correlated with time to accelerator release), and RDP from braking onset to collision zone (F[5,40]=17.66, *p*<0.0001, correlated with time to brake).

Time to peak brake (F[5,40]=3.13, *p*=0.0176): This variable was significantly correlated with time to brake. After considering the effects of this plan initiation variable, participants who experienced the Brake Pulse reached peak deceleration faster (approximately 0.4 s) than those who did not.

Table 7 Means of significant main effects of DVI type and Brake Pulse presence.

Variable (N)	CAMP Tone, No Brake Pulse (7)	Speech, No Brake Pulse (8)	CAMP Tone with Brake Pulse (14)	Speech with Brake Pulse (17)	Baseline (1)
Time to accelerator release (s)	0.69	0.62	0.24	0.26	0.69
Time to brake (s)	1.11	1.08	0.82	0.74	1.06
Distance before stop	-9.9	-8.64	-2.04	-0.67	-9.63

bar (ft)					
Peak deceleration (g)	0.66	0.63	0.64	0.62	0.56
Constant decel (g)	0.44	0.46	0.42	0.42	0.38
RDP from warning to stop bar (g)	0.29	0.3	0.32	0.32	0.26
RDP from brake to stop bar (g)	0.48	0.48	0.44	0.45	0.4
RDP from warning to collision zone (g)	0.22	0.23	0.26	0.26	0.2
RDP from brake to collision zone (g)	0.32	0.34	0.32	0.31	0.28
Time to peak brake (s)	2.76	2.8	2.39	2.49	2.78

Analysis of subjective data indicated one significant effect ($F[3,68]=2.80$, $p=0.046$) between the DVI groups with respect to perceived comfort or difficulty stopping. The *post hoc* test found that participants receiving verbal speech warnings reported a more comfortable stop, or if they did not stop, felt that they would have been able to stop with less difficulty. None of the other post-surprise trial subjective measures revealed significant differences between the DVI types.

These results indicate that the presence of the Brake Pulse appears to directly contribute to quicker reactions, harder decelerations, and stops that were farther away from the collision zone. Most importantly, participants who experienced a warning that included the Brake Pulse tended to be more likely to comply with that warning. This evidence strongly suggests that the brake pulse should be considered an integral, primary part of a TCD violation warning DVI.

3.3.4 Differences in Timing with the Naturalistic Protocol

Differences in timing within naturalistic protocol conditions were assessed by using the Visual icon + Speech (‘Stop Light’) + Brake Pulse warning at four different timings: 2.44 s TTI (Study 6), 2.24 s TTI (Study 8), 2.04 s TTI (Study 9), and 1.84 s TTI (Study 10) (Note that although the absence/presence of the PBA system and the PBA entrance criterion, which was loosened for some studies, differed, the PBA system ultimately played a negligible role in the results since so few subjects activated the PBA system under these intersection approach experimental conditions).

Analysis of compliance percentages for these conditions showed that participants in the 1.84 s TTI condition complied with the warning at a much lower percentage (33%) than participants experiencing the warning at longer timings (overall, >79%). Other conditions were not statistically different, but there is a clear trend toward increased compliance as the TTI warning timing became earlier (i.e., farther from the intersection).

Analysis of plan initiation variables showed no significant main effects. However, some main effects were observed for plan execution variables, which are illustrated in Table 8 and described below:

Distance before stop bar ($F[4,39]=7.78$, $p<0.0001$): This variable was significantly correlated with time to brake. After accounting for the effects of this latter variable, results showed that participants in the 2.44 s group stopped significantly closer in front of the stop bar (by at least 1 ft) than all other groups. Although not significantly different, there was a tendency for participants to stop farther beyond the stop bar as the timings became shorter.

Peak deceleration ($F[3,40]=6.0$, $p=0.0018$): Larger peak decelerations were observed as the timings became shorter. Participants in the intermediate 2.24 and 2.04 s timing groups showed statistically similar peak decelerations. However, the 1.84 s (the latest timing condition) and 2.44 s (earliest timing) groups exhibited approximately 0.17 g larger and 0.13 g smaller decelerations than the intermediate timing groups, respectively.

Constant deceleration ($F[3,40]=7.47$, $p=0.0004$): Incrementally larger constant decelerations (between 0.02 and 0.06 g for each 0.2 s change in TTI warning timing) were observed as timings became shorter.

RDP from warning onset to stop bar ($F[4,38]=41.18$, $p<0.0001$): Time to accelerator release was strongly correlated with RDP. After accounting for this variable, larger RDPs were observed as timings became shorter. Similar findings were observed for RDP from braking onset to stop bar, RDP from warning onset to collision zone ($F[4,38]=19.99$, $p<0.0001$, correlated with time to accelerator release), and RDP from braking onset to collision zone ($F[3,39]=11.8$, $p<0.0001$).

Time to peak deceleration ($F[4,38]=5.02$, $p=0.0024$): This variable was significantly correlated with time to brake. After considering the effects of this variable, it was observed that participants in the 1.84 s timing reached peak deceleration faster (by at least 0.3 s) than participants experiencing other timings.

Table 8 Means for all significant main effects of timing.

Variable (N)	1.84 s TTI (3)	2.04 s TTI (7)	2.24 s TTI (16)	2.44 s TTI (17)
Distance before stop bar (ft)	-9.23	-7.31	-2.25	1.37
Peak decel (g)	0.9	0.74	0.72	0.6
Constant decel (g)	0.5	0.48	0.42	0.4
RDP: warning to stop bar (g)	0.41	0.39	0.34	0.32
RDP: brake to stop bar (g)	0.55	0.51	0.43	0.39
RDP: warning to collision zone (g)	0.31	0.3	0.27	0.26
RDP: brake to collision zone (g)	0.36	0.36	0.31	0.29
Time to peak decel (s)	1.94	2.38	2.34	2.37

As suggested above, although PBA was available to participants in the 2.24 s, 2.04 s, and 1.84 s conditions, only two compliant participants engaged this system. One participant did so in the 2.24 s condition and stopped 13.89 ft before the stop bar. The second participant engaged PBA in the 1.84 s condition and stopped 17.28 ft after the stop bar. Statistical analysis of these observations was not possible due to the small representation of PBA-engagement within the study sample. Analysis of subjective data indicated no significant difference in responses among participants experiencing the different timings.

Overall, these results suggest that although shorter timings elicit slightly quicker reactions and significantly harder decelerations from drivers, this does not necessarily translate to a stop that is farther away from the collision zone. This agrees with the observations obtained in comparing similar timings under the occlusion protocol, and suggests there is a discretionary element drivers use when deciding exactly where to stop relative to the stop bar. The most important observation in the timing comparison was related to compliance with the warning, which showed a trend toward dropping as the timings became shorter, particularly at the 1.84 s TTI warning timing condition.

Furthermore, it appears reasonable to assume that, as the TTI warning timing decreases, more drivers will decide to continue through the intersection since they may feel that it is not possible to safely stop in the distance remaining. Therefore, warnings should be presented as early as possible to the extent that their earlier presentation does not result in an unacceptable number of warnings perceived by the driver as “too early” or unnecessary. Consequently, determination of the timing of the recommended warning (i.e., Visual icon + Speech [‘Stop Light’] + Brake Pulse, which was tested across a wide range of timings) needs to take into account forthcoming results from Subtask 3.2. This latter subtask involves characterizing a massive number of intersection approaches observed under naturalistic driving conditions.

3.3.5 Differences between Speech and Beep Tone Warnings

This section compares the results obtained for the Visual icon + Speech (‘Stop Light’) + Brake Pulse warning and the Visual icon + Beep Tone + Brake Pulse warning at 2.24 s TTI warning timing (Study 7 and Study 8, respectively). The motivation for this comparison was to continue to evaluate the hypothesis that the Brake Pulse was the dominant factor behind the favorable compliance and driver behavior results obtained when a warning was presented. If this hypothesis was true, perhaps a less salient (and hence, potentially less annoying) auditory warning could be coupled with the brake pulse warning without degrading warning effectiveness (It should be noted that although PBA was active for both of these comparison studies, only one compliant participant activated PBA during either condition [this participant was in the Speech condition and stopped 13.9 ft before the stop bar]).

Analysis of compliance percentages indicated a trend toward participants experiencing the Speech warning complying at a higher percentage (89%) than participants who experienced the Beep Tone warning (50%), a difference that approached statistical significance ($p=0.0940$).

While analysis of plan initiation variables failed to indicate significant main effects, analysis of plan execution variables showed some significant main effects, as described below and summarized in Table 9:

Distance before stop bar ($F[2,19]=6.42$, $p=0.0074$): Time to brake was significantly correlated with this variable. After considering the effects of this plan initiation variable, participants in the Beep Tone group were observed to stop at longer distances before the stop bar than participants in the Speech warning condition.

Constant deceleration ($F[1,20]=8.84$, $p=0.0075$): Participants in the Beep Tone group yielded larger constant deceleration values (approximately 0.07 g) than those in the Speech group.

RDP from warning onset to stop bar ($F[2,18]=12.06$, $p=0.0005$): This variable significantly correlated with time to accelerator release. After accounting for the effect of this plan initiation variable, participants in the Beep Tone group were observed to exhibit a slightly greater average RDP from warning onset to stop bar (roughly 0.04 g) than those in the Speech group. Similar results were observed for RDP from braking onset to stop bar ($F[2,18]=5.98$, $p=0.0105$, correlated with time to brake), RDP from warning onset to collision zone ($F[2,18]=8.44$, $p=0.0026$, correlated with time to accelerator release), and RDP from braking onset to collision zone ($F[1,19]=5.09$, $p=0.0361$)

Time to peak deceleration ($F[2,18]=7.85$, $p=0.0035$): This variable was correlated with time to brake. After accounting for the effect of this plan initiation variable, participants in the Beep Tone group were observed to achieve peak deceleration faster (by roughly 0.15 s) than those in the Speech group.

Table 9 Means of significant differences between the Speech and Beep Tone warning conditions.

Variable (N)	Speech Warning (16)	Beep Tone Warning (5)
Distance before stop bar (ft)	-4.22	1.88
Constant deceleration (g)	0.42	0.49
RDP from warning to stop bar (g)	0.34	0.36
RDP from brake to stop bar (g)	0.43	0.48
RDP from warning to collision zone (g)	0.27	0.29
RDP from brake to collision zone (g)	0.31	0.34
Time to peak deceleration (s)	2.43	2.25

Analysis of subjective data indicated no significant differences in responses between the Speech and Beep Tone warnings. However, a trend was observed indicating that participants in the Speech group felt more in control of the vehicle during the surprise event than those in the Beep Tone group.

The most intriguing result of this comparison was the relative difference in compliance percentages. Although compliant participants in the Beep Tone group reacted more quickly and stopped farther away from the collision zone, participants in the Speech group complied with the warning at a much higher percentage. It should be noted that the unbalanced number of compliant participants across the comparison studies used for this Beep Tone versus Speech warning analysis necessarily confounds the analysis of stopping distance and deceleration behavior (which is based only on compliant participants). Hence, the main conclusion from this comparison is that the Speech warning appears to contribute to an increase in warning effectiveness relative to a Beep Tone warning when both are coupled with the brake pulse warning.

3.3.6 The Influence of PBA

Recall that for a subset of participants, additional trials were completed following the surprise trials that aimed to examine the extent to which Panic Brake Assist (PBA) may be activated during intersection approaches, and if so, the nature of the braking behavior that would be observed. During these "alerted" trials, subjects were instructed to wait for an auditory alert as a signal to brake hard to come to a stop at the intersection, but were not given a specific target stopping location.

Five different sensitivities of PBA were tested. Higher sensitivities indicated a less stringent activation threshold, which was expected to increase the frequency with which PBA was activated. Results for these different sensitivities are illustrated in Appendix J, Table 22 through Table 26. Overall, of 88 additional trials run, 27 elicited a stop which activated PBA (31% of trials). The high sensitivity PBA group showed the highest percentage of PBA activation (54%), while the low sensitivity PBA group showed the lowest percentage of PBA activation (23%).

As expected, participants who activated the PBA system (and hence, violated the PBA entrance criterion) tended to experience harder decelerations and stopped before those who did not activate PBA. However, very few participants activated PBA, resulting in unbalanced samples.

Furthermore, participants who did not activate PBA still tended to stop well short of the collision zone, suggesting that PBA was not strictly required for drivers to stop before the collision zone. While one might hypothesize that presenting the warning at later timing would necessarily results in more PBA system activations, the authors speculated that under late timing conditions (e.g., 1.84 TTI) drivers may decide to proceed through the intersection based on their perception that it is not possible to safely stop at the intersection (even though the vehicle may be capable of a safe stop).

In any case, these results should not be taken to represent a general measure of the effectiveness of PBA within the intersection violation scenario. Participants in these conditions were expecting the need for a hard braking (which may have yielded more controlled stops), and there was no consequence due to potential cross traffic. Thus, these experimental conditions may underestimate the potential benefits of a PBA system under real-world driving conditions. Further discussion of PBA in the context of the surprise condition is provided in the next section, as one of the main implications of the Subtask 3.3 effort.

4 Implications and Recommendations

The results presented in the previous section showcase the substantial differences in driver performance and behavior that can result from the use of different DVIs and the timing at which those DVIs are presented for TCD violation warning. These differences were present during both plan initiation (i.e., pre-braking behavior) and plan execution (i.e., braking behavior) stages and in some cases resulted in significant differences in compliance with the different warning combinations. In many instances, observable, sensible, and orderly trends suggested that further statistically significant differences may have been found with larger sample sizes than those employed in the current studies. This section summarizes the key differences and trends observed in the current studies and suggests future research directions.

The main implication of the results from all 11 studies is the selection of a DVI for Subtask 3.4 of the CICAS-V program. Driver behavior, performance, and compliance with the warnings (as well as subjective data) suggest that the Visual icon + Speech (‘Stop Light’) + Brake Pulse warning has the higher probability of success amongst the warnings tested. Therefore, this warning is recommended for the CICAS-V Subtask 3.4 pilot test. The warning, which contains elements from the visual, auditory, and haptic modalities, also performed relatively well across a number of relatively late presentation timings, which may have positive implications for the Subtask 3.2 algorithm development aimed at addressing the potential nuisance alert implications (e.g., anticipated alert rates) of various alert timing approaches.

Before focusing on differences between warnings, it is relevant to note that Age and Gender generally failed to notably affect driver performance and behavior. Although the limited sample sizes (further reduced by the fact that not all drivers within a sample were compliant) prevented statistical comparisons in most cases, observation of compliance trends did not suggest any increased compliance likelihood for particular age and gender combinations. Hence, these results tentatively suggest that driver age and gender effects do not exert an important influence on an intersection violation warning effectiveness.

With no evidence that Age and Gender are significant factors thus far, five main research questions were addressed by the studies in this effort (as described in the Introduction to this report). Based on the results of the statistical analyses and observation of trends (as discussed in Section 3.3), the remainder of this section provides summary answers to these questions and indicates areas where further research is needed.

4.1 Are there differences in the outcome of experiments employing occlusion versus naturalistic distraction techniques that would make either more useful for evaluation of the different DVIs?

The ICAV and IDS studies used occlusion as the method to induce ‘distraction’ during the surprise trial. While the occlusion method worked well in the context of those studies (where it was sufficient to make relative comparisons between countermeasures under well-controlled experimental conditions), the question remained as to whether their output could be effectively used for the estimation of safety benefits (one of the goals of the CICAS-V effort). In addition, it cannot be stated with absolute certainty that the relative differences observed with the occlusion method would necessarily be preserved under more naturalistic distraction conditions. To address these issues, the occlusion approach was compared to a naturalistic distraction protocol.

The significant differences observed between results for both protocols suggested that the naturalistic method would be more useful in supporting the use of these data to achieve the goals of CICAS-V. Although compliance rates were not statistically different between the occlusion and naturalistic protocol methods, compliance levels were about 30% higher for the occlusion protocol. In addition, significant differences were observed for many driver performance variables, which indicated that drivers in the occlusion protocol generally reacted faster and braked slightly harder than did naturalistic protocol drivers. These results suggest that there may be different underlying factors at play when drivers are asked to respond to the intersection approach scenario in the occlusion relative to the naturalistic method. In any case, since the naturalistic protocol provided a closer approximation to real-world driving and the naturalistic distraction technique proved to be reasonably effective (i.e., most subjects were caught looking down when the alert was presented), the naturalistic distraction method was selected as the approach of choice for the remainder of the tests with different warning combinations. It should be noted that although it may be possible to determine correction factors that allow generalization of occlusion protocol data to naturalistic data, this determination was beyond the scope of the current research effort and could not be addressed while meeting project timing requirements.

4.2 Within the auditory modality, how does the effectiveness of speech warnings compare to non-speech warnings?

There were two auditory warnings of primary interest, the CAMP Tone and the Speech (‘Stop Light’) warning. There were no significant differences observed between the CAMP Tone and Speech (‘Stop Light’) warnings with or without the brake pulse warning. However, compliance rates suggested there may be a slightly increased likelihood of stopping with the Speech (‘Stop Light’) warning over the CAMP Tone.

A third auditory warning, in the form of a Beep Tone, was also tested on an exploratory basis in attempt to potentially reduce potential driver annoyance issues associated with the CAMP tone. This tone was accompanied by a brake pulse. The main goal of using this tone was to determine if the lack of observable differences between the CAMP Tone and the Speech ('Stop Light') warnings also transferred to a less urgent (and hence, less annoying) sound. Since the tone was accompanied by a brake pulse, this would also determine the extent to which the Brake Pulse was the main factor in eliciting compliance (see the next section for further discussion of this topic). Results showed that the Beep Tone elicited a significantly lower compliance percentage than the Speech warning. Although participants that complied with the traffic signal after receiving the Beep Tone stopped slightly harder than those in the Speech warning condition, these differences are small from a practical perspective and may be the result of unbalanced data. Therefore, the Beep Tone was considered a less effective warning alternative and its use did not extend beyond the initial exploratory study.

4.3 Is scenario outcome improved by the addition of a brake pulse warning?

Results suggested that the brake pulse warning (i.e., a single, brief vehicle jerk cue) substantially improved driver compliance with the warning (relative to conditions without a brake pulse). This tendency towards improved compliance may have been due to significant differences in plan initiation (i.e., pre-braking behavior) and plan execution (i.e., braking behavior) variables. Drivers receiving a brake pulse were faster to react and reached peak deceleration faster than drivers who did not experience a brake pulse warning. This, in turn, required slightly less braking effort from drivers receiving a brake pulse warning than for drivers not receiving a brake pulse, even though drivers receiving a brake pulse were also able to brake to a stop in less distance.

Given that these results were observed across two different types of auditory warnings (CAMP Tone and Speech), it appears that the Brake Pulse was indeed a primary elicitor of compliance. However, recall that results with a Beep Tone auditory warning showed lower compliance levels than those observed for the Speech auditory warning. Therefore, although the Brake Pulse warning appears to be the primary factor in eliciting compliance, it is recommended based on the observed results that this warning be paired with a speech warning (which provided warning context) rather than a non-speech auditory warning.

4.4 Does the availability of Panic Brake Assist (PBA) functionality improve the scenario outcomes?

The availability of the PBA system, as well as the alteration of the PBA system entrance criterion across studies, had either a negligible or no effect towards improving the compliance rates. Across the studies in which it was available, PBA was seldom activated by drivers. Although every instance of PBA system activation resulted in compliance, it usually resulted in drivers stopping well short of the intersection stop bar. This suggests that the driver may have also complied without assistance from the activated PBA system.

It should be stressed that these results do not negate the potential effectiveness of PBA for other crash scenarios or for intersection violation scenarios under real-world conditions. Under these latter conditions, the consequences of crashing due a TCD violation are far more substantial than could be replicated under the current experimental conditions (which may result in higher incidence of PBA system activations).

4.5 Within the context of the experimental scenario, what is the effectiveness of each different DVI warning relative to when a warning was not presented?

This question would ideally be answered by examining driver compliance, performance, and behaviors during the surprise trial. However, comparisons of driver performance and behaviors beyond compliance were not possible, since only one driver complied with the traffic signal when a warning was not presented. This result, however, produced a significant difference in compliance between the Baseline condition (in which drivers did not receive a warning) and all other similarly timed warning conditions. As shown earlier in Table 3, baseline drivers were substantially less likely to comply with the traffic signal. While the real-world magnitude of these differences is subject to statistical confidence (Table 10), differences in compliance rates suggest substantial improvements for most of the warnings, especially those employing a brake pulse. The minimum and maximum benefit estimates are based on 95%confidence intervals and calculated by subtracting the lower and upper confidence limits of the Baseline case from the corresponding limit on each warning condition. For example, the Study 3 lower and upper confidence limits are 16.4% and 61.4%, respectively. Therefore, at a minimum, that warning condition has a 16.4% - 16.1 % = 0.3% benefit (the 16.1% is the upper confidence limit for the baseline condition). Likewise, at most, that warning condition has a 61.4% - 0.0% = 61.4% benefit (the 0.0% is the lower confidence limit for the baseline condition).

Table 10 Compliance percentage comparisons of warning conditions against a baseline.

Study	Compliance	Minimum Benefit	Maximum Benefit
CAMP Tone, No Brake Pulse (Study 3)	39%	0.3%	61%
Speech, No Brake Pulse (Study 4)	39%	0.3%	61%
CAMP Tone with Brake Pulse (Study 5)	78%	43%	97%
Speech with Brake Pulse (Study 6)	94%	68%	~100%
Baseline Condition (Study 11)	5.6%	--	--

4.6 Recommendations

The results suggest a number of potential recommendations for the design and implementation of DVIs for intersection violation avoidance systems. These are:

- The brake pulse warning appears to play the primary, dominant role in the observed effectiveness of this warning format, and therefore should be strongly considered for inclusion as part of the DVI warning approach for intersection violation avoidance systems.

- The speech warning (which should accompany the brake pulse warning) appears to play a secondary role in the effectiveness of this warning format, and is preferred over a non-speech warning for inclusion as part of the DVI warning approach for this warning format. The speech warning provides relatively specific information with respect to the context of the warning.

- A visual warning, which it could be argued has had limited utility as a primary warning modality in this case, should be provided as a tool for the driver to confirm the type of multi-modal warning that he/she just received. This visual warning was included in all the studies, with no observation of instances where glance fixations were directed to the visual warning instead of the forward roadway.

- Amongst the warning formats tested, a Visual icon + Speech ('Stop Light') + Brake Pulse warning yielded the best TCD compliance results.

When combined with some of the warning modalities tested, PBA did not have any measurable effects on the outcome of the evaluations. No incompatibilities or issues were identified when PBA was active in combination with one or more other warnings tested in these studies. Instances of PBA activation in response to the different intersection violation warnings were rare under these experimental conditions. However, it should be stressed that the threat levels experienced by test participants in these test-track studies may not be representative of those experienced by drivers during real-world, intersection crash threat conditions (where there may be a higher incidence of PBA system activations). Furthermore, the results in no way support discounting PBA as ineffective in other driving situations where it may be activated.

The main goal of this series of studies was to inform the selection of a DVI for the CICAS-V system. In the process of accomplishing that goal, data were obtained that describe relative compliance levels and performance measures for these systems under a small sample of warning timings. While these compliance levels and performance measures (as a function of timing and warning) may inform the activation algorithm for CICAS-V, finalization of such algorithm should be based on data from real-world exposure to these systems. Input from Subtask 3.2 (which is examining naturalistic intersection approach data) could serve as an initial step in this algorithm development process. In particular, Subtask 3.2 will be able to provide guidance as to anticipated alert rates with various timing approaches, which can be used to help ensure the timing approach does not result in an unacceptable number of alerts perceived as "too early" or unnecessary.

5 References

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6 Appendices

6.1 Appendix A: Driver Screening Questionnaire

4. Note to Researcher:

5. Initial contact between participants and researchers may take place over the phone. If this is the case, read the following Introductory Statement, followed by the questionnaire. Regardless of how contact is made, this questionnaire must be administered verbally before a decision is made regarding suitability for this study. **Do not place any participant information on this questionnaire**, it should only be used to record participant answers. Once eligibility has been determined (i.e., the participant answers comply with all the screening criteria) and you've recorded the participant information on the last page, discard the rest of this questionnaire.

6. Introductory Statement:

7. After prospective participant calls or you call them, use the following script as a guideline in the screening interview.

8. Hello. My name is **_____** and I'm a researcher with the Virginia Tech Transportation Institute in Blacksburg, VA. We are currently recruiting people to participate in a research study. This study involves participating in one driving session during daylight hours. The session lasts approximately one hour. Participants will be paid $20.00 per hour. Participants will drive a vehicle that will be equipped with data collection equipment on the Smart Road and grounds of VTTI. Does this sound interesting to you?

9. If No, thank them for their time and finish the call.

10. If Yes:

11. First, I would like to collect some information from you to determine if you're eligible.

1. **Do you have a valid unrestricted driver's license?**
    - **Yes**
    - **No**

(STOP and tell them they're not eligible for the study if they answer No)

2. **How old are you? _______________**

(STOP and tell them they're not eligible for the study if they are not 20-30, 40-50, or 60-70)

3. **Are you eligible for employment in the United States? Please note that we are NOT offering employment to you.**
    - **Yes**
    - **No**

(STOP and tell them they're not eligible for the study if they answer No)

4. **Are you able to drive an automatic transmission without assistive devices or special equipment?**
    - **Yes**
    - **No**

(STOP and tell them they're not eligible for the study if they answer No)

5. **Have you participated in any experiments at the Virginia Tech Transportation Institute? If "yes," please briefly describe the study.**
    - **Yes ____**
    - **No**

(STOP and tell them they're not eligible for the study if they have participated in previous studies involving surprise trials)

6. **Have you had any moving violations in the past 3 years? If so, please explain.**
    - **Yes ____**
    - **No**

(STOP and tell them they're not eligible for the study if they've had more than 2 in the past 3 years)

7. **Have you been involved in any accidents within the past 3 years? If so, please explain.**
    - **Yes ____**
    - **No**

(STOP and tell them they're not eligible if they've caused an accident resulting in injury in the past 3 years)

8. **Do you have a history of any of the following? If yes, please explain.**

12. Heart Condition No____
Yes____________________________
13. Stroke No____
Yes____________________________
14. Brain tumor No____
Yes____________________________
15. Head injury No____
Yes____________________________
16. Neck or back pain or injury No____
Yes____________________________
17. Epileptic seizures No____
Yes____________________________
18. Respiratory disorders No____
Yes____________________________
19. Motion sickness No____
Yes____________________________
20. Inner ear problems No____
Yes____________________________
21. Dizziness, vertigo, or other balance problems No___
22. Yes__________________________________
23. Diabetes No____
Yes____________________________
24. Migraine, tension headaches No____
Yes______________________
25. (See criterion 8 on next page to determine eligibility if they answer Yes to any of the conditions)

9. **(Females only, of course) Are you currently pregnant?** ***If yes, explain that they can not participate because the Virginia Tech IRB does not allow pregnant women to participate in this type of driving studies.***
   - **Yes**
   - **No**

10. **Are you currently taking any medications that may interfere with your driving ability (e.g., medications that may cause drowsiness, medication that may make you dizzy)? If yes, please list them.**
    - **Yes ____**

- **No**

(STOP and tell them they're not eligible if they're taking any substances that may interfere with their driving)

11. Do you have normal or corrected to normal hearing and vision? If no, please explain.

- **Yes**
- **No ____**

(STOP and tell them they're not eligible if they report CORRECTED vision lower than 20/40 or uncorrected hearing)

26. **<u>Criteria for Participation:</u>**

1. ***Must hold a valid driver's license.***
2. ***Must be 20-30, 40-50, or 60-70 years of age.***
3. ***Must be eligible for employment in the U.S.***
4. ***Must be able to drive an automatic transmission without special equipment.***
5. ***Must not have been a participant in previous VTTI studies involving surprise trials.***
6. ***Must not have more than two moving violations in the past three years.***
7. ***Must not have caused an injurious accident in the past two years.***
8. ***Must not have lingering effects of back or neck injury or pain. Cannot have lingering effects of heart condition, brain damage from stroke, tumor, head injury, recent concussion, or infection. Cannot have had epileptic seizures within 12 months, respiratory disorders, motion sickness, inner ear problems, dizziness, vertigo, balance problems, diabetes for which insulin is required, chronic migraine or tension headaches.***
9. ***Must not be pregnant.***
10. ***Cannot currently be taking any substances that may interfere with driving ability (cause drowsiness or impair motor abilities).***
11. ***Must have normal (or corrected to normal) hearing and vision.***

27. **If the Participant is Not Eligible:**

28. Unfortunately, you are not eligible to perform the study because ________________. Thanks for your time.

29. **If the Participant is Eligible:**

30. You're eligible to participate in this study. If you verify the following contact information, one of our researchers will contact you to determine a mutually agreeable time for you to complete the study.

6.2 Appendix B: Informed Consent Form for Occlusion Studies

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Information Sheet for Participants of Investigative Projects

Title of Project: **INVESTIGATION OF THE USE OF OCCLUSION GOGGLES TO SIMULATE THE DISTRACTED DRIVER**

Investigators: Brian Williams, Chris Edwards, Derek Viita, Kendra Wiegand, Miguel Perez, and Vicki Neale

I. The Purpose of this Research/Project

This experiment will look at whether a special type of goggles used to examine driver distraction behavior can be employed in future studies. These goggles are called occlusion goggles, and they will blank out for up to 2 seconds while you are driving. We are interested in whether driver behavior during those 2 seconds is similar to the behavior of a driver who is looking away from the road for up to 2 seconds due to an in-vehicle distraction such as tuning the radio.

II. Procedures

1. Read and sign this Information Sheet Form (if you agree to participate).
2. Show a current valid driver's license.
3. Complete questionnaires.
4. Complete a series of vision tests
5. Participate in the experimental session.

Your role during this session will be to drive a vehicle on the VTTI Smart Road facility. It is important that you understand that we are not evaluating you in any way. We are collecting information about drivers and the occlusion goggles.

III. Collection and Use of Personal Information

For purposes of this experiment, certain personal information will be collected from you such as your name, address, telephone number, taxpayer identification, video images, and health information. This information will be used only for the purposes described in this consent and will only be shared with individuals working on this experiment and the study sponsor. Digital video of your image will only be shared with the sponsor if you provide additional consent by checking the appropriate box in section XI of this form.

IV. Risks

Caution should be exercised when operating a vehicle with which you are not familiar. Be aware that accidents can happen at any time while driving.

As a participant, you may be exposed to the following risks or discomforts by volunteering for this research:

1) The risk of an accident normally present while driving.
2) Any risk present when driving a new and unfamiliar vehicle.
3) While you are driving the vehicle, cameras will videotape you. Due to this fact, we may ask you not to wear sunglasses. If this at any time during the course of the experiment this impairs your ability to drive the vehicle safely, please notify the experimenter.
4) If you have had previous eye injuries or surgeries you are at an increased risk of further eye injury by participating in a study where risks, although minimal, include the possibility of collision and airbag deployment.

The following precautions will be taken to ensure minimal risk to you:

1) You may take breaks or decide not to participate at any time.
2) The vehicle is equipped with a driver's side and passenger's side airbag supplemental restraint system, fire extinguisher and first-aid kit.
3) All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.
4) The experiment will not be run during hazardous road conditions, including wet or icy conditions.
5) You will be required to wear the lap and shoulder belt restraint system while in the car.
6) In the event of a medical emergency, or at your request, VTTI staff will arrange medical transportation to a nearby hospital emergency room. Note that in addition to the in-vehicle experimenter being present, the road and its communications channels are monitored by dispatchers at all times, who can quickly notify the necessary emergency services if required.

In the event of an accident or injury in an automobile, automobile liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, workers compensation does not apply to volunteers; therefore, if not in an automobile, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses.

V. Benefits of this Project

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study will contribute to the improvement of future studies concerning advanced vehicle systems.

VI. Extent of Anonymity and Confidentiality

The data gathered in this experiment, including the Health Screening Questionnaire, will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). If you choose to do so, you will be allowed to see your data and withdraw the data from the study if you so desire. If you want to base withdrawal of your data on observation of the data, you must ask for an appointment to see the data immediately after you finish your participation. If upon seeing your data you decide to withdraw it from the experiment, the data will be promptly removed and discarded. At no time will the researchers release data identifiable to an individual to anyone other than individuals working on the project without your written consent. VTTI will not turn over the video of your image to its client without your permission.

VII. Compensation

You will be paid $20.00 per hour for participating. You will be paid at the end of your experimental session in cash.

VIII. Freedom to Withdraw

As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any question or respond to experimental situations without penalty.

IX. Approval of Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained.

X. Subject's Responsibilities

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To follow the experimental procedures as well as you can.
2. To inform the experimenter if you have difficulties of any type.
3. To wear your seat and lap belt.
4. To abide by the posted speed limits and traffic laws.
5. To abstain from any substances that will impair your ability to drive.
6. To drive the test vehicle in a safe and responsible manner.

XI. Participant's Permissions and acknowledgments

Check one of the following:

- ☐ I have **not** had an eye injury/eye surgery (including, but not limited to, LASIK, Radial Keratotomy, and cataract surgery.)

- ☐ I **have** had an eye injury/eye surgery and I have been informed of the possible risks to participants who have had eye surgery. I choose to accept this possible risk to participate in this study.

Check one of the following:

- ☐ VTTI **has my permission** to provide digital video including my image to the sponsor of this research. I understand that the sponsor will only use the video for research purposes.

- ☐ VTTI **does not have my permission** to provide digital video including my image to the sponsor of this research. I understand that VTTI will maintain possession of the digital video, and that it will only be used for research purposes.

XII. SUBJECT'S PERMISSION

I have read and understand the Information Sheet and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

____

Participant Signature   Date

____

Experimenter Signature   Date

Should I have any questions about this research or its conduct, I may contact:

Brian Williams	xxx-xxxx
Kendra Wiegand	xxx-xxxx
Miguel Perez	xxx-xxxx
Vicki Neale	xxx-xxxx
David Moore (Institutional Review Board Chair)	xxx-xxxx

6.3 Appendix C: Informed Consent Form for Naturalistic Studies

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Information Sheet for Participants of Investigative Projects

Title of Project: INVESTIGATION OF IN-VEHICLE DISTRACTIONS

Investigators: Brian Williams, Chris Edwards, Derek Viita, Kendra Wiegand, Miguel Perez, and Vicki Neale

I. The Purpose of this Research/Project

This experiment will look at in-vehicle tasks and their roles in driver distraction behavior. We are interested in what types of tasks can be employed in future driver distraction studies.

II. Procedures

1. Read and sign this Information Sheet Form (if you agree to participate).
2. Show a current valid driver's license.
3. Complete questionnaires.
4. Complete a series of vision tests
5. Participate in the experimental session.

Your role during this session will be to drive a vehicle on the VTTI Smart Road facility. It is important that you understand that we are not evaluating you in any way. We are collecting information about the influence of in-vehicle tasks on driving behavior.

III. Collection and Use of Personal Information

For purposes of this experiment, certain personal information will be collected from you such as your name, address, telephone number, taxpayer identification, video images, and health information. This information will be used only for the purposes described in this consent and will only be shared with individuals working on this experiment and the study sponsor. Digital video of your image will only be shared with the sponsor if you provide additional consent by checking the appropriate box in section XI of this form.

IV. Risks

Caution should be exercised when operating a vehicle with which you are not familiar. Be aware that accidents can happen at any time while driving.

As a participant, you may be exposed to the following risks or discomforts by volunteering for this research:

1) The risk of an accident normally present while driving.

2) Any risk present when driving a new and unfamiliar vehicle.
3) While you are driving the vehicle, cameras will videotape you. Due to this fact, we may ask you not to wear sunglasses. If this at any time during the course of the experiment this impairs your ability to drive the vehicle safely, please notify the experimenter.
4) If you have had previous eye injuries or surgeries you are at an increased risk of further eye injury by participating in a study where risks, although minimal, include the possibility of collision and airbag deployment.

The following precautions will be taken to ensure minimal risk to you:

1) You may take breaks or decide not to participate at any time.
2) The vehicle is equipped with a driver's side and passenger's side airbag supplemental restraint system, fire extinguisher and first-aid kit.
3) All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.
4) The experiment will not be run during hazardous road conditions, including wet or icy conditions.
5) You will be required to wear the lap and shoulder belt restraint system while in the car.
6) In the event of a medical emergency, or at your request, VTTI staff will arrange medical transportation to a nearby hospital emergency room. Note that in addition to the in-vehicle experimenter being present, the road and its communications channels are monitored by dispatchers at all times, who can quickly notify the necessary emergency services if required.
7) In the event of an accident or injury in an automobile, automobile liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, workers compensation does not apply to volunteers; therefore, if not in an automobile, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses.

V. Benefits of this Project

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study will contribute to the improvement of future studies concerning advanced vehicle systems.

VI. Extent of Anonymity and Confidentiality

The data gathered in this experiment, including the Health Screening Questionnaire, will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). If you choose to do so, you will be allowed to see your data and withdraw the data from the study if you so desire. If you want to base withdrawal of your data on observation of the data, you must ask for an appointment to see the data immediately after you finish your participation. If upon seeing your data you decide to withdraw it from the experiment, the data will be promptly removed and discarded. At no time will the researchers release data identifiable to an individual to anyone other than individuals working on the project without your written consent. VTTI will not turn over the video of your image to its client without your permission.

VII. Compensation

You will be paid $20.00 per hour for participating. You will be paid at the end of your experimental session in cash.

VIII. Freedom to Withdraw

As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any question or respond to experimental situations without penalty.

IX. Approval of Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained.

X. Subject's Responsibilities

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To follow the experimental procedures as well as you can.
2. To inform the experimenter if you have difficulties of any type.
3. To wear your seat and lap belt.
4. To abide by the posted speed limits and traffic laws.
5. To abstain from any substances that will impair your ability to drive.
6. To drive the test vehicle in a safe and responsible manner.

XI. Participant's Permissions and acknowledgments

Check one of the following:

☐ I have **not** had an eye injury/eye surgery (including, but not limited to, LASIK, Radial Keratotomy, and cataract surgery.)

☐ I **have** had an eye injury/eye surgery and I have been informed of the possible risks to participants who have had eye surgery. I choose to accept this possible risk to participate in this study.

Check one of the following:

- ☐ VTTI **has my permission** to provide digital video including my image to the sponsor of this research. I understand that the sponsor will only use the video for research purposes.

- ☐ VTTI **does not have my permission** to provide digital video including my image to the sponsor of this research. I understand that VTTI will maintain possession of the digital video, and that it will only be used for research purposes.

XII. Subject's Permission

I have read and understand the Information Sheet and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

____

Participant Signature Date

____

Experimenter Signature Date

Should I have any questions about this research or its conduct, I may contact:

Brian Williams	xxx-xxxx
Kendra Wiegand	xxx-xxxx
Miguel Perez	xxx-xxxx
Vicki Neale	xxx-xxxx
David Moore (Institutional Review Board Chair)	xxx-xxxx

6.4 Appendix D: Health Screening Questionnaire

Health Screening Questionnaire

1. Are you in good general health? Yes No

   If no, list any health-related conditions you are experiencing or have experienced in the recent past.
   ____
   ____
   ____
   ____

2. Have you, in the last 24 hours, experienced any of the following conditions?

Inadequate sleep	Yes	No
Hangover	Yes	No
Headache	Yes	No
Cold symptoms	Yes	No
Depression	Yes	No
Allergies	Yes	No
Emotional upset	Yes	No

3. Do you have a history of any of the following?

   Visual Impairment Yes No

   (If yes, please describe.)
   ____
   ____
   ____

   Seizures or other lapses of consciousness Yes No

   (If yes, please describe.)
   ____
   ____

Any disorders similar to the above or that would impair your driving ability Yes No

(If yes, please describe.) ____
____
____

4. List any prescription or non-prescription drugs you are currently taking or have taken in the last 24 hours that may interfere with your ability to drive (e.g., medications that may cause drowsiness, medications that may make you dizzy). ____
____

5. List the approximate amount of alcohol (beer, wine, fortified wine, or liquor) you have consumed in the last 24 hours. ____
____

6. Emergency Contact Information (Optional)
Name:______________________________
Telephone Number: ______________________

______________________________ ______________________________
Signature Date

For experimenter use:

Vision Test (Snellen) ________________

Color vision: __________
____
____
____

6.5 Appendix E: Informed Consent Debriefing Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent for Participants of Investigative Projects

Debriefing and Informed Consent for Participants of Investigative Projects

Title of Project: Cooperative Intersection Collision Avoidance Systems

Investigators: Brian Williams, Chris Edwards, Derek Viita, Kendra Wiegand, Miguel Perez, and Vicki Neale

THE PURPOSE OF THIS RESEARCH

The true purpose of this research is to evaluate a system which would warn drivers if they are about to run a red light or stop sign. One aspect of the research project deals with how people might respond to such a warning the first time they encounter it. To do this, we needed to create a situation in which you were presented with the warning while looking away from the forward roadway. If you had been looking directly at the road, you might have seen the light turn red and the data would not have been as useful. There was no "correct" or "incorrect" information in the data that you provided. We are simply evaluating how drivers respond to this situation. All known precautions were taken to ensure your complete safety throughout this session and during the presentation of the scenario. We would like to thank you for your participation in this study, as the results may contribute to future improvements of collision avoidance systems. We would also like to ask that you do not talk about the details of this study to others for at least 8 months after your participation as this may invalidate future data that may be collected.

We again assure you that all data will be treated with complete anonymity. Shortly after participating, your name will be separated from the data. A coding scheme will be employed to identify the data by subject number only (for example, Subject No. 3).

All other aspects of the earlier informed consent you signed, including risks, benefits, safety precautions, and your responsibilities, continue to apply to the remainder of this experiment.

I hereby acknowledge the above and give my voluntary consent for my data to be used in this project.

____

Participant's Signature   Date

Should I have any questions about this research or its conduct, I may contact:

Brian Williams	xxx-xxxx
Kendra Wiegand	xxx-xxxx

Miguel Perez	xxx-xxxx
Vicki Neale	xxx-xxxx
David Moore (Institutional Review Board Chair)	xxx-xxxx

6.6 Appendix F: Event Questionnaire (Stopped)

Participant Number: ____

Post-Unexpected Event Questionnaire for Those Who Stopped

The true purpose of this research is to evaluate warnings which are intended to warn you that you may be about to go through either a red light or stop sign, and you may have to stop quickly. One aspect of the research project deals with how people might respond to such a warning the first time they encounter it. To do this, we needed to create a situation where you were presented with the warning while not looking at the forward roadway. If you had been looking directly at the road, you might have seen the light turn red and the data would not have been as useful. There was no "correct" or "incorrect" information in the data that you provided. We are simply evaluating how drivers respond to this situation. All known precautions were taken to ensure your complete safety throughout this session and during the presentation of the scenario. Please let the experimenter know at this time if you would like further explanation before completing this questionnaire.

Questionnaire

There was no "correct," "incorrect," or expected way for you to respond.

Please **circle one number** that most closely corresponds to your experience during this stop.

1. I expected this event at the time it occurred.

Do Not at All Agree	1	2	3	4	5	6	7	Strongly Agree

2. What do you think about the timing of the warning?

Very Early	1	2	3	4	5	6	7	Very Late
				Just Right				

3. How comfortable was the stop you just made?

Very Uncomfortable	1	2	3	4	5	6	7	Very Comfortable

4. Please rate your level of vehicle control during the stop you just made.

Very Much In Control	1	2	3	4	5	6	7	Very Much Out of Control

5. Please rate your feeling of safety during the stop.

Not At All Safe	1	2	3	4	5	6	7	Very Safe

6. Did you notice anything come on or happen inside the car before you began braking?

Yes No

If yes, please describe what came on (please be as specific as possible).

7. Did you notice anything else come on or happen inside the car before you began braking?

Yes No

If yes, please describe what came on (please be as specific as possible).

If driver noticed a warning:

8. Please describe the warning you just received.

If driver noticed visual alert:

9. What color was the indicator?

10. Where was this indicator located?

11. Please describe the picture.

12. What does this picture mean to you?

If driver noticed auditory alert:

13. What was the type of sound you noticed?

14. Was the sound a tone, a word, or both?

If you heard a tone, please describe the sound.

If you heard a word, please say the word.

If driver noticed brake pulse alert:

15. Please describe the sensation or what you felt.

16. Why do you think this occurred? *After they answer, clarify that it was meant to be a warning, if it is not clearly understood.*

17. Please rate the strength and duration of the brake pulse using the following scales:

a. How would you rate the strength of the vehicle jerk that occurred during this warning?

1	2	3	4	5	6	7
Extremely Weak	Moderately Weak	Slightly Weak	Just Right	Slightly Strong	Moderately Strong	Extremely Strong

b. How would you rate the duration or length of this warning?

1	2	3	4	5	6	7

Extremely Short	Moderately Short	Slightly Short	Just Right	Slightly Long	Moderately Long	Extremely Long

18. How many times did you feel the car _______? (*use the term the participant used to refer to the system*)

19. How many times did you feel ______ happening?

6.7 Appendix G: Event Questionnaire (Did Not Stop)

Participant Number: ____

Post-Unexpected Event Questionnaire for Those Who Do Not Stop

The true purpose of this research is to evaluate warnings which are intended to warn you that you may be about to go through either a red light or stop sign, and you may have to stop quickly. One aspect of the research project deals with how people might respond to such a warning the first time they encounter it. To do this, we needed to create a situation where you were presented with the warning while not looking at the forward roadway. If you had been looking directly at the road, you might have seen the light turn red and the data would not have been as useful. There was no "correct" or "incorrect" information in the data that you provided. We are simply evaluating how drivers respond to this situation. All known precautions were taken to ensure your complete safety throughout this session and during the presentation of the scenario. Please let the experimenter know at this time if you would like further explanation before completing this questionnaire.

Questionnaire

There was no "correct," "incorrect," or expected way for you to respond.

Please **circle one number** that most closely corresponds to your experience during this stop.

1. I expected this event at the time it occurred.

Do Not at All Agree	1	2	3	4	5	6	7	Strongly Agree

2. What do you think about the timing of the warning?

Very Early	1	2	3	4 Just Right	5	6	7	Very Late

3. Why did you decide not to stop?

4. If I had decided to stop the car it would have been:

Not At All Difficult	1	2	3	4	5	6	7	Very Difficult

5. If I had decided to stop, I would have been:

Very Much In Control of the Vehicle	1	2	3	4	5	6	7	Very Much Out of Control of the Vehicle

6. Please rate your feeling of safety as you crossed the intersection

Not At All Safe	1	2	3	4	5	6	7	Very Safe

7. Did you notice anything come on or happen inside the car before you crossed the intersection?

Yes No

If yes, please describe what came on (please be as specific as possible).

8. Did you notice anything else come on or happen inside the car before you crossed the intersection?

Yes No

If yes, please describe what came on (please be as specific as possible).

If driver noticed a warning:

9. Please describe the warning you just received.

If driver noticed visual alert:

10. What color was the indicator?
11. Where was this indicator located?
12. Please describe the picture.
13. What does this picture mean to you?

If driver noticed auditory alert:

14. What was the type of sound you noticed?
15. Was the sound a tone, a word, or both?

    If you heard a tone, please describe the sound.

    If you heard a word, please say the word.

If driver noticed brake pulse alert:

16. Please describe the sensation or what you felt.
17. Why do you think this occurred? *After they answer, clarify that it was meant to be a warning, if it is not clearly understood.*
18. Please rate the strength and duration of the brake pulse using the following scales:

a. How would you rate the strength of the vehicle jerk that occurred during this warning?

1	2	3	4	5	6	7
Extremely Weak	Moderately Weak	Slightly Weak	Just Right	Slightly Strong	Moderately Strong	Extremely Strong

b. How would you rate the duration or length of this warning?

1	2	3	4	5	6	7
Extremely Short	Moderately Short	Slightly Short	Just Right	Slightly Long	Moderately Long	Extremely Long

19. How many times did you feel the car ________? (*use the term the participant used to refer to the system*)

20. How many times did you feel _______ happening?

6.8 Appendix H: Descriptive Statistics by Study

Table 11 Study 1. Summary dependent measures for the Visual icon + CAMP Tone warning at 2.24 s TTI (Occlusion protocol) condition.

Variable	N	Mean	Standard Deviation
Distance before stop bar (ft) [neg = beyond stop bar]	9	-2.3	2.0
Peak deceleration (g)	9	0.69	0.06
Constant deceleration (g)	9	0.48	0.05
Required deceleration from warning onset to stop bar (g)	9	0.35	0.01
Required deceleration from braking onset to stop bar (g)	9	0.53	0.04
Required deceleration from warning onset to collision zone (g)	9	0.28	0.01
Required deceleration from braking onset to collision zone (g)	9	0.37	0.02
Time to accelerator release (s)	9	0.35	0.06
Time to brake (s)	9	0.69	0.1
Time from accelerator to brake (s)	9	0.34	0.05
Time to peak deceleration (s)	9	2.54	0.58
Time from brake to peak deceleration (s)	9	1.84	0.61
Maximum brake velocity (%/s)	9	3.18	0.91
Time to first glance (s)	N.A.	N.A.	N.A.
Last glance duration (s)	N.A.	N.A.	N.A.
Time from stimulus to forward fixation (s)	N.A.	N.A.	N.A.
Number of glances	N.A.	N.A.	N.A.

Table 12 Study 2. Summary dependent measures for the Visual icon + CAMP Tone warning at 2.44 s TTI (Occlusion protocol) condition.

Variable	N	Mean	Standard Deviation
Distance before stop bar (ft) [neg = beyond stop bar]	13	-1.3	1.9
Peak deceleration (g)	13	0.65	0.06
Constant deceleration (g)	13	0.45	0.03
Required deceleration from warning onset to stop bar (g)	13	0.32	0.02
Required deceleration from braking onset to stop bar (g)	13	0.47	0.06
Required deceleration from warning onset to collision zone (g)	13	0.25	0.01
Required deceleration from braking onset to collision zone (g)	13	0.34	0.03
Time to accelerator release (s)	13	0.43	0.10
Time to brake (s)	13	0.80	0.13
Time from accelerator to brake (s)	13	0.37	0.06
Time to peak deceleration (s)	13	2.61	0.52
Time from brake to peak deceleration (s)	13	1.81	0.48
Maximum brake velocity (%/s)	13	3.29	1.13
Time to first glance (s)	N.A.	N.A.	N.A.
Last glance duration (s)	N.A.	N.A.	N.A.
Time from stimulus to forward fixation (s)	N.A.	N.A.	N.A.
Number of glances	N.A.	N.A.	N.A.

Table 13 Study 3. Summary dependent measures for the Visual icon + CAMP Tone warning at 2.44 s TTI (Natural Distraction protocol) condition.

Variable	N	Mean	Standard Deviation
Distance before stop bar (ft) [neg = beyond stop bar]	7	-4.3	2.3
Peak deceleration (g)	7	0.72	0.08
Constant deceleration (g)	7	0.48	0.08
Required deceleration from warning onset to stop bar (g)	7	0.32	0.02
Required deceleration from braking onset to stop bar (g)	7	0.55	0.08
Required deceleration from warning onset to collision zone (g)	7	0.25	0.02
Required deceleration from braking onset to collision zone (g)	7	0.39	0.05
Time to accelerator release (s)	7	0.69	0.40
Time to brake (s)	7	1.11	0.36
Time from accelerator to brake (s)	7	0.42	0.30
Time to peak deceleration (s)	7	2.97	0.63
Time from brake to peak deceleration (s)	7	1.84	0.65
Maximum brake velocity (%/s)	7	2.69	0.95
Time to first glance (s)			
- Compliers	7	0.37	0.30
- Non-compliers	11	0.60	0.40
Last glance duration (s)			
- Compliers	7	0.92	0.47
- Non-compliers	11	1.07	0.52
Time from stimulus to forward fixation (s)			
- Compliers	7	0.51	0.43
- Non-compliers	11	1.26	1.15
Number of glances			
- Compliers	7	2.00	1.00
- Non-compliers	11	1.73	0.9

Table 14 Study 4. Summary dependent measures for the Visual icon + Speech ('Stop Light') warning at 2.44 s TTI (Naturalistic Distraction protocol) condition.

Variable	N	Mean	Standard Deviation
Distance before stop bar (ft) [neg = beyond stop bar]	7	-3.8	2.4
Peak deceleration (g)	7	0.68	0.15
Constant deceleration (g)	7	0.49	0.07
Required deceleration from warning onset to stop bar (g)	7	0.33	0.02
Required deceleration from braking onset to stop bar (g)	7	0.58	0.11
Required deceleration from warning onset to collision zone (g)	7	0.26	0.02
Required deceleration from braking onset to collision zone (g)	7	0.40	0.07
Time to accelerator release (s)	7	0.66	0.23
Time to brake (s)	7	1.08	0.15
Time from accelerator to brake (s)	7	0.42	0.18
Time to peak deceleration (s)	7	2.98	0.34
Time from brake to peak deceleration (s)	7	1.90	0.34
Maximum brake velocity (%/s)	7	3.41	0.77
Time to first glance (s)			
- Compliers	7	0.78	0.57
- Non-compliers	11	0.73	0.58
Last glance duration (s)			
- Compliers	7	0.89	0.47
- Non-compliers	11	0.93	0.48
Time from stimulus to forward fixation (s)			
- Compliers	7	0.55	0.30
- Non-compliers	11	0.91	0.83
Number of glances			
- Compliers	7	1.29	0.49
- Non-compliers	11	1.45	0.69

Table 15 Study 5. Summary dependent measures for the Visual icon + CAMP Tone + Brake Pulse warning at 2.44 s TTI (Naturalistic Distraction protocol) condition.

Variable	N	Mean	Standard Deviation
Distance before stop bar (ft) [neg = beyond stop bar]	14	-0.3	2.1
Peak deceleration (g)	14	0.61	0.05
Constant deceleration (g)	14	0.41	0.05
Required deceleration from warning onset to stop bar (g)	14	0.32	0.02
Required deceleration from braking onset to stop bar (g)	14	0.42	0.07
Required deceleration from warning onset to collision zone (g)	14	0.26	0.02
Required deceleration from braking onset to collision zone (g)	14	0.31	0.05
Time to accelerator release (s)	14	0.24	0.07
Time to brake (s)	14	0.82	0.20
Time from accelerator to brake (s)	14	0.58	0.19
Time to peak deceleration (s)	14	2.33	0.67
Time from brake to peak deceleration (s)	14	1.48	0.64
Maximum brake velocity (%/s)	14	2.86	0.99
Time to first glance (s)			
- Compliers	14	0.61	0.33
- Non-compliers	4	0.49	0.36
Last glance duration (s)			
- Compliers	14	0.77	0.36
- Non-compliers	4	0.54	0.15
Time from stimulus to forward fixation (s)			
- Compliers	14	0.30	0.10
- Non-compliers	4	0.32	0.15
Number of glances			
- Compliers	14	1.29	0.61
- Non-compliers	4	1.50	0.60

Table 16 Study 6. Summary dependent measures for the Visual icon + Speech ('Stop Light') + Brake Pulse warning at 2.44 s TTI (Naturalistic Distraction protocol) condition.

Variable	N	Mean	Standard Deviation
Distance before stop bar (ft) [neg = beyond stop bar]	17	0.6	2.5
Peak deceleration (g)	17	0.60	0.07
Constant deceleration (g)	17	0.40	0.04
Required deceleration from warning onset to stop bar (g)	17	0.32	0.01
Required deceleration from braking onset to stop bar (g)	17	0.39	0.04
Required deceleration from warning onset to collision zone (g)	17	0.26	0.01
Required deceleration from braking onset to collision zone (g)	17	0.29	0.03
Time to accelerator release (s)	17	0.26	0.11
Time to brake (s)	17	0.74	0.14
Time from accelerator to brake (s)	17	0.48	0.11
Time to peak deceleration (s)	17	2.36	0.63
Time from brake to peak deceleration (s)	17	1.63	0.60
Maximum brake velocity (%/s)	17	2.98	0.83
Time to first glance (s)			
- Compliers	17	0.74	0.44
- Non-compliers	1	0.40	N.A.
Last glance duration (s)			
- Compliers	17	0.67	0.21
- Non-compliers	1	1.01	N.A.
Time from stimulus to forward fixation (s)			
- Compliers	17	0.29	0.13
- Non-compliers	1	0.36	N.A.
Number of glances			
- Compliers	17	1.24	0.56
- Non-compliers	1	1.00	N.A.

Table 17 Study 7. Summary dependent measures for the Visual icon + Beep Tone + Brake Pulse warning at 2.24 s TTI (Naturalistic Distraction method) condition.

Variable	N	Mean	Standard Deviation
Distance before stop bar (ft) [neg = beyond stop bar]	5	0.9	1.9
Peak deceleration (g)	5	0.76	0.11
Constant deceleration (g)	5	0.49	0.03
Required deceleration from warning onset to stop bar (g)	5	0.36	0.02
Required deceleration from braking onset to stop bar (g)	5	0.48	0.05
Required deceleration from warning onset to collision zone (g)	5	0.29	0.01
Required deceleration from braking onset to collision zone (g)	5	0.34	0.03
Time to accelerator release (s)	5	0.28	0.20
Time to brake (s)	5	0.77	0.14
Time from accelerator to brake (s)	5	0.49	0.16
Time to peak deceleration (s)	5	2.21	0.34
Time from brake to peak deceleration (s)	5	1.45	0.34
Maximum brake velocity (%/s)	5	3.37	0.86
Time to first glance (s)			
- Compliers	5	0.54	0.39
- Non-compliers	5	0.45	0.30
Last glance duration (s)			
- Compliers	5	0.75	0.38
- Non-compliers	5	0.80	0.40
Time from stimulus to forward fixation (s)			
- Compliers	5	0.31	0.17
- Non-compliers	5	0.28	0.13
Number of glances			
- Compliers	5	1.20	0.45
- Non-compliers	5	1.20	0.45

Table 18 Study 8. Summary dependent measures for the Visual icon + Speech ('Stop Light') + Brake Pulse warning at 2.24 s TTI (Naturalistic Distraction protocol) condition.

Variable	N	Mean	Standard Deviation
Distance before stop bar (ft) [neg = beyond stop bar]	16	-0.9	2.8
Peak deceleration (g)	16	0.72	0.16
Constant deceleration (g)	16	0.42	0.05
Required deceleration from warning onset to stop bar (g)	16	0.34	0.02
Required deceleration from braking onset to stop bar (g)	16	0.43	0.03
Required deceleration from warning onset to collision zone (g)	16	0.27	0.02
Required deceleration from braking onset to collision zone (g)	16	0.31	0.02
Time to accelerator release (s)	16	0.29	0.17
Time to brake (s)	16	0.79	0.17
Time from accelerator to brake (s)	16	0.50	0.11
Time to peak deceleration (s)	16	2.44	0.62
Time from brake to peak deceleration (s)	16	1.65	0.51
Maximum brake velocity (%/s)	16	2.92	1.04
Time to first glance (s)			
- Compliers	16	0.42	0.39
- Non-compliers	2	0.38	0.53
Last glance duration (s)			
- Compliers	16	0.78	0.29
- Non-compliers	2	0.63	0.18
Time from stimulus to forward fixation (s)			
- Compliers	16	0.27	0.18
- Non-compliers	2	0.35	0.05
Number of glances			
- Compliers	16	1.47	0.74
- Non-compliers	2	2.0	1.41

Table 19 Study 9. Summary dependent measures for the Visual icon + Speech ('Stop Light') + Brake Pulse warning at 2.04 s TTI (Naturalistic Distraction protocol) condition.

Variable	N	Mean	Standard Deviation
Distance before stop bar (ft) [neg = beyond stop bar]	7	-1.5	2.6
Peak deceleration (g)	7	0.74	0.06
Constant deceleration (g)	7	0.48	0.06
Required deceleration from warning onset to stop bar (g)	7	0.4	0.01
Required deceleration from braking onset to stop bar (g)	7	0.51	0.03
Required deceleration from warning onset to collision zone (g)	7	0.31	0.01
Required deceleration from braking onset to collision zone (g)	7	0.36	0.02
Time to accelerator release (s)	7	0.24	0.07
Time to brake (s)	7	0.69	0.12
Time from accelerator to brake (s)	7	0.45	0.13
Time to peak deceleration (s)	7	2.27	0.31
Time from brake to peak deceleration (s)	7	1.59	0.20
Maximum brake velocity (%/s)	7	3.19	1.91
Time to first glance (s)			
- Compliers	7	0.44	0.31
- Non-compliers	2	0.31	0.13
Last glance duration (s)			
- Compliers	7	0.59	0.30
- Non-compliers	2	1.25	0.07
Time from stimulus to forward fixation (s)			
- Compliers	7	0.18	0.15
- Non-compliers	2	0.27	0.01
Number of glances			
- Compliers	7	1.43	0.53
- Non-compliers	2	1.0	0.00

Table 20 Study 10. Summary dependent measures for the Visual icon + Speech ('Stop Light') + Brake Pulse warning at 1.84 s TTI (Naturalistic Distraction method) condition.

Variable	N	Mean	Standard Deviation
Distance before stop bar (ft) [neg = beyond stop bar]	3	-1.4	3.6
Peak deceleration (g)	3	0.90	0.29
Constant deceleration (g)	3	0.50	0.05
Required deceleration from warning onset to stop bar (g)	3	0.42	0.03
Required deceleration from braking onset to stop bar (g)	3	0.55	0.09
Required deceleration from warning onset to collision zone (g)	3	0.31	0.03
Required deceleration from braking onset to collision zone (g)	3	0.36	0.06
Time to accelerator release (s)	3	0.17	0.04
Time to brake (s)	3	0.63	0.13
Time from accelerator to brake (s)	3	0.46	0.17
Time to peak deceleration (s)	3	1.72	0.50
Time from brake to peak deceleration (s)	3	1.09	0.54
Maximum brake velocity (%/s)	3	3.92	0.39
Time to first glance (s)			
- Compliers	3	0.47	0.41
- Non-compliers	6	0.47	0.38
Last glance duration (s)			
- Compliers	3	0.54	0.26
- Non-compliers	6	0.63	0.21
Time from stimulus to forward fixation (s)			
- Compliers	3	0.30	0.09
- Non-compliers	6	0.35	0.07
Number of glances			
- Compliers	3	1.33	0.58
- Non-compliers	6	1.33	0.82

Table 21 Study 11. Summary dependent measures for the Baseline Condition (No warning), Light change stimulus at 2.44 s TTI (Naturalistic Distraction protocol) condition.

Variable	N	Mean	Standard Deviation
Distance before stop bar (ft) [neg = beyond stop bar]	1	-12.9	N.A.
Peak deceleration (g)	1	0.63	N.A.
Constant deceleration (g)	1	0.41	N.A.
Required deceleration from warning onset to stop bar (g)	1	0.29	N.A.
Required deceleration from braking onset to stop bar (g)	1	0.5	N.A.
Required deceleration from warning onset to collision zone (g)	1	0.23	N.A.
Required deceleration from braking onset to collision zone (g)	1	0.34	N.A.
Time to accelerator release (s)	1	0.69	N.A.
Time to brake (s)	1	1.06	N.A.
Time from accelerator to brake (s)	1	0.37	N.A.
Time to peak deceleration (s)	1	2.94	N.A.
Time from brake to peak deceleration (s)	1	1.89	N.A.
Maximum brake velocity (%/s)	1	2.35	N.A.
Time to first glance (s)			
- Compliers	1	0.57	N.A.
- Non-compliers	17	0.58	0.64
Last glance duration (s)			
- Compliers	1	0.81	N.A.
- Non-compliers	17	0.97	0.43
Time from stimulus to forward fixation (s)			
- Compliers	1	0.26	N.A.
- Non-compliers	17	1.06	0.80
Number of glances			
- Compliers	1	1.0	N.A.
- Non-compliers	17	1.88	0.86

6.9 Appendix I: Subjective Response Graphs

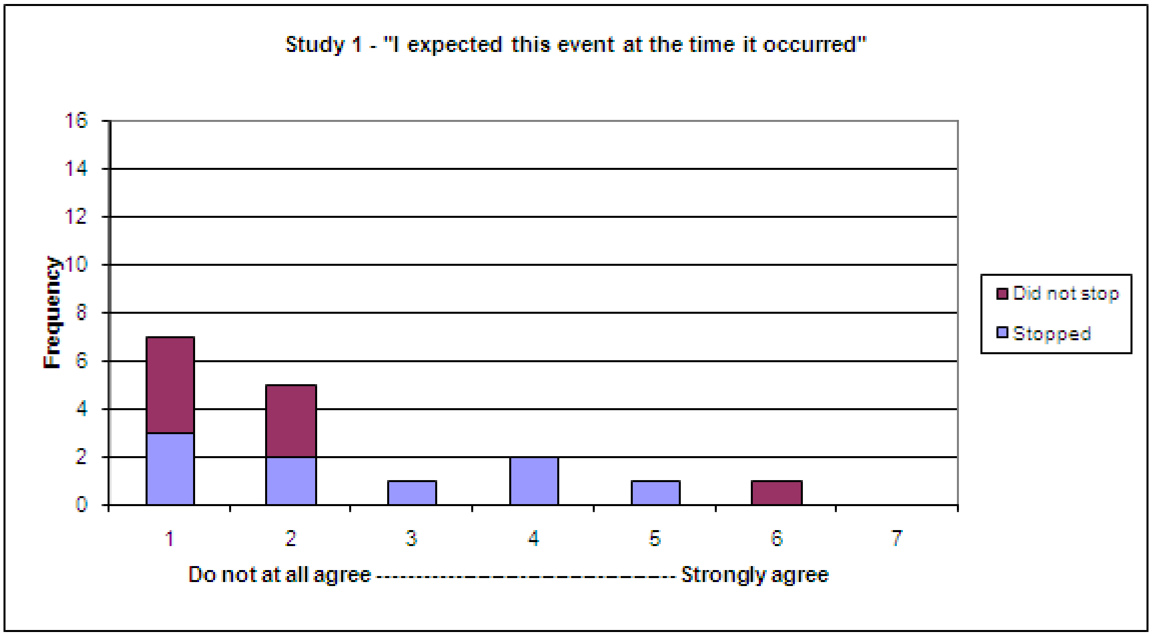

Figure 16 Surprise event expectation for Study 1.

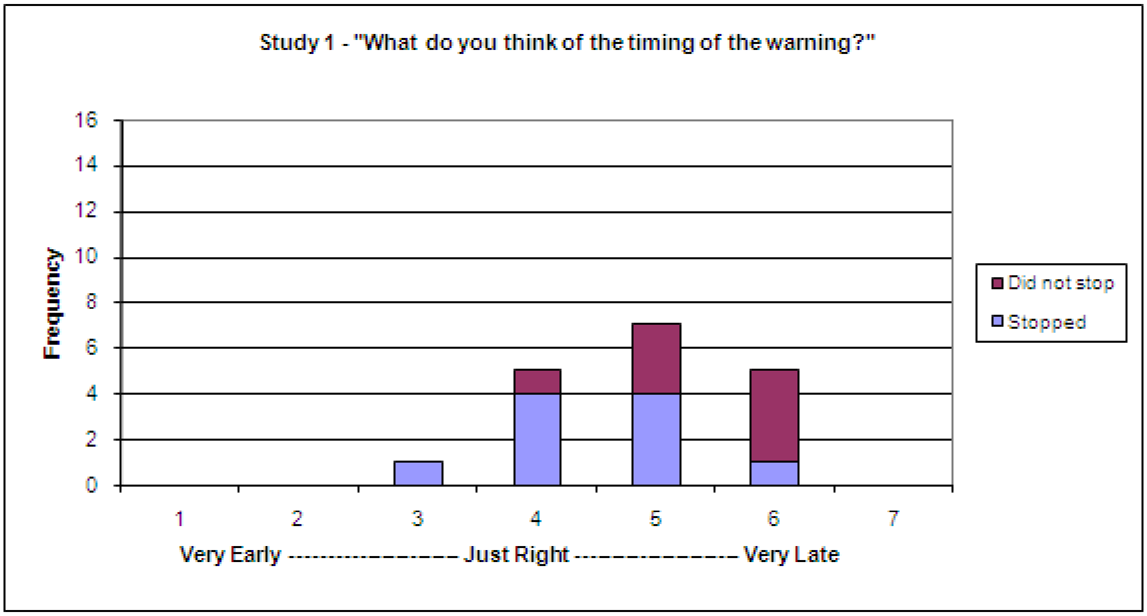

Figure 17 Rating of warning timing for Study 1.

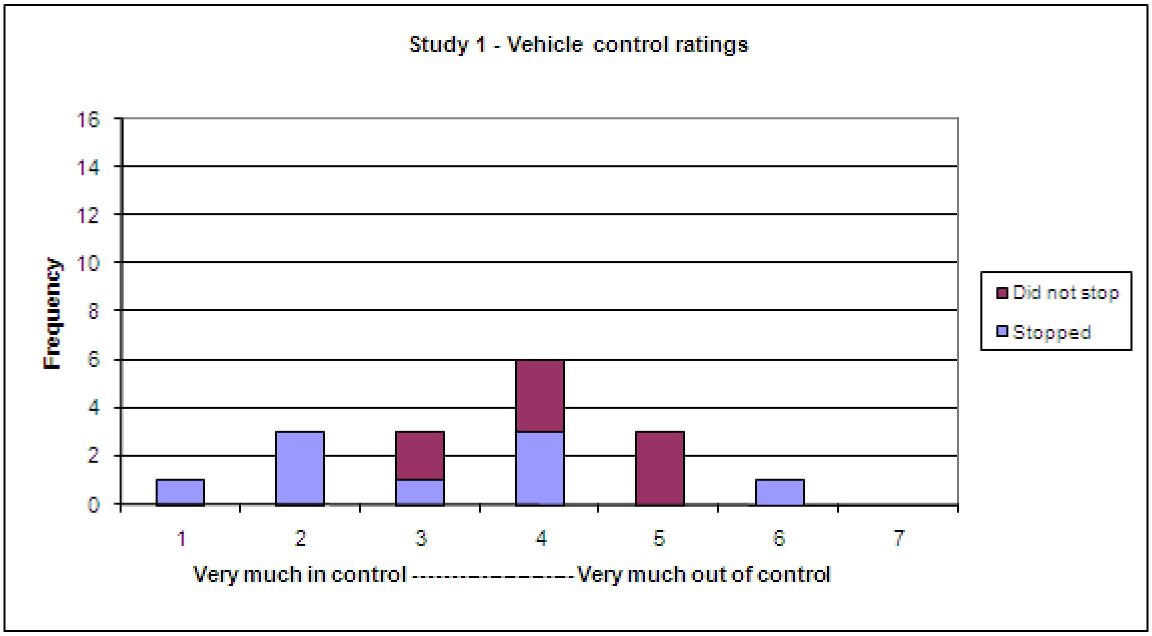

Figure 18 Vehicle control ratings for Study 1.

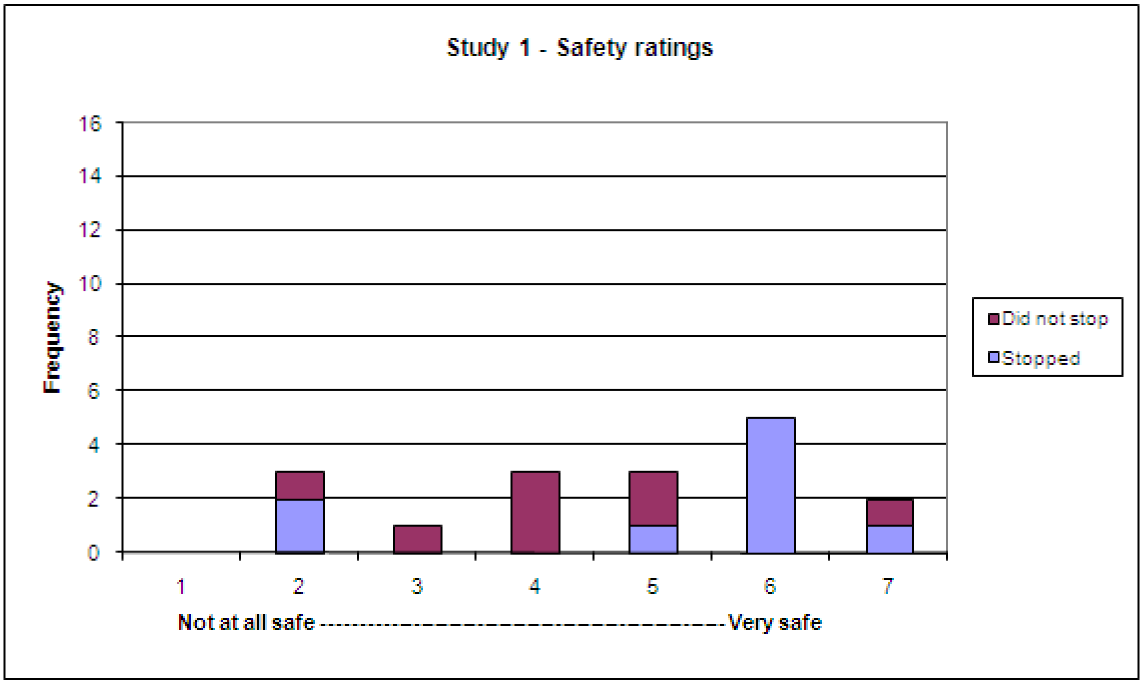

Figure 19 Safety ratings for Study 1.

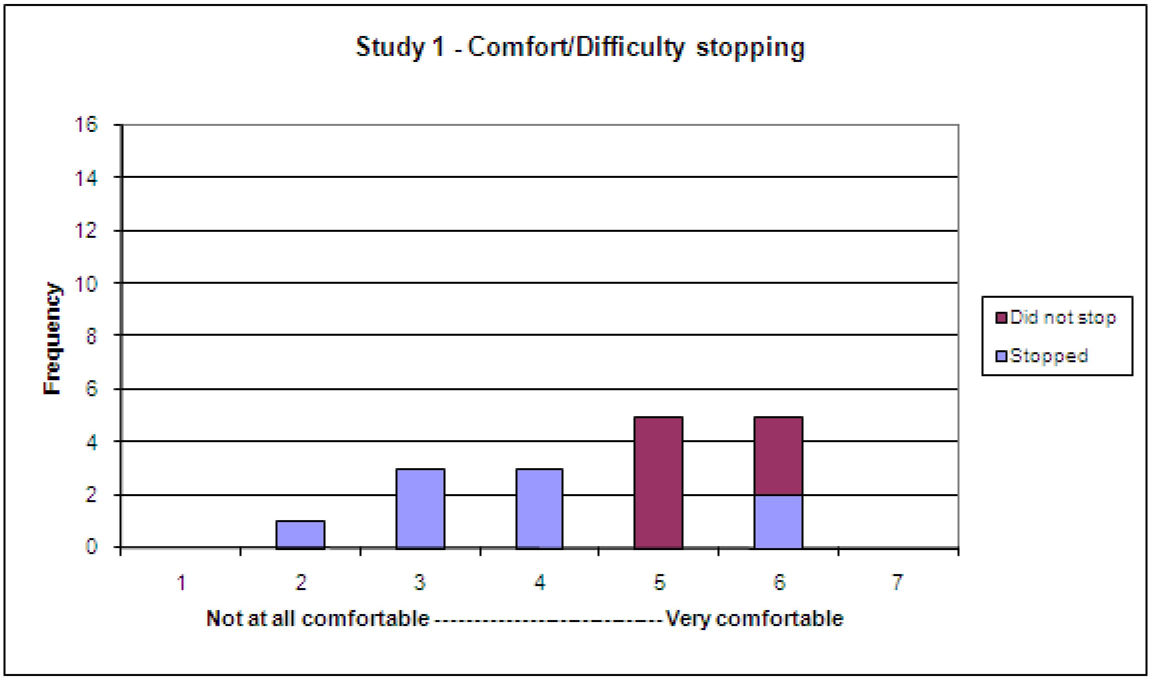

Figure 20 Rating comfort and difficulty stopping for Study 1.

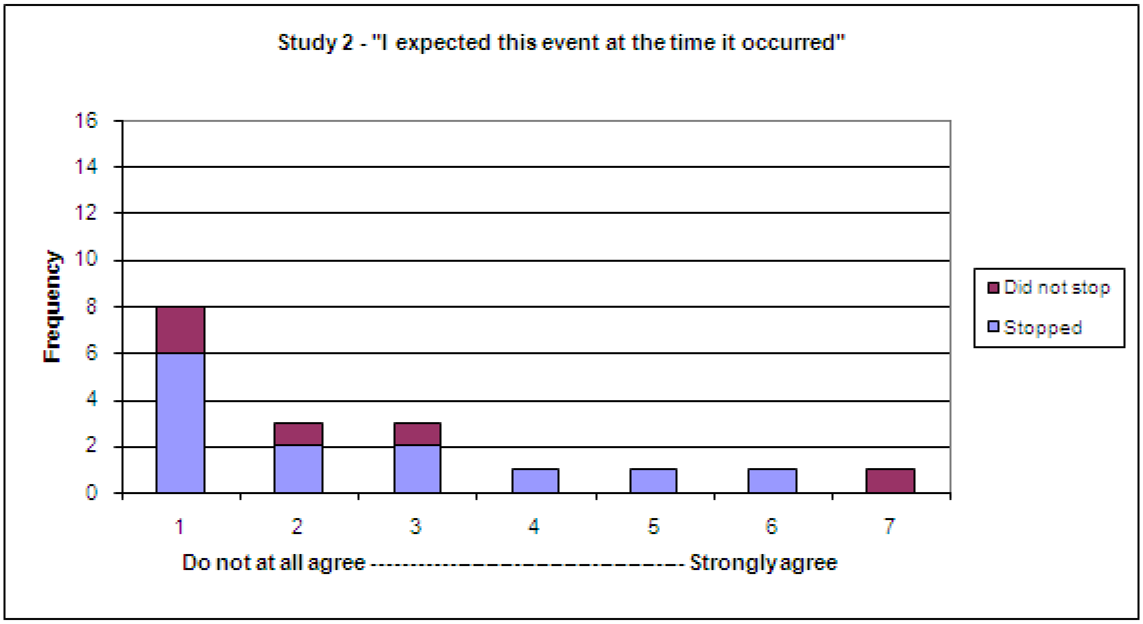

Figure 21 Surprise event expectation for Study 2.

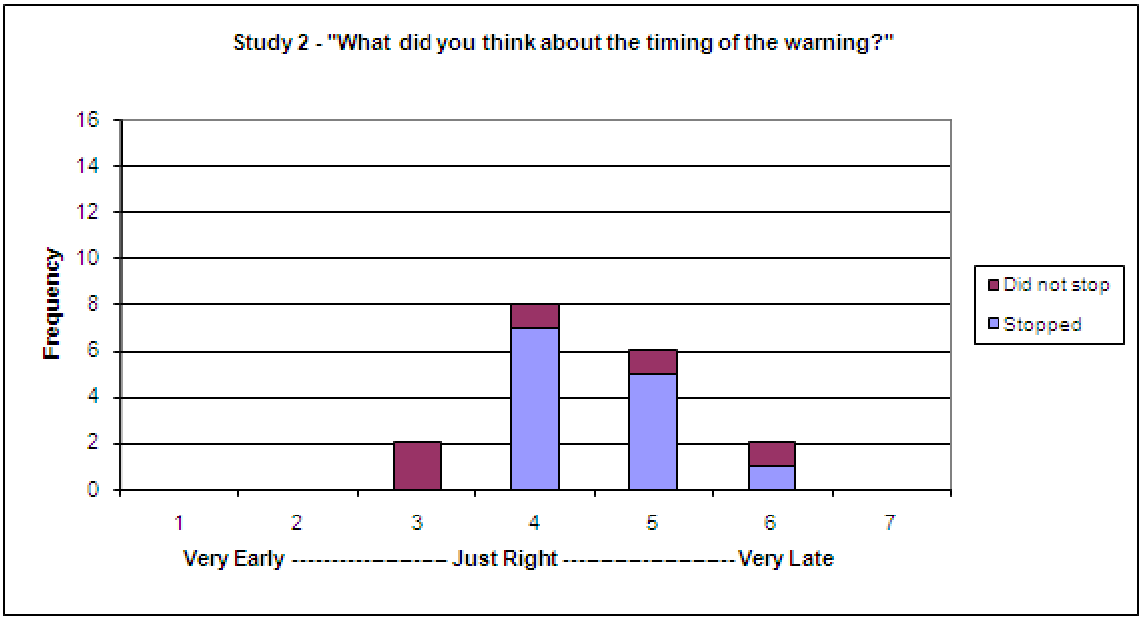

Figure 22 Rating of warning time for Study 2.

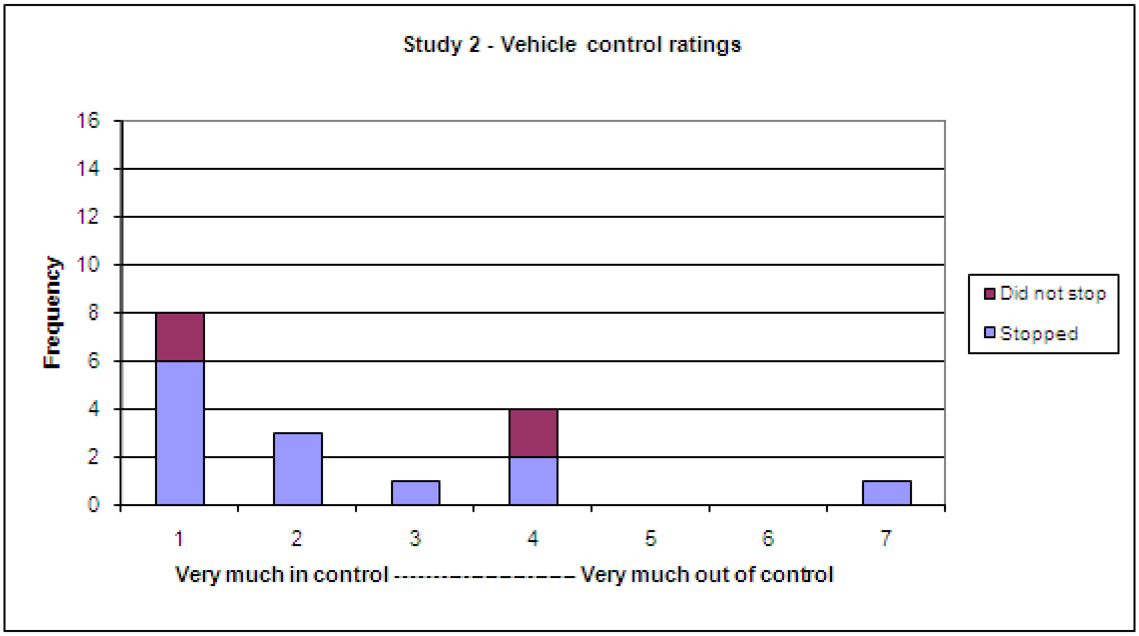

Figure 23 Vehicle control ratings for Study 2.

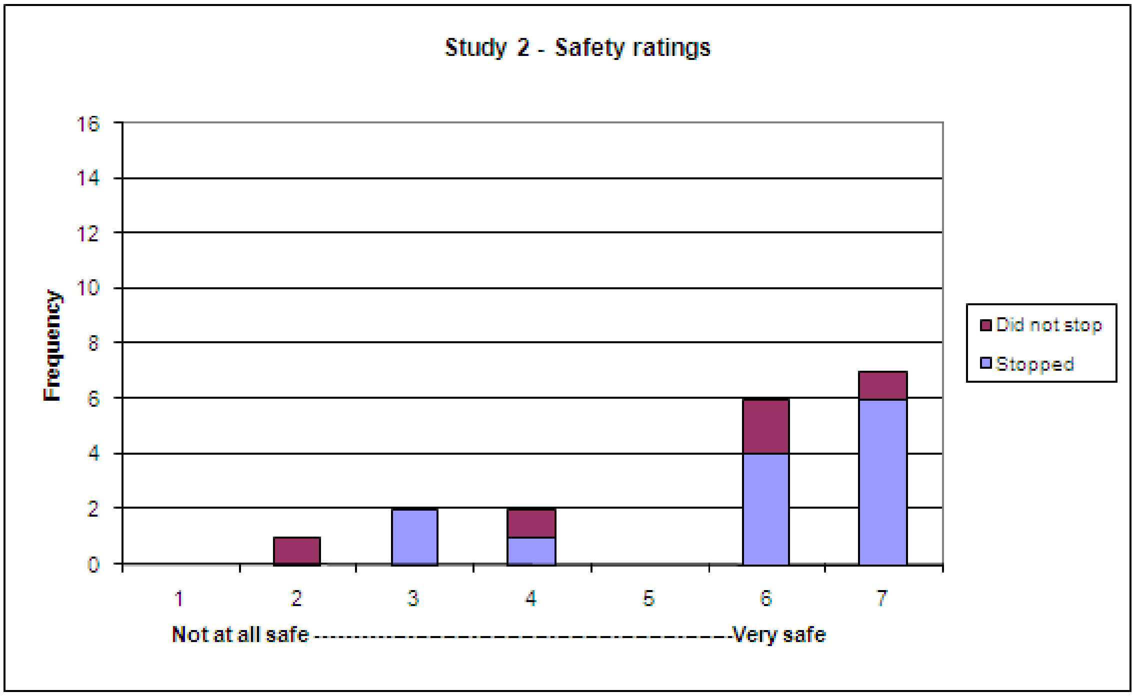

Figure 24 Safety ratings for Study 2.

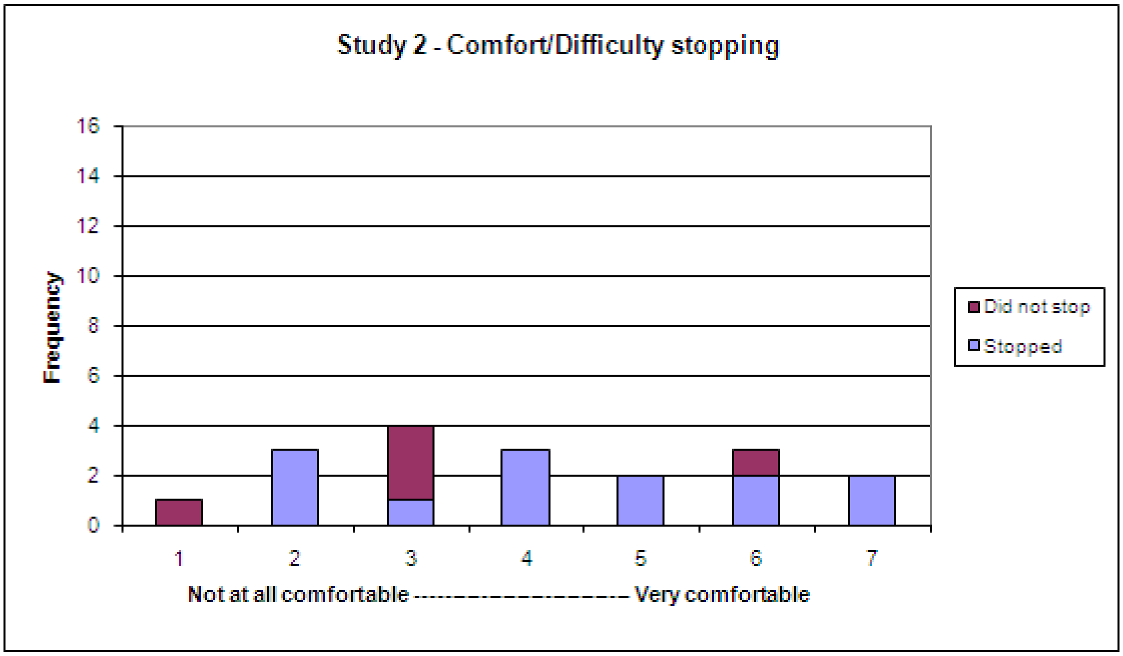

Figure 25 Rating comfort and difficulty stopping for Study 2.

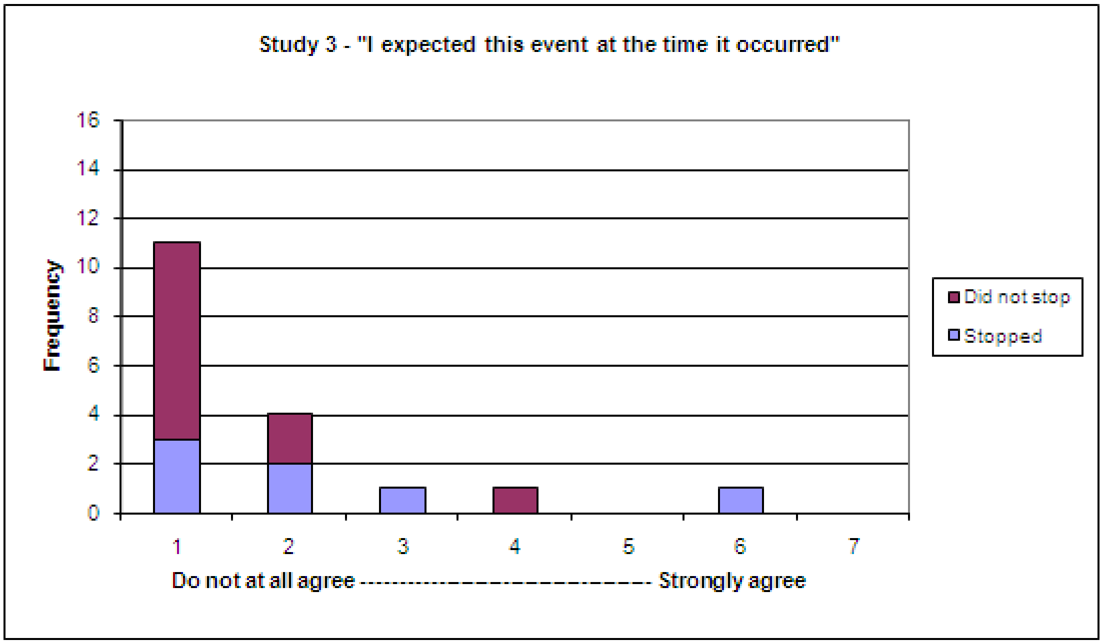

Figure 26 Surprise event expectation for Study 3.

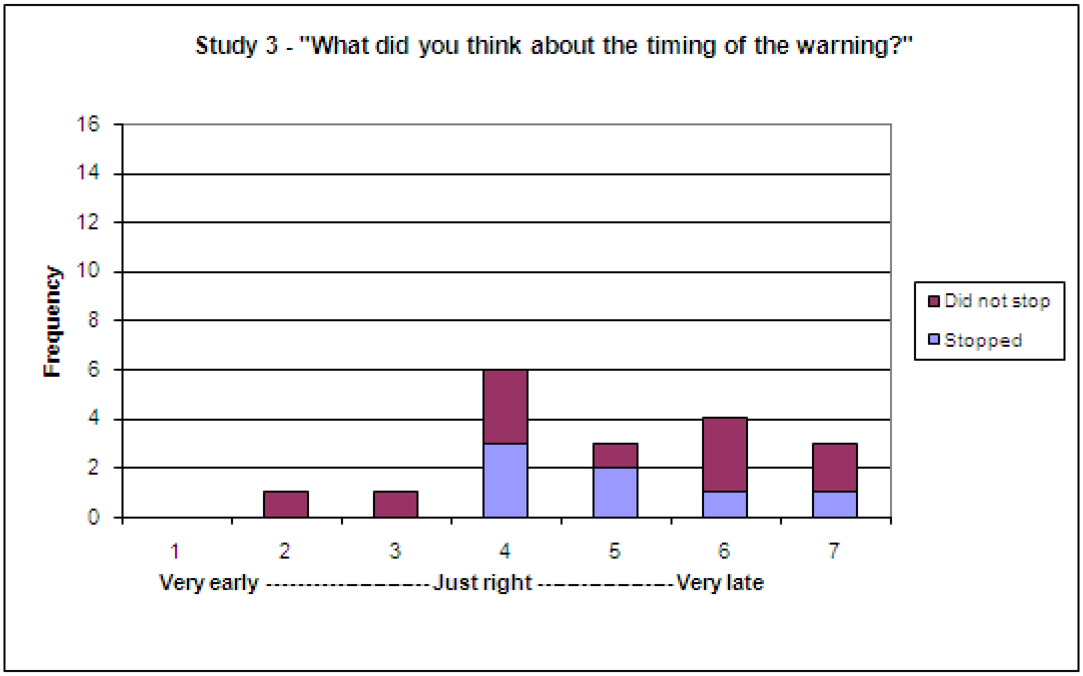

Figure 27 Rate of warning time for Study 3.

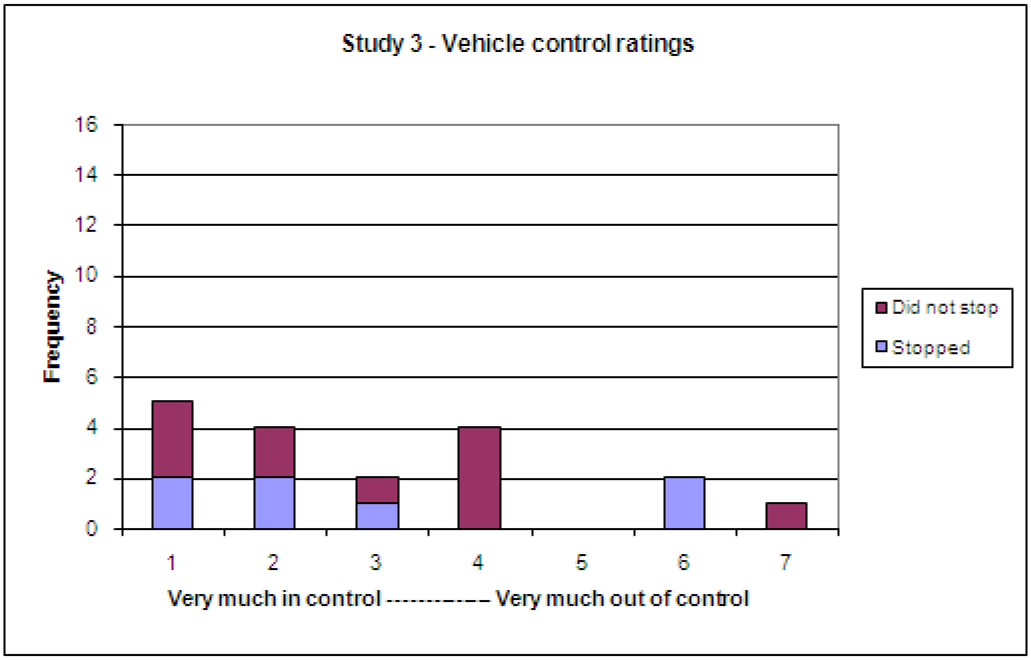

Figure 28 Vehicle control ratings for Study 3.

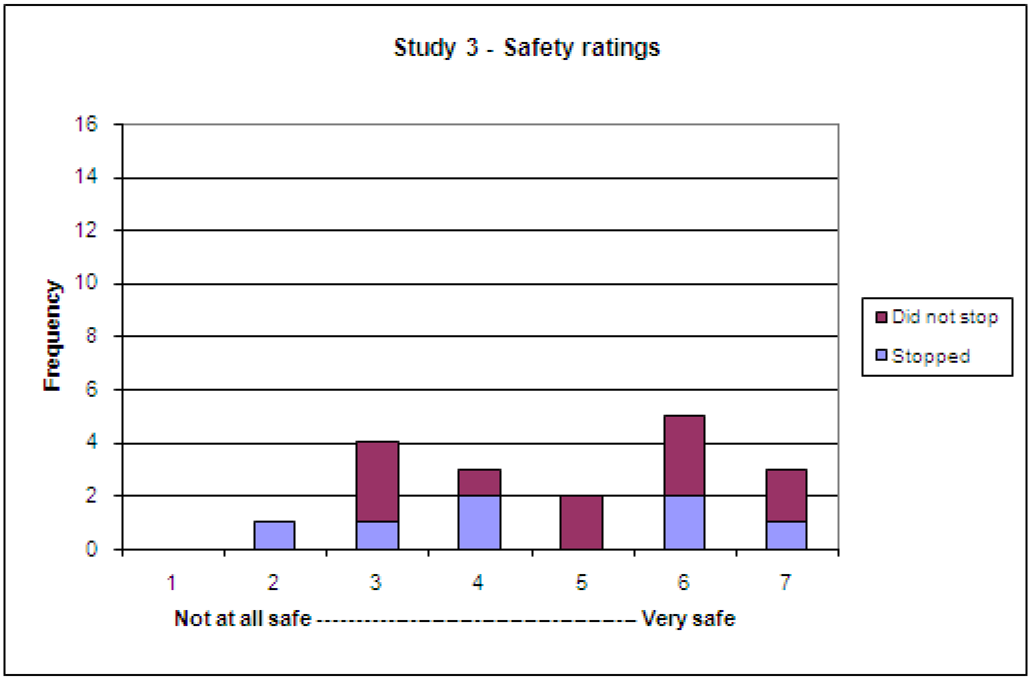

Figure 29 Safety ratings for Study 3.

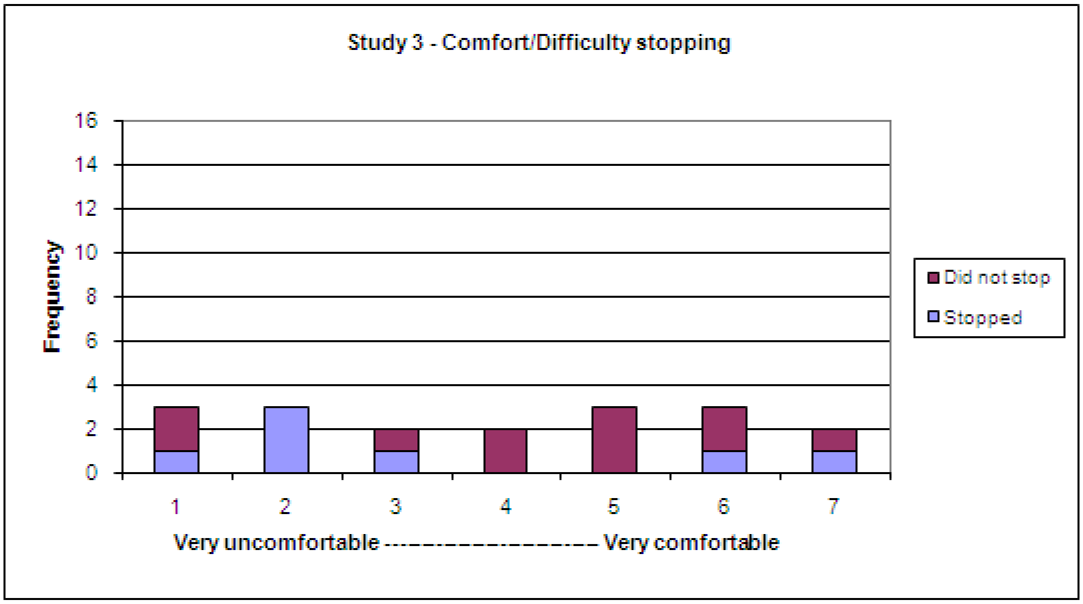

Figure 30 Rating comfort and difficulty stopping for Study 3.

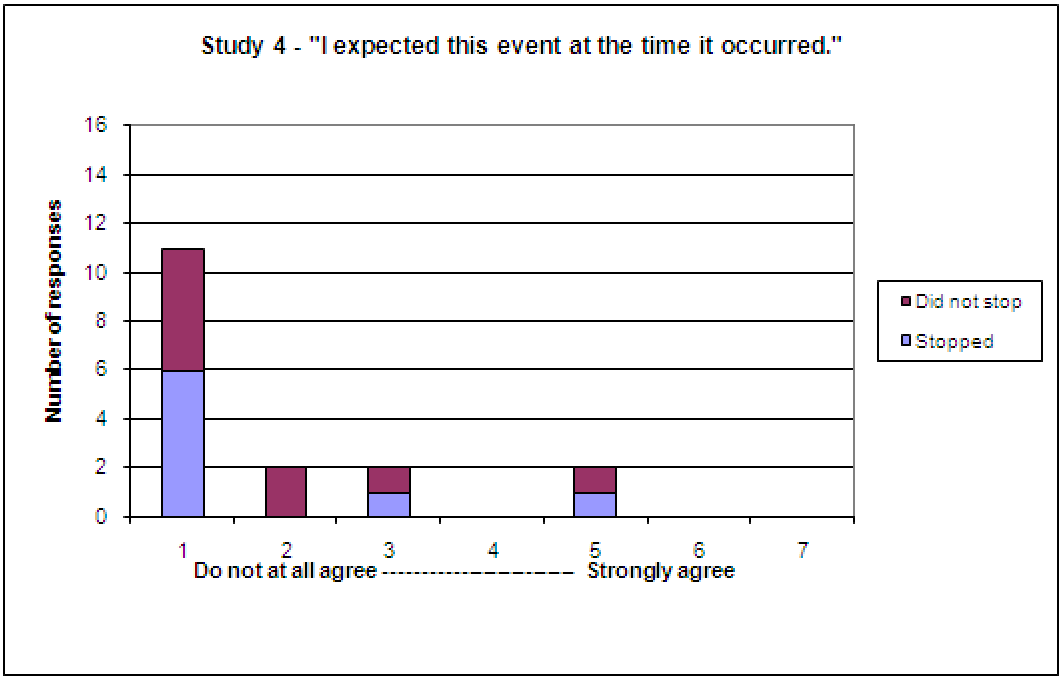

Figure 31 Surprise event expectation for Study 4.

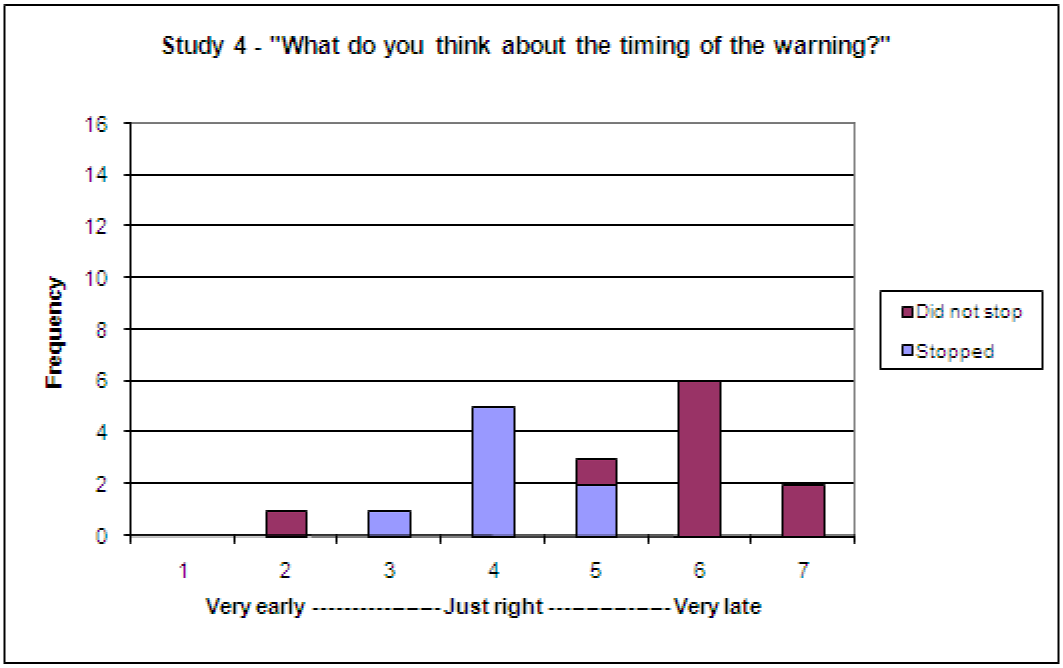

Figure 32 Rate of warning time for Study 4.

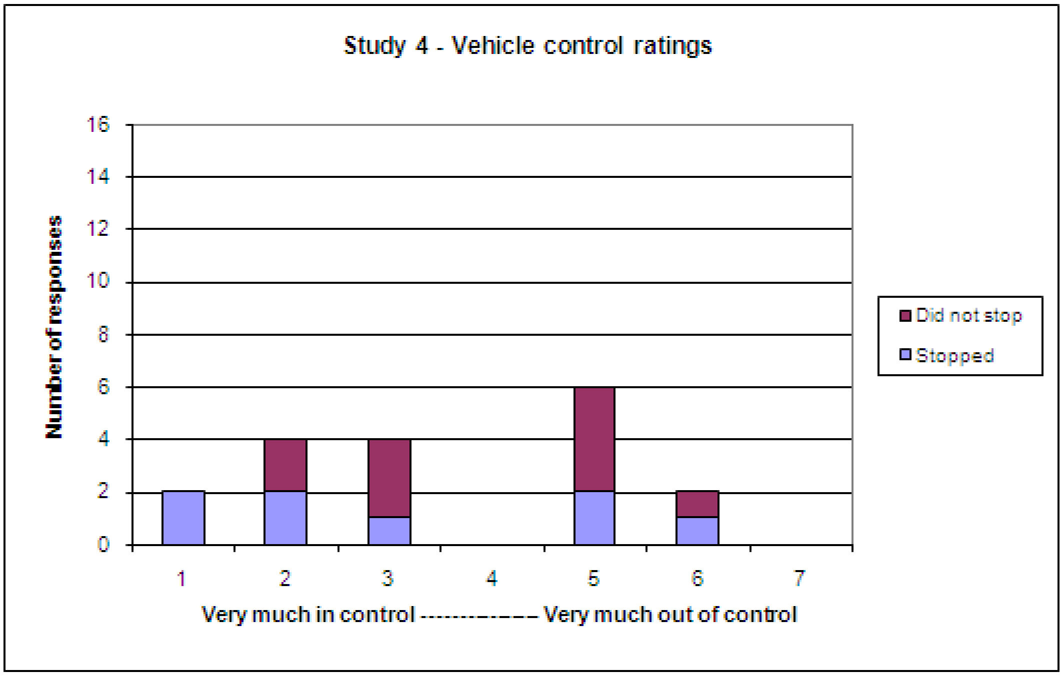

Figure 33 Vehicle control ratings for Study 4.

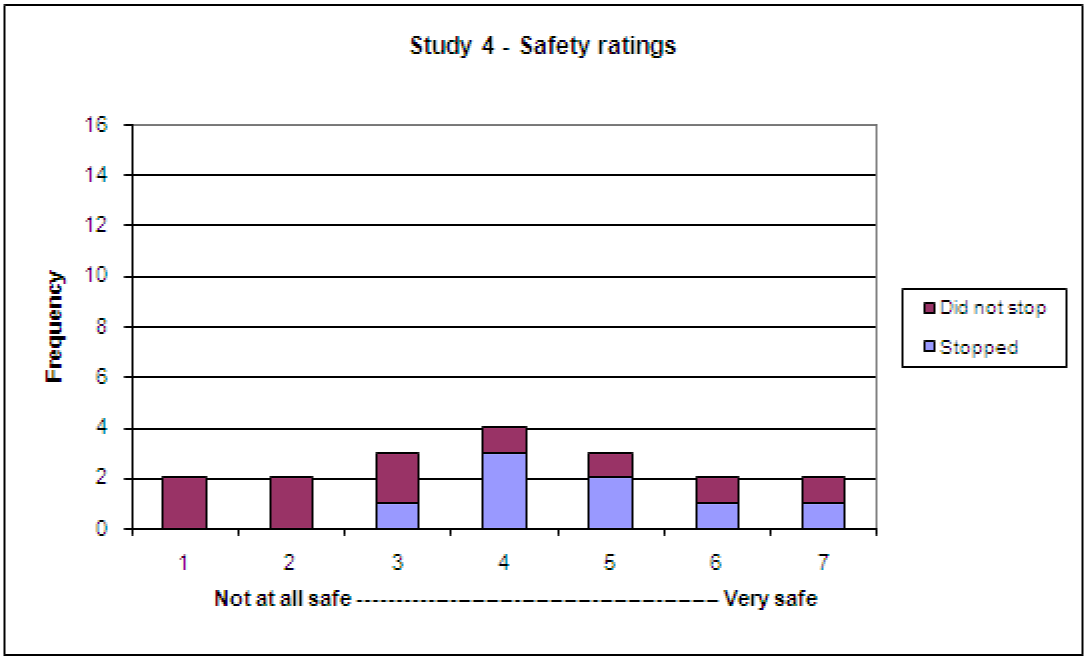

Figure 34 Safety ratings for Study 4.

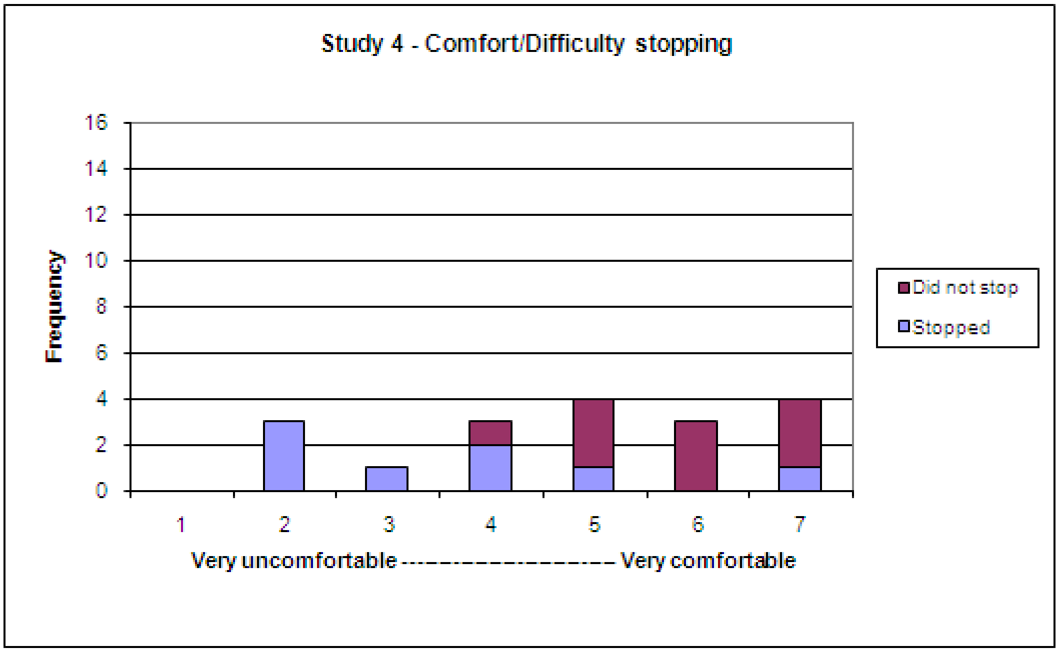

Figure 35 Rating comfort and difficulty stopping for Study 4.

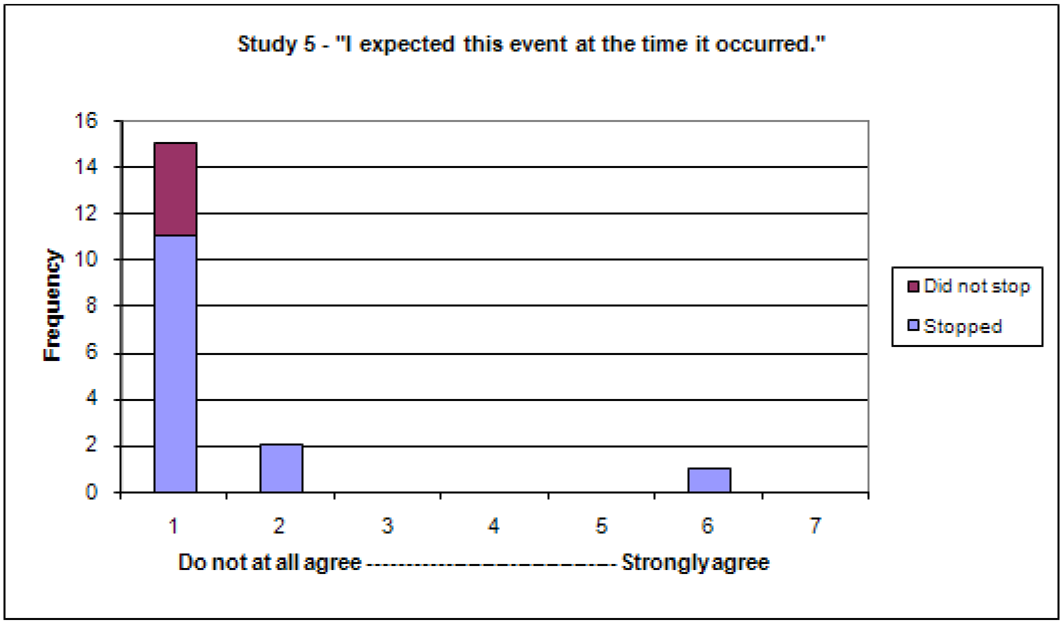

Figure 36 Surprise event expectation for Study 5.

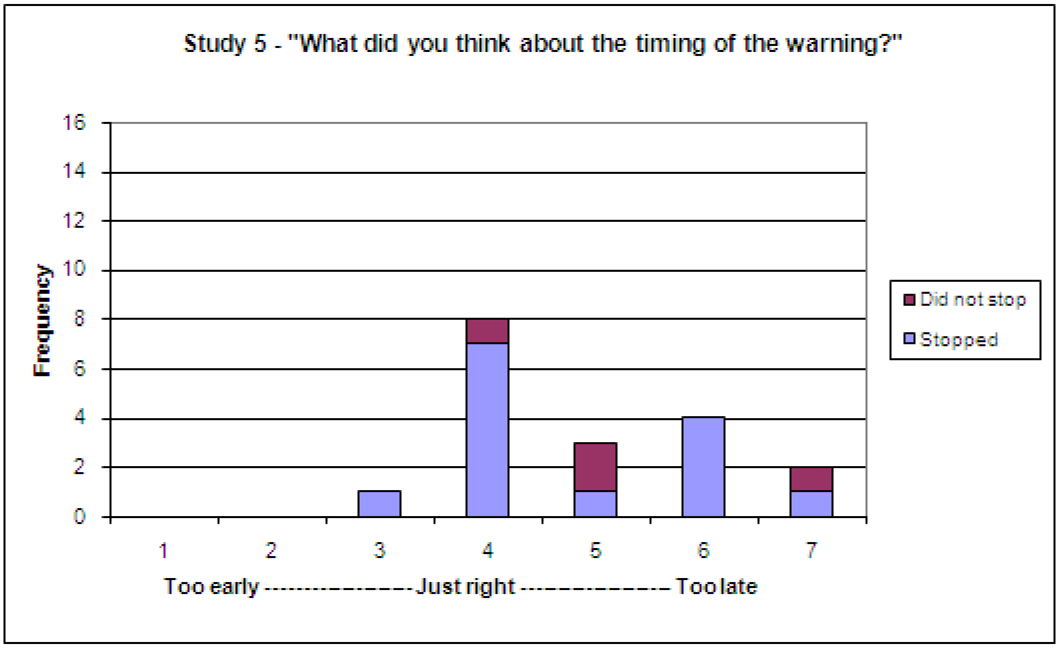

Figure 37 Rate of warning time for Study 5.

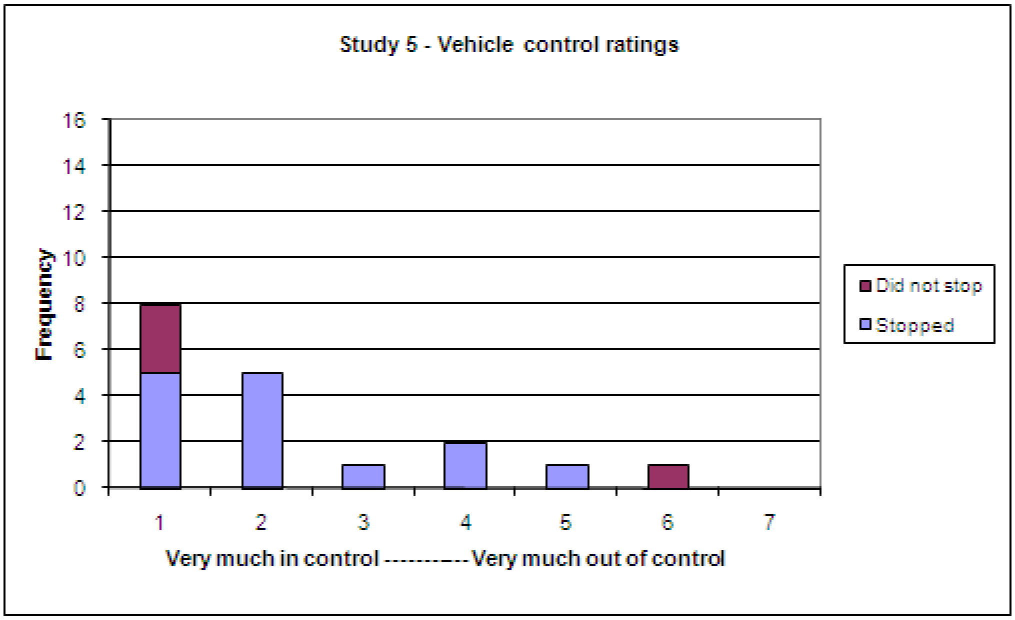

Figure 38 Vehicle control ratings for Study 5.

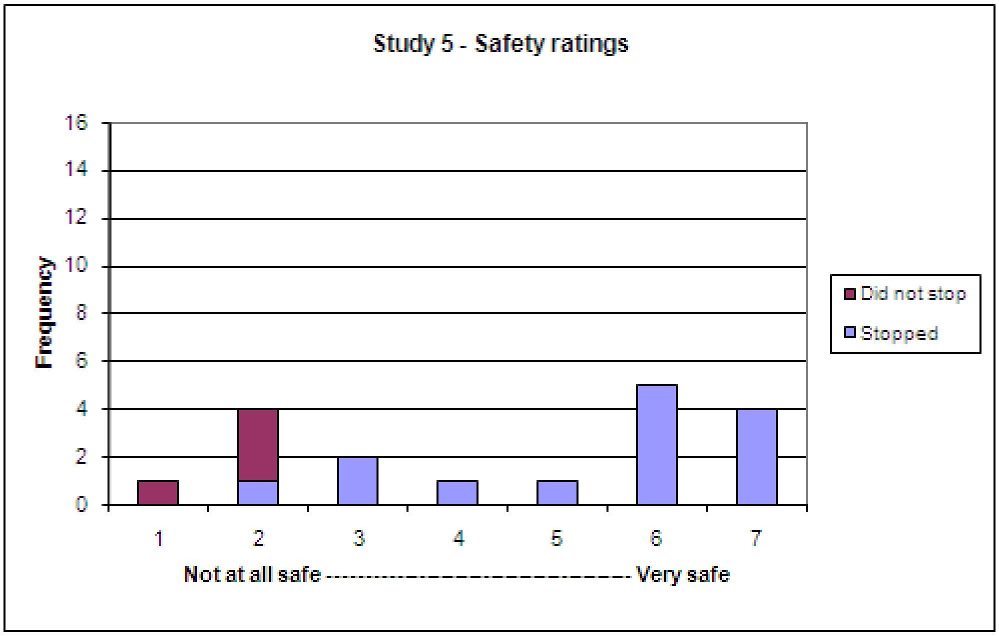

Figure 39 Safety ratings for Study 5.

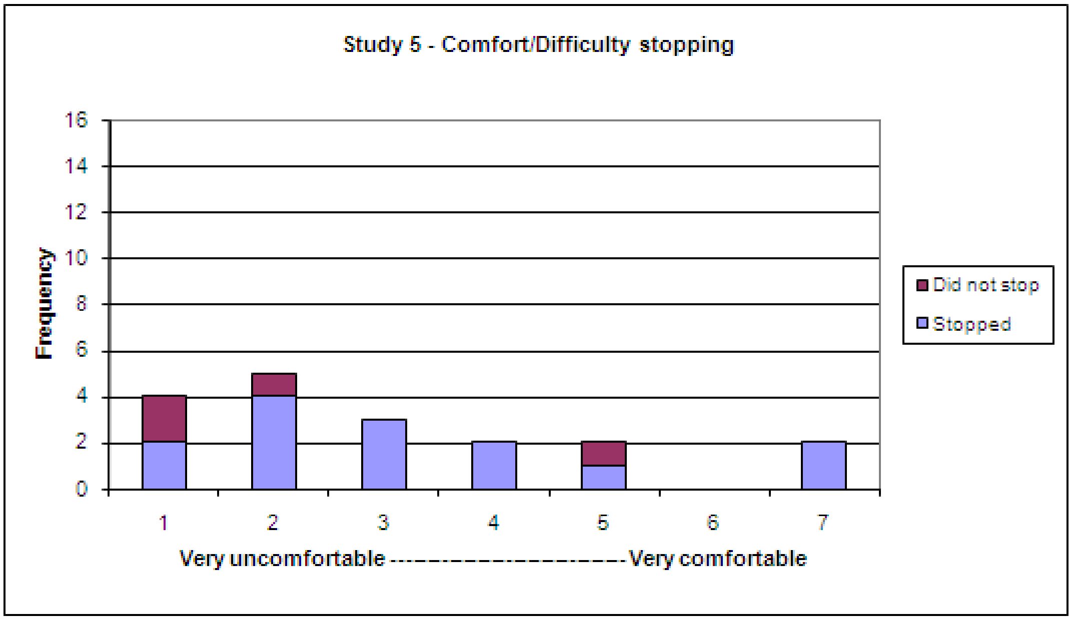

Figure 40 Rating comfort and difficulty stopping for Study 5.

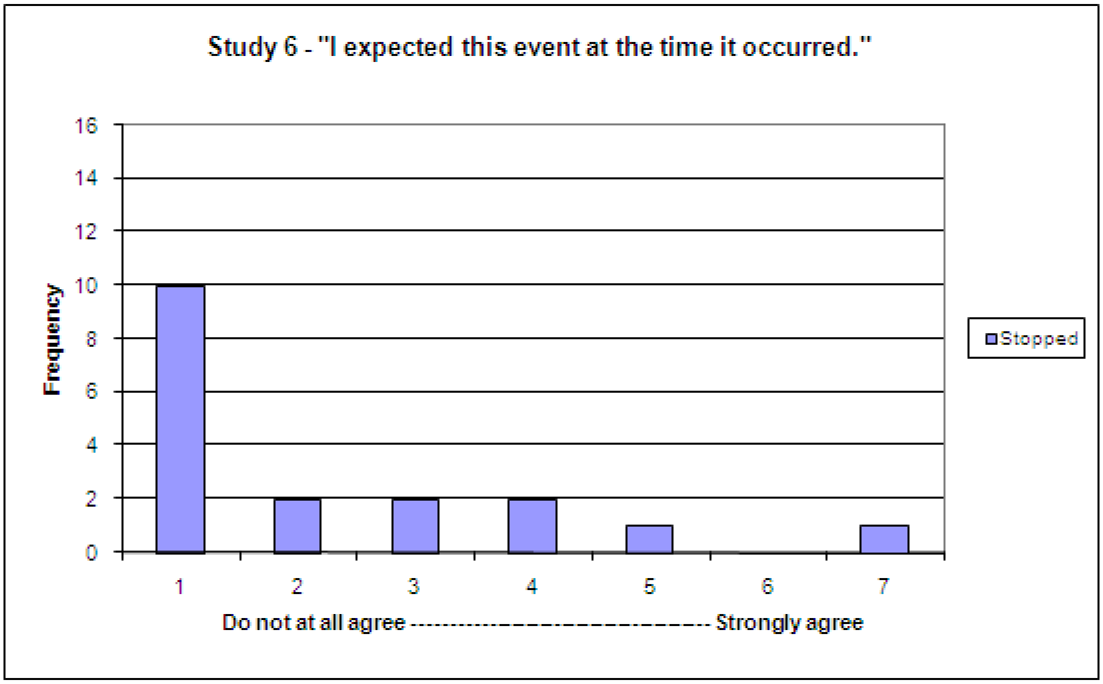

Figure 41 Surprise event expectation for Study 6.

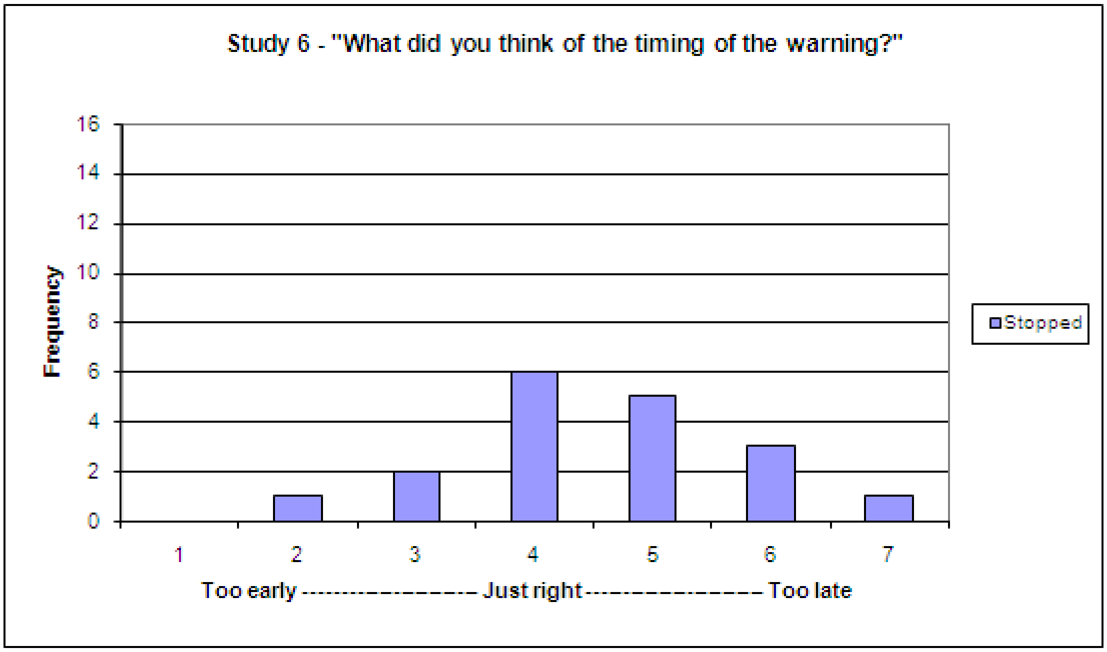

Figure 42 Rate of warning time for Study 6.

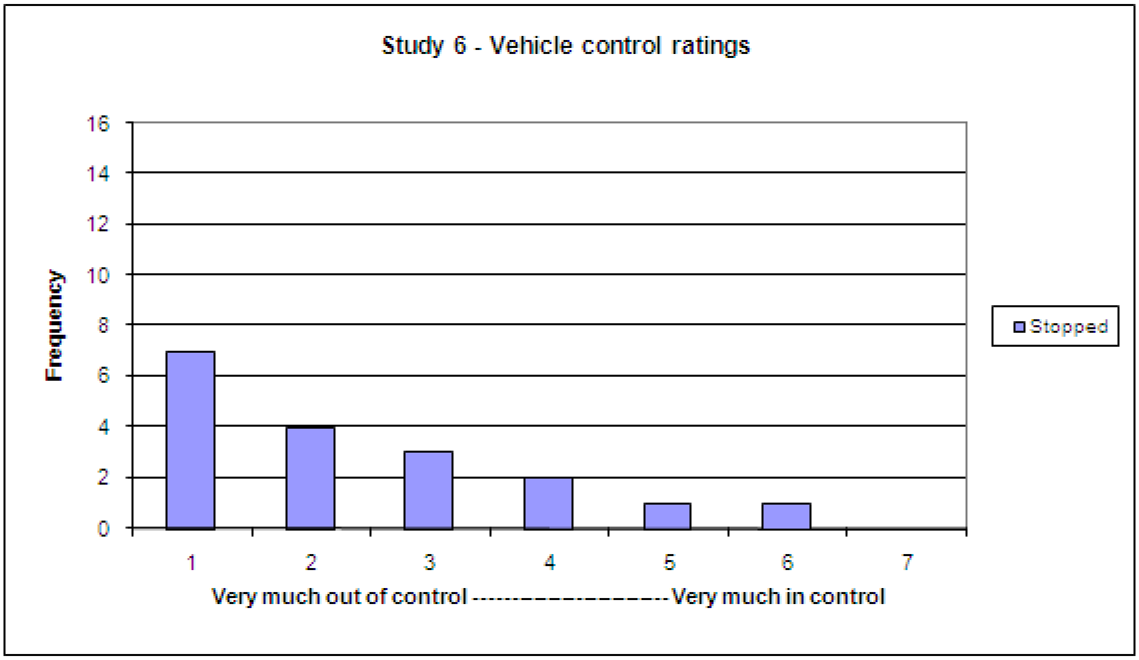

Figure 43 Vehicle control ratings for Study 6.

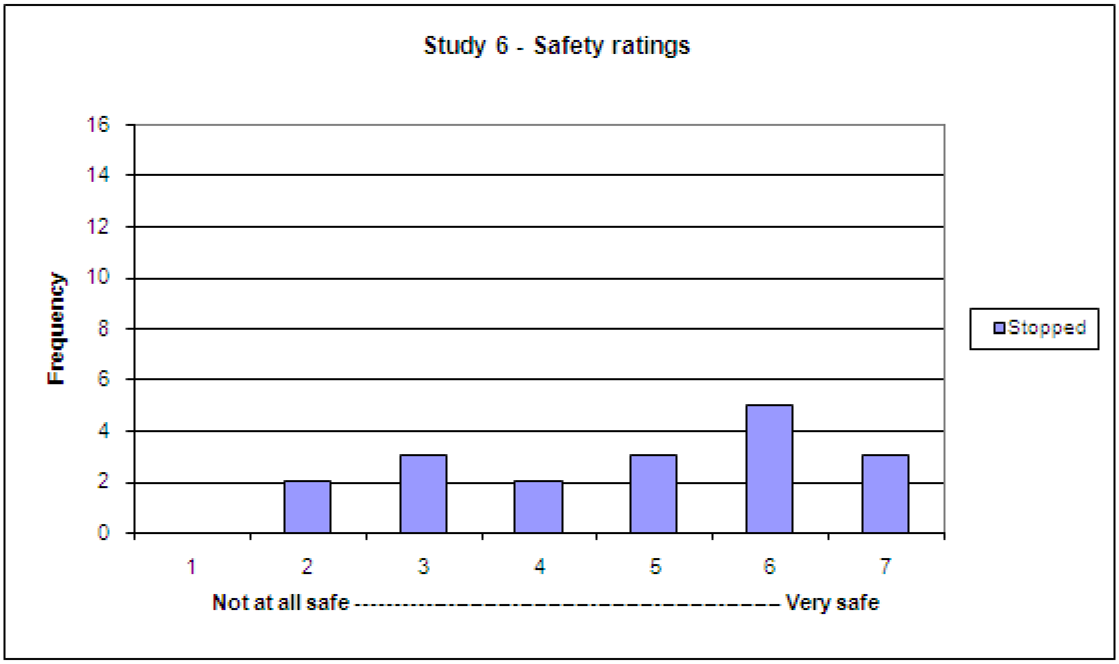

Figure 44 Safety ratings for Study 6.

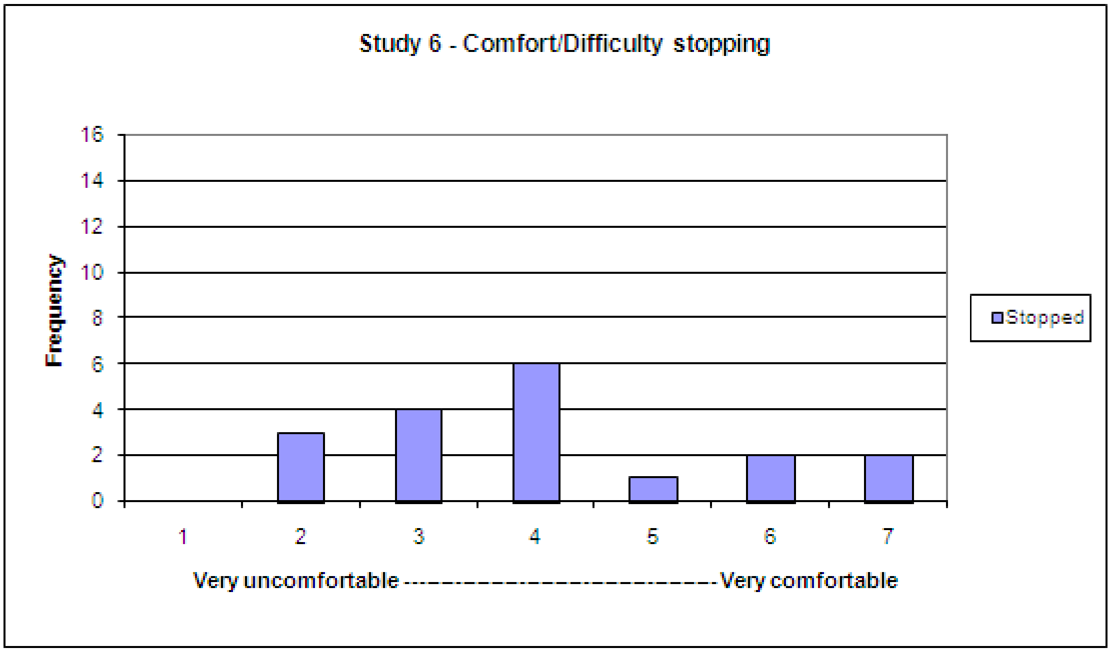

Figure 45 Rating comfort and difficulty stopping for Study 6.

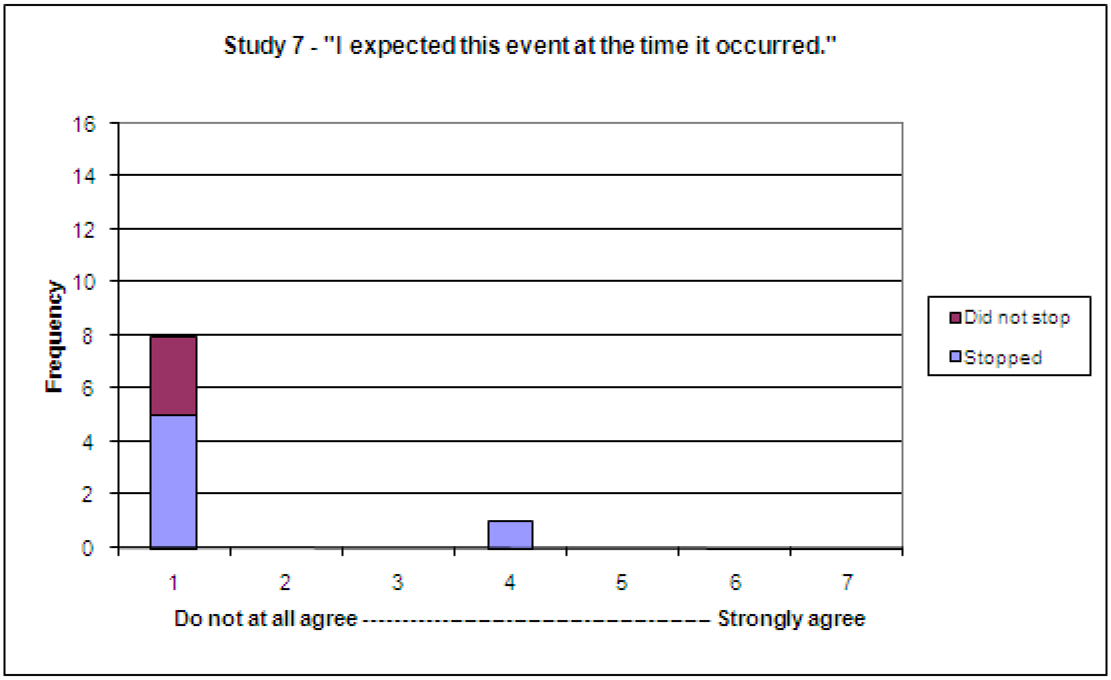

Figure 46 Surprise event expectation for Study 7.

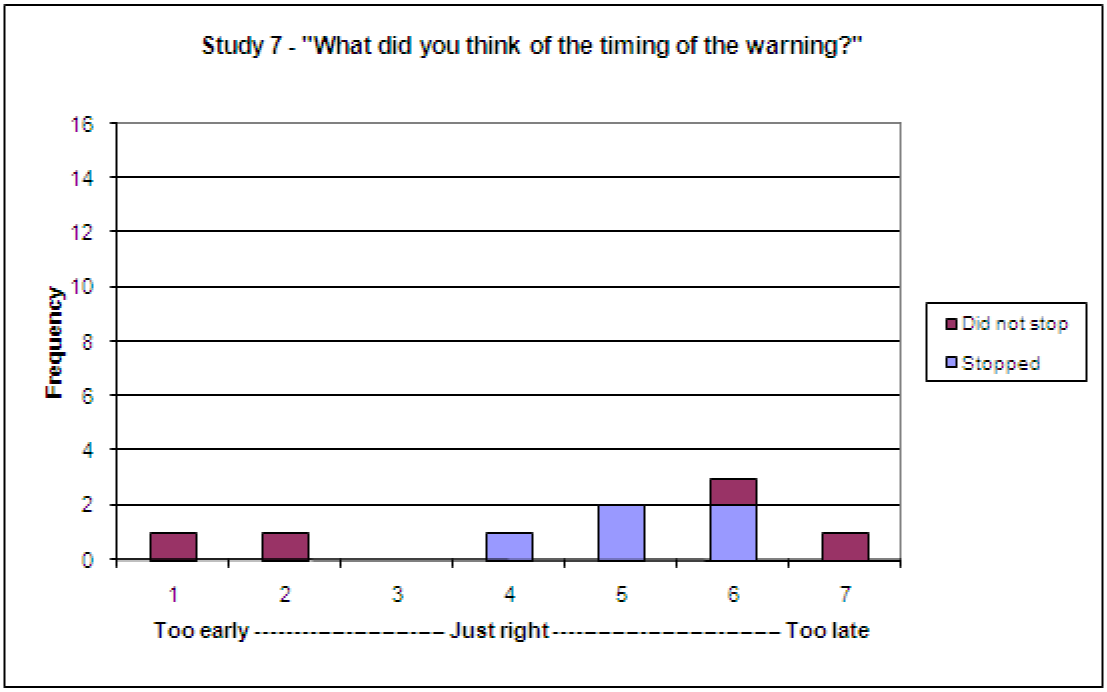

Figure 47 Rate of warning time for Study 7.

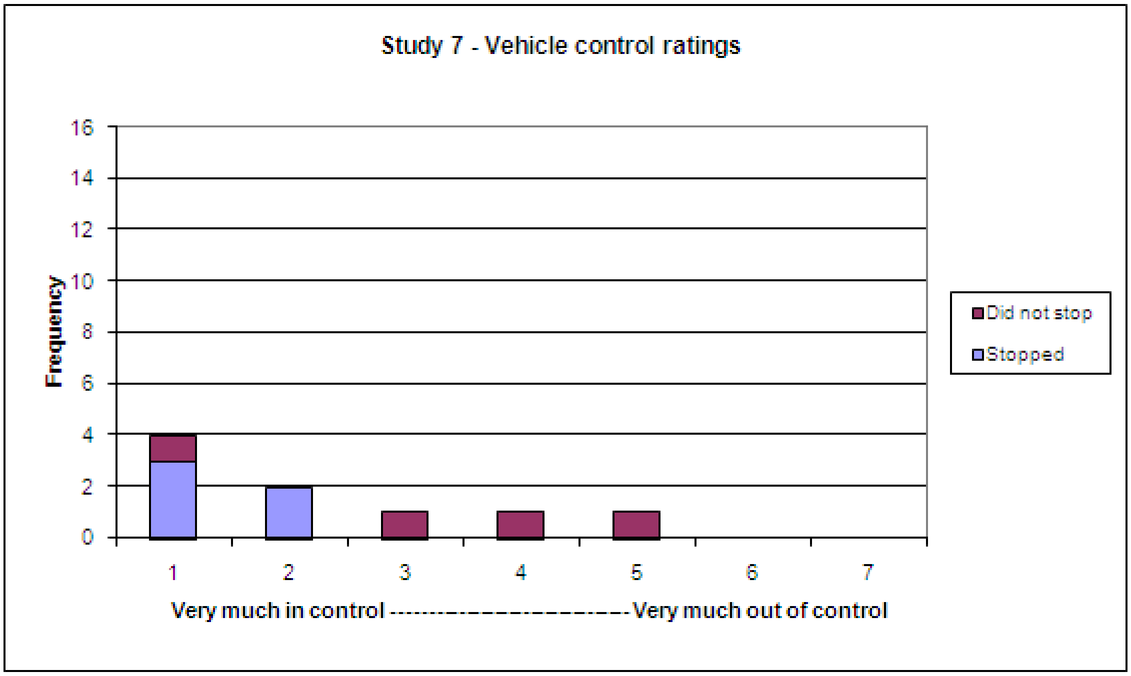

Figure 48 Vehicle control ratings for Study 7.

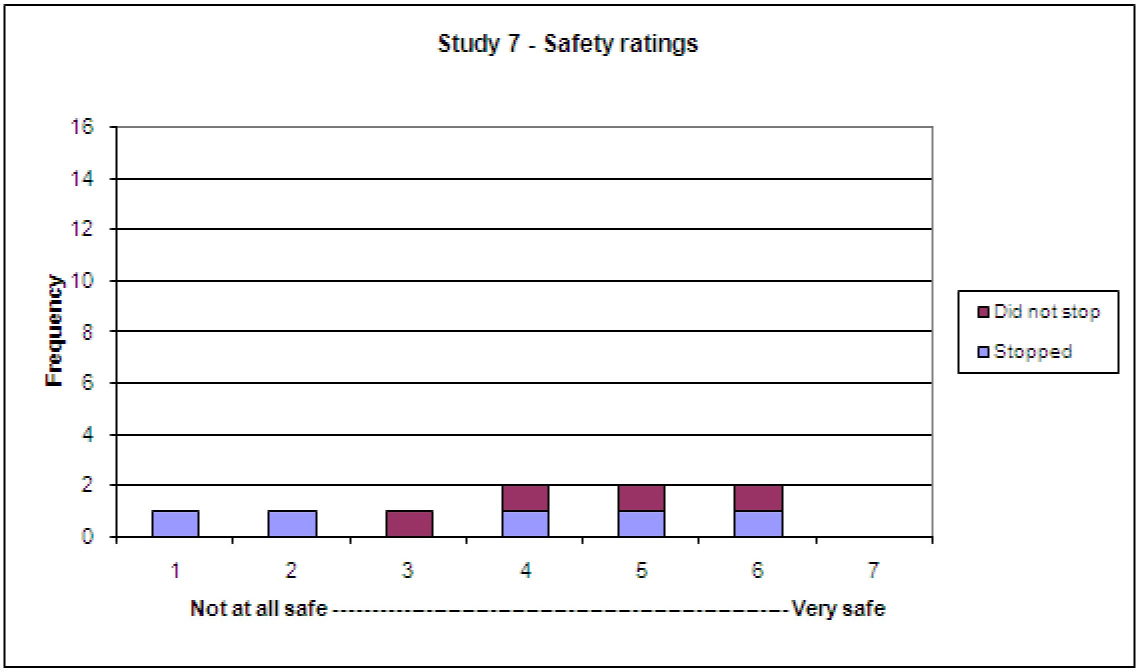

Figure 49 Safety ratings for Study 7.

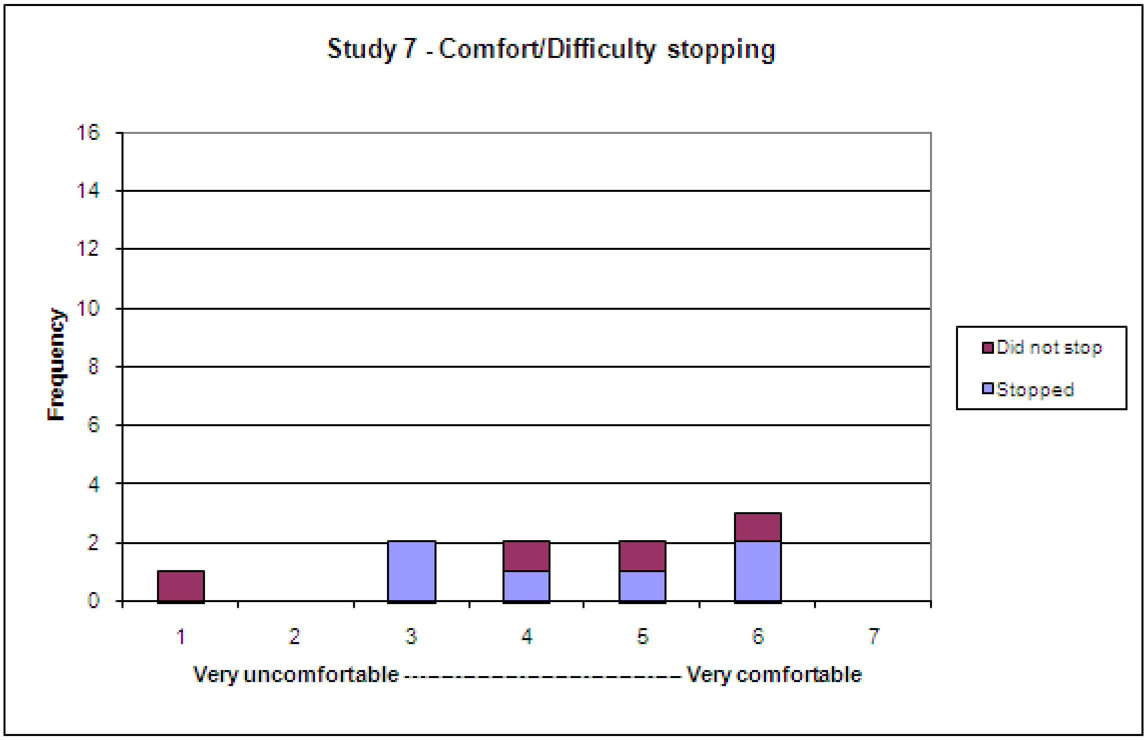

Figure 50 Rating comfort and difficulty stopping for Study 7.

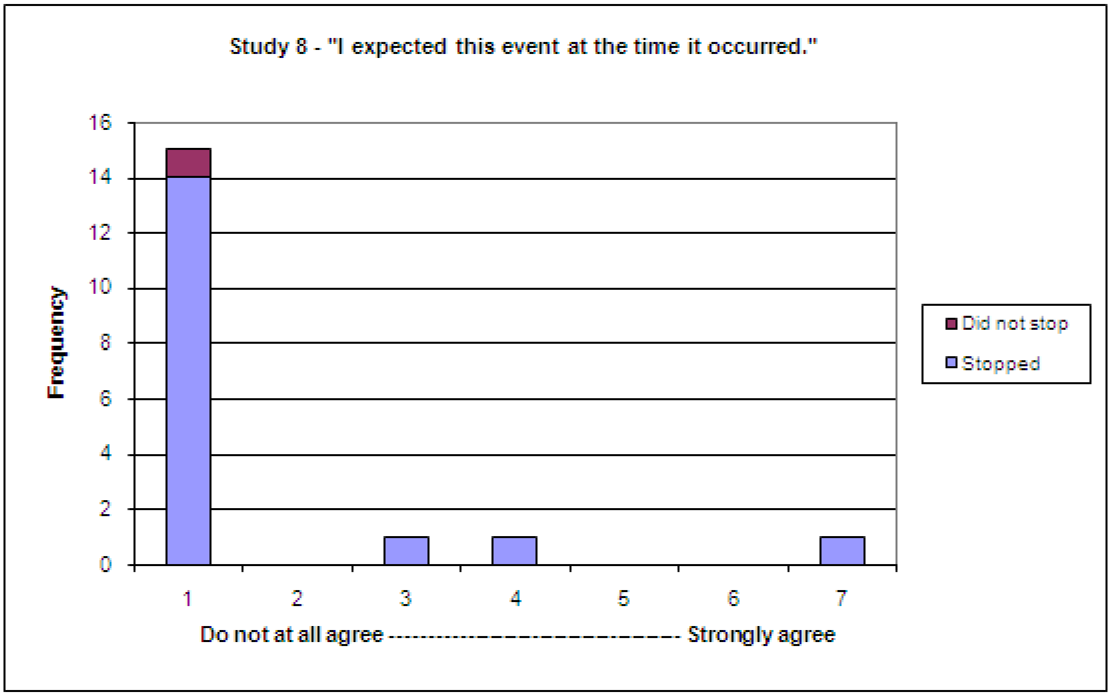

Figure 51 Surprise event expectation for Study 8.

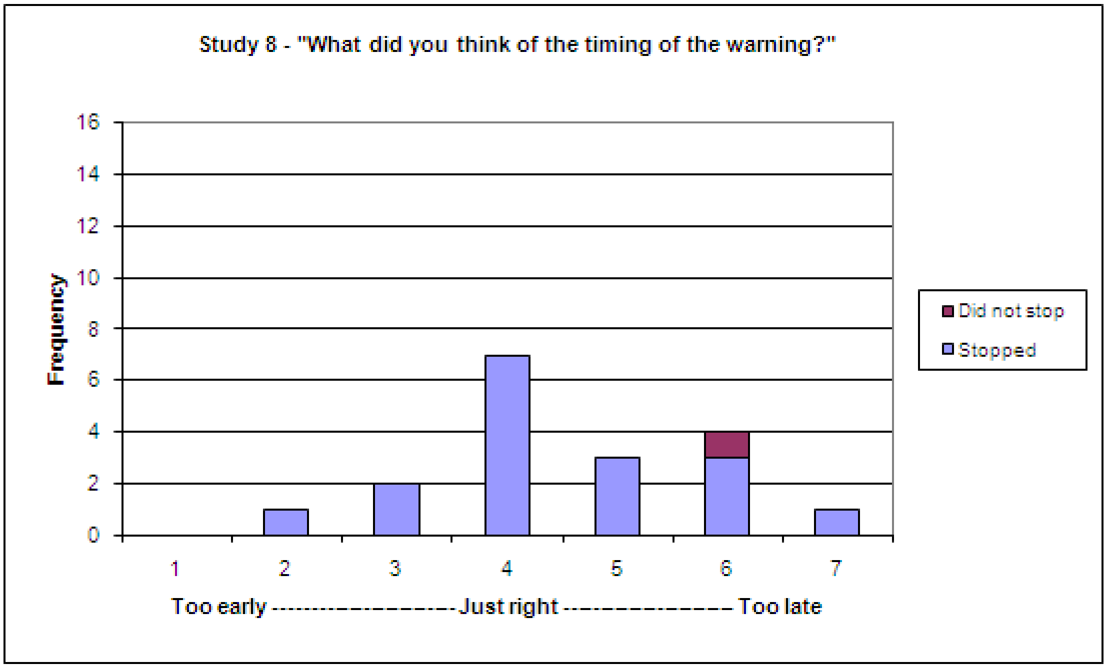

Figure 52 Rate of warning time for Study 8.

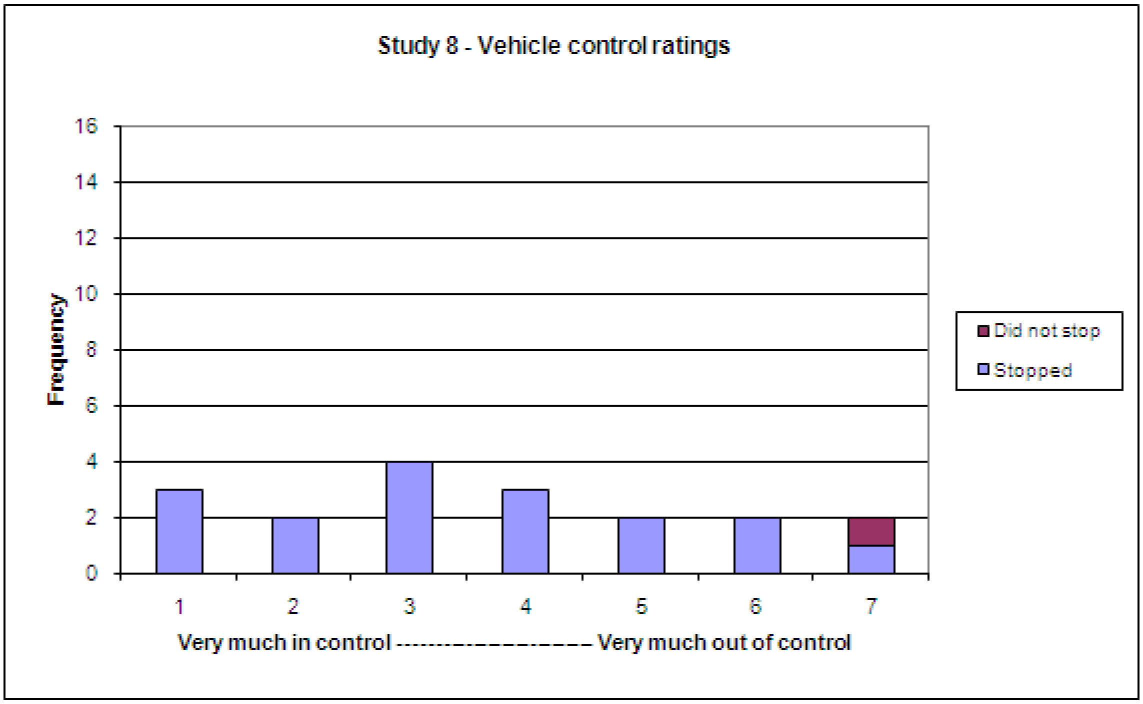

Figure 53 Vehicle control ratings for Study 8.

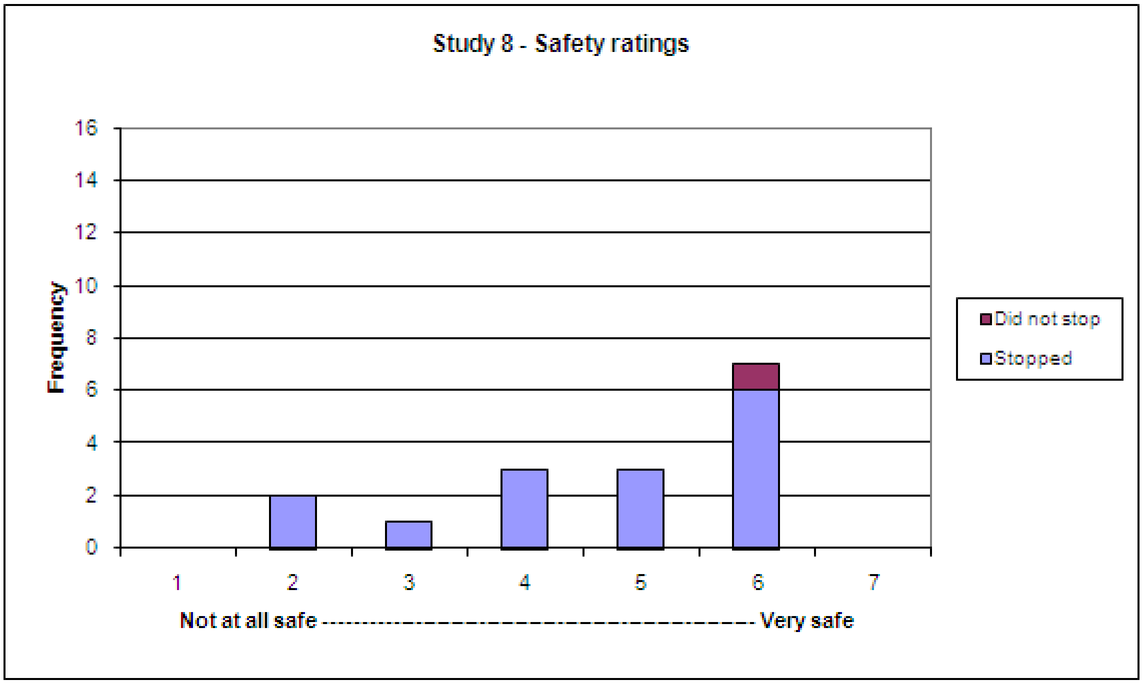

Figure 54 Safety ratings for Study 8.

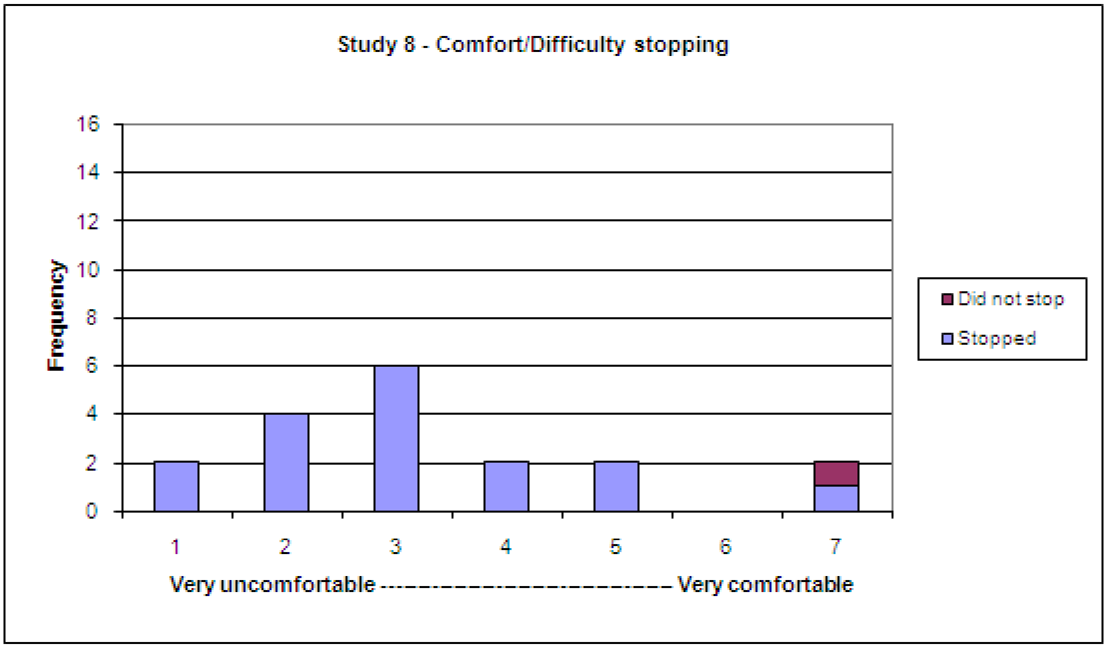

Figure 55 Rating comfort and difficulty stopping for Study 8.

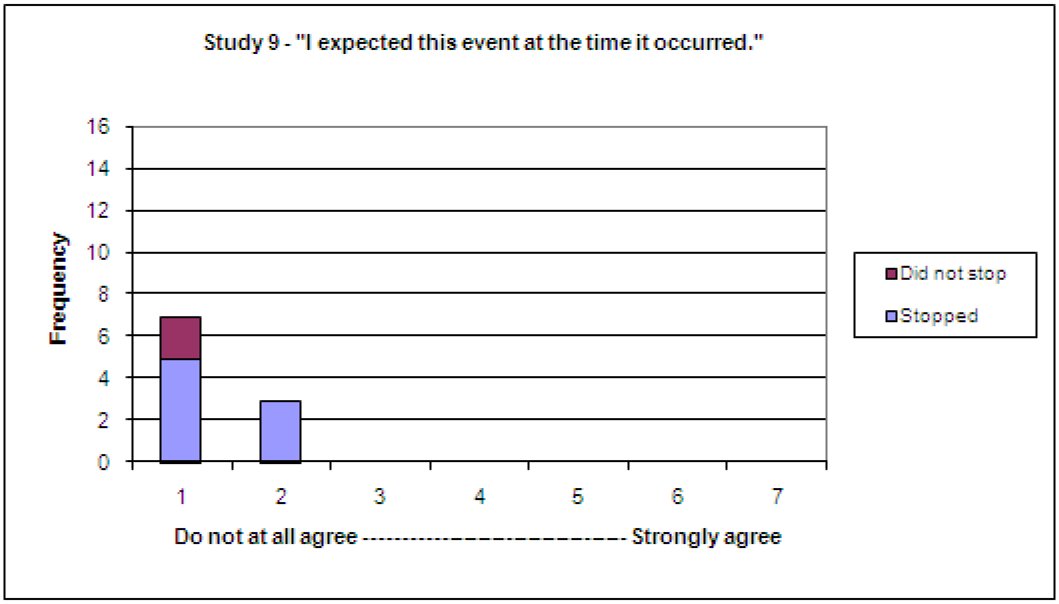

Figure 56 Surprise event expectation for Study 9.

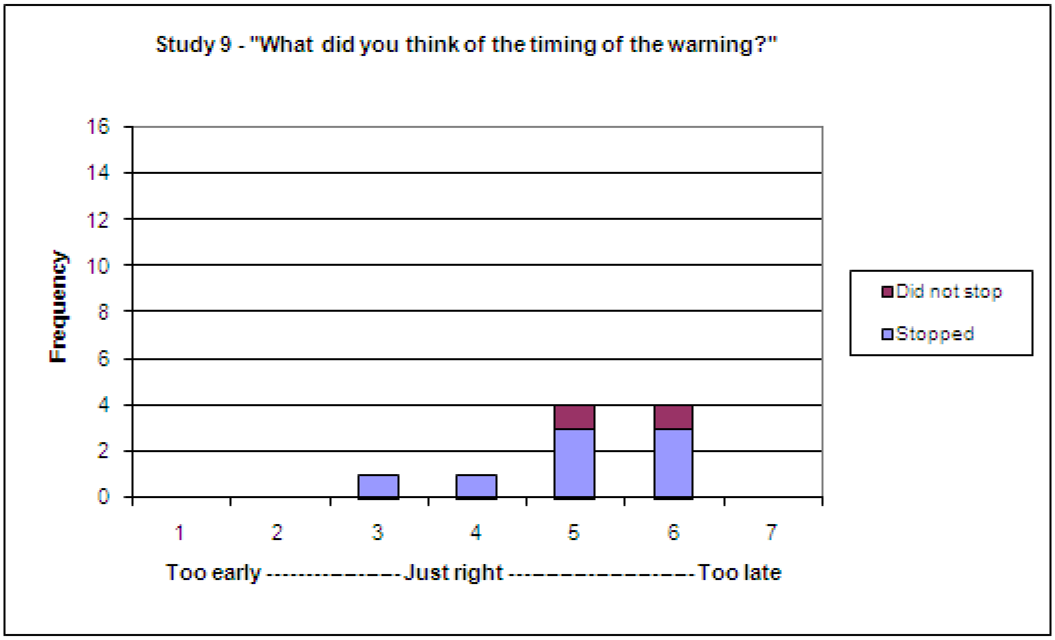

Figure 57 Rate of warning time for Study 9.

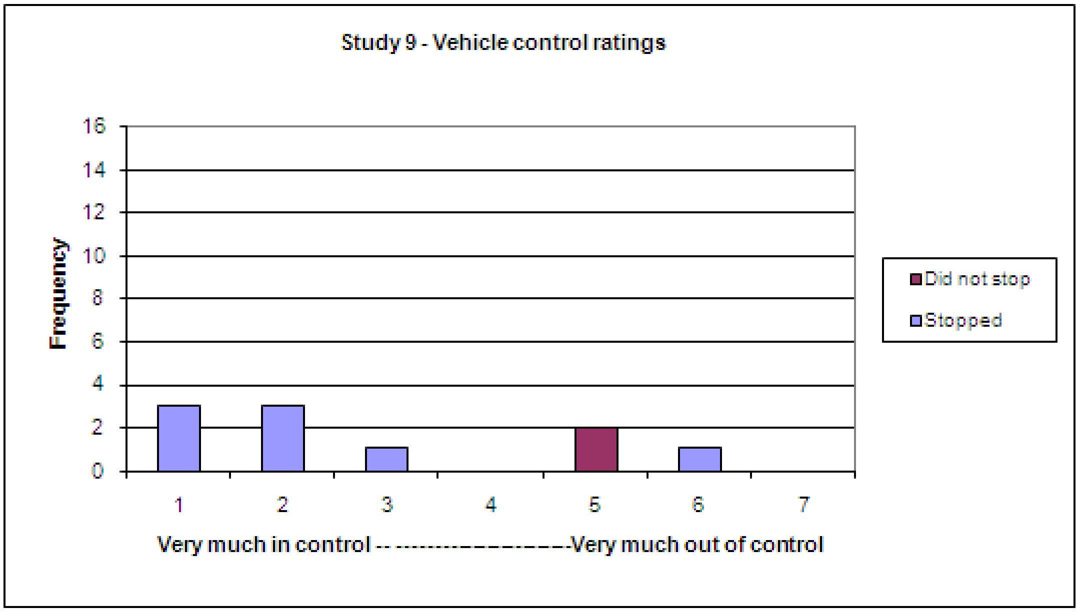

Figure 58 Vehicle control ratings for Study 9.

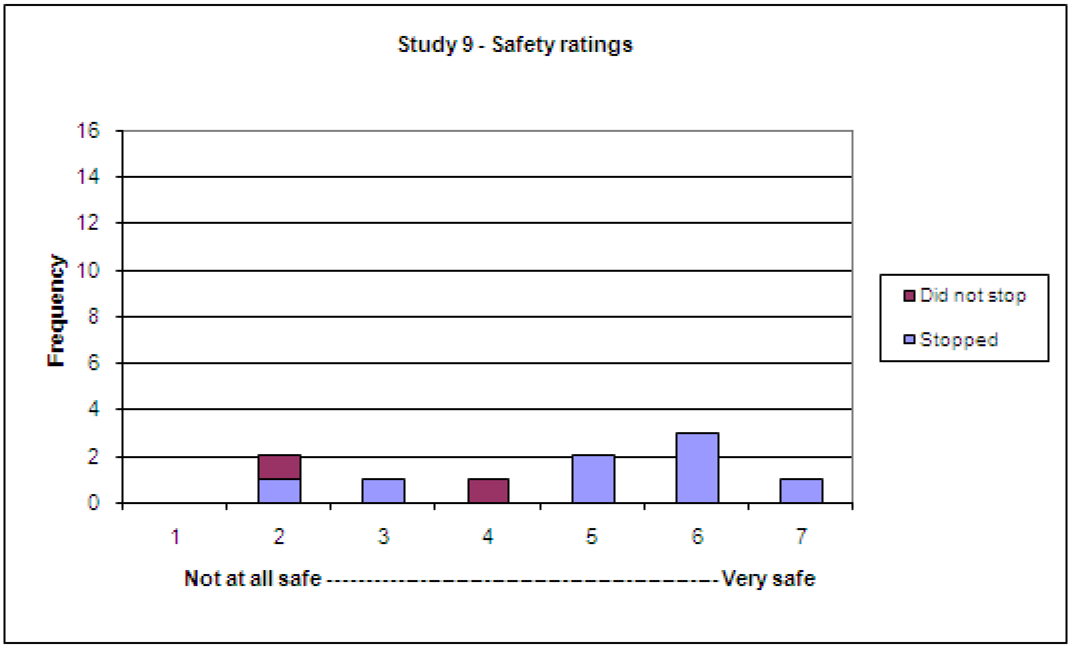

Figure 59 Safety ratings for Study 9.

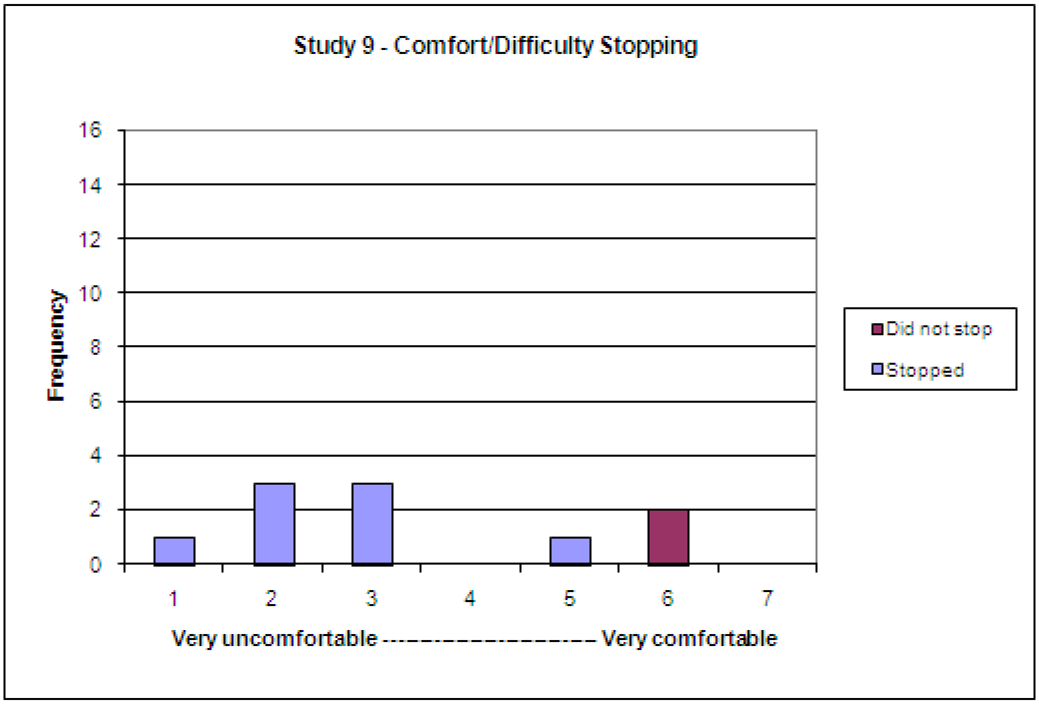

Figure 60 Rating comfort and difficulty stopping for Study 9.

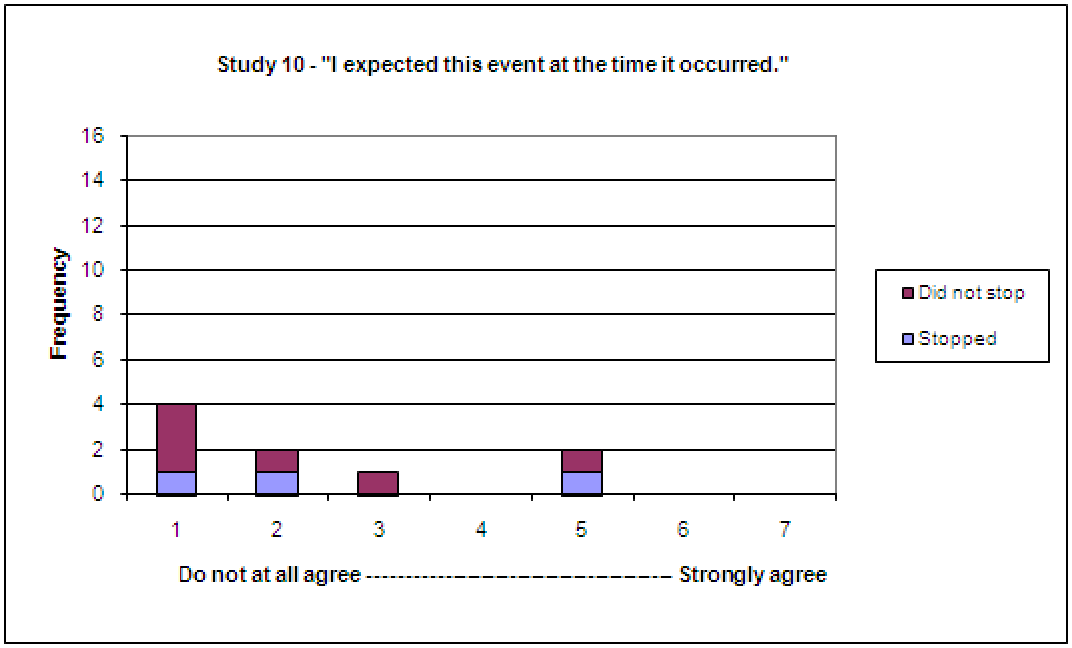

Figure 61 Surprise event expectation for Study 10.

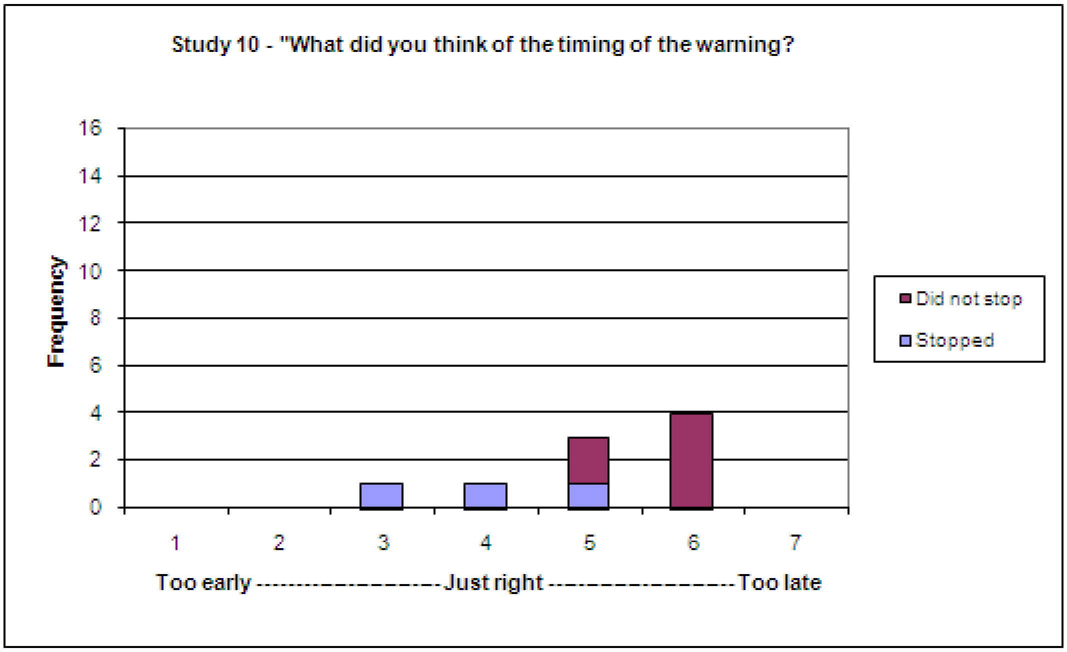

Figure 62 Rate of warning time for Study 10.

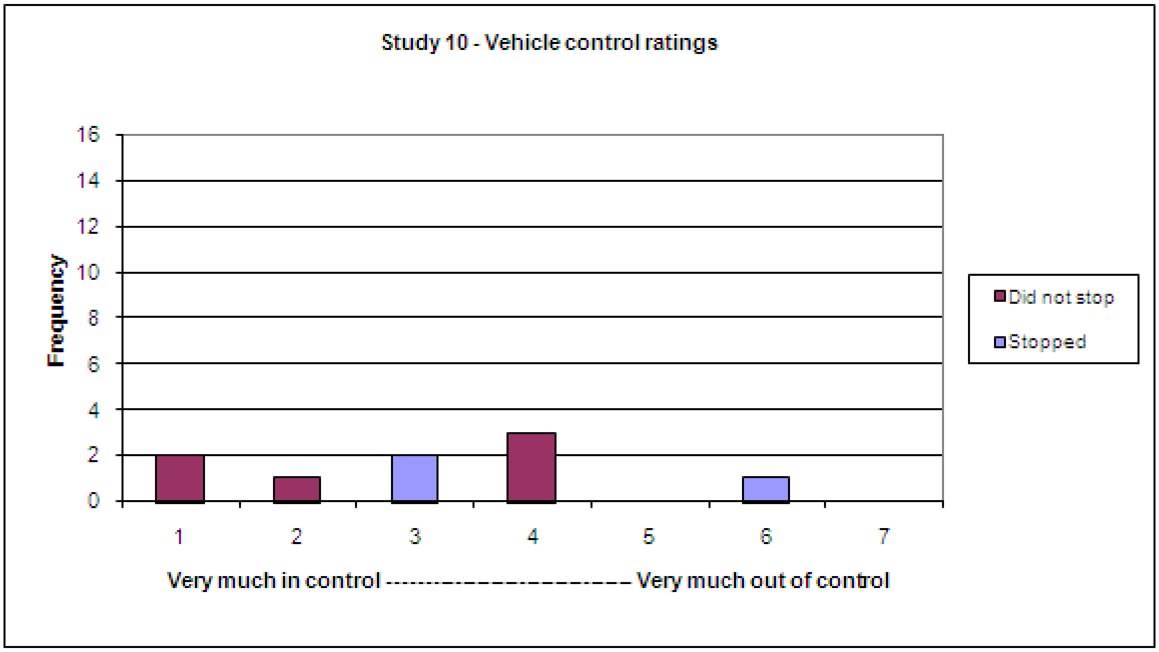

Figure 63 Vehicle control ratings for Study 10.

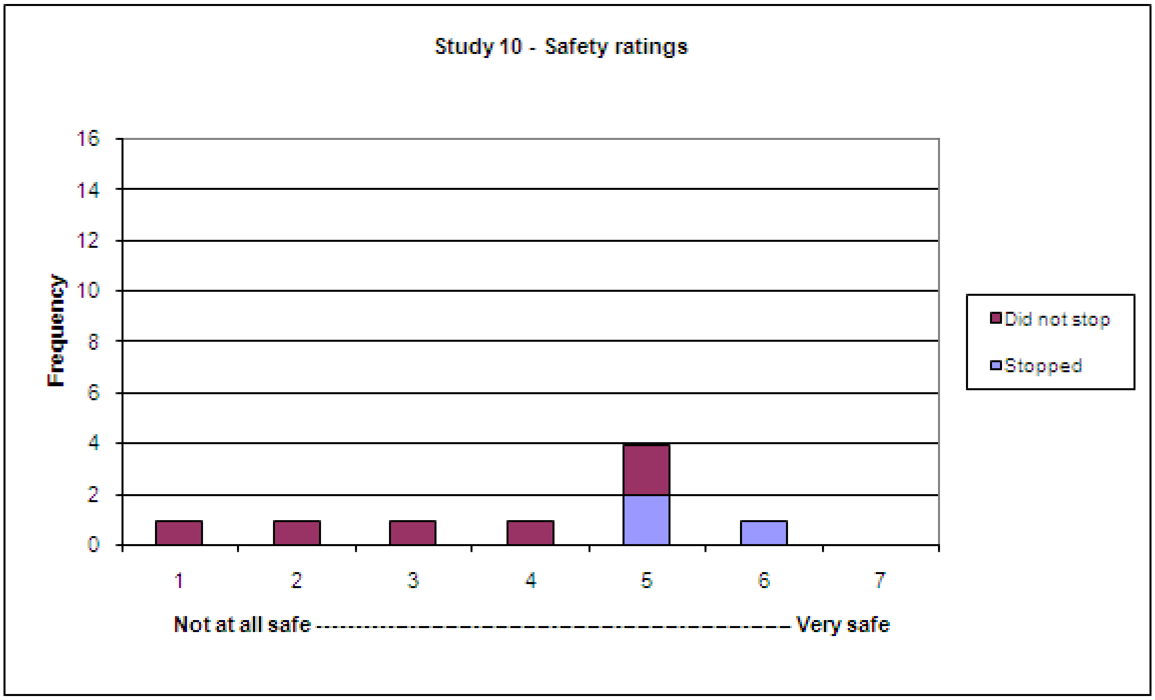

Figure 64 Safety ratings for Study 10.

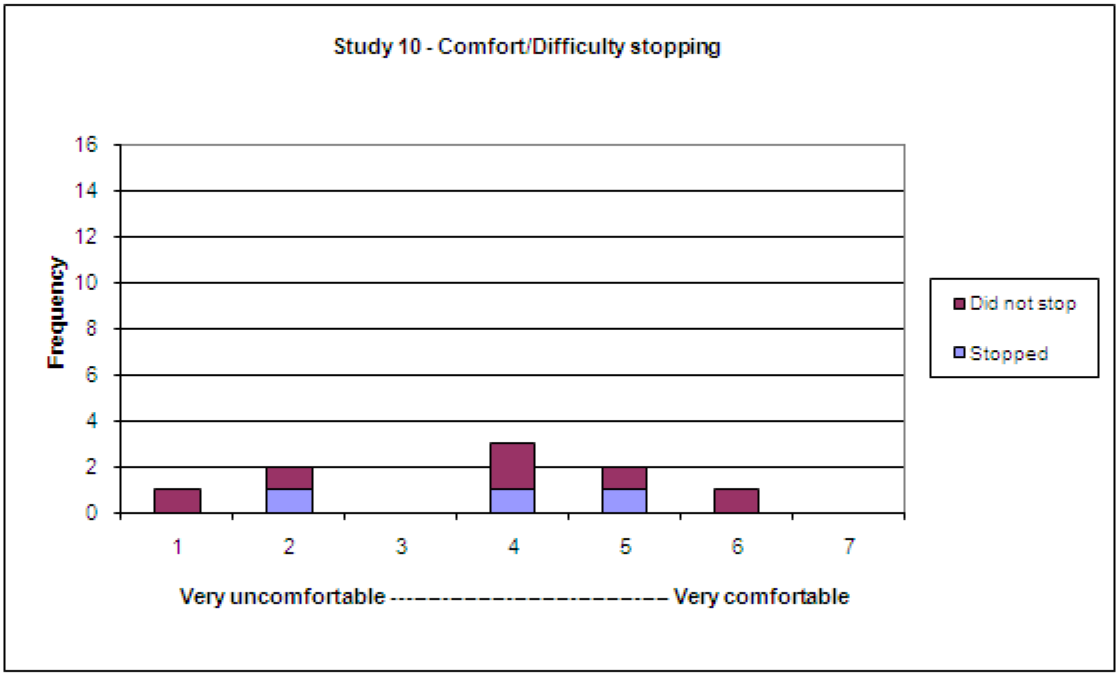

Figure 65 Rating comfort and difficulty stopping for Study 10.

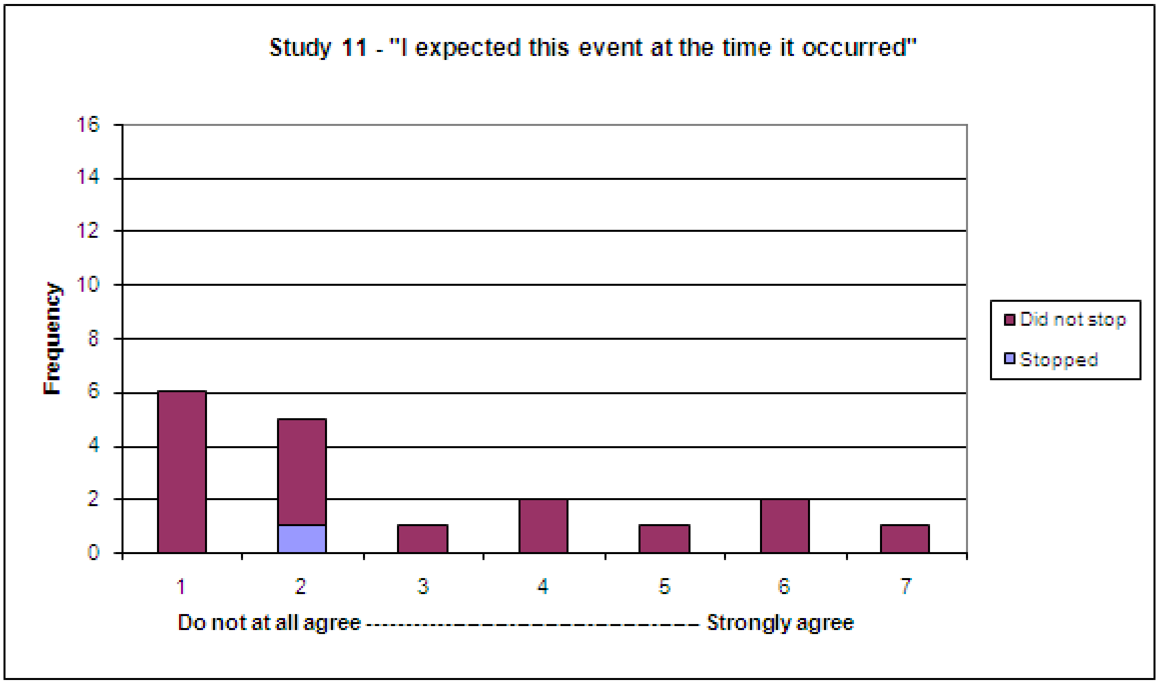

Figure 66 Surprise event expectation for Study 11.

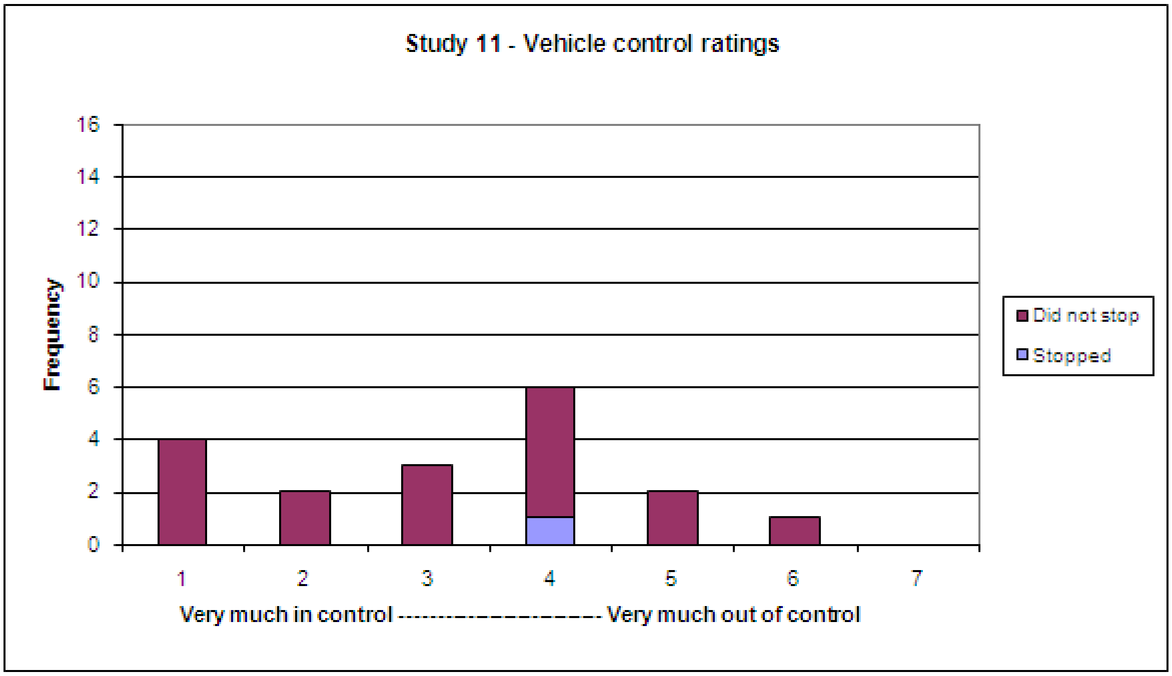

Figure 67 Vehicle control ratings for Study 11.

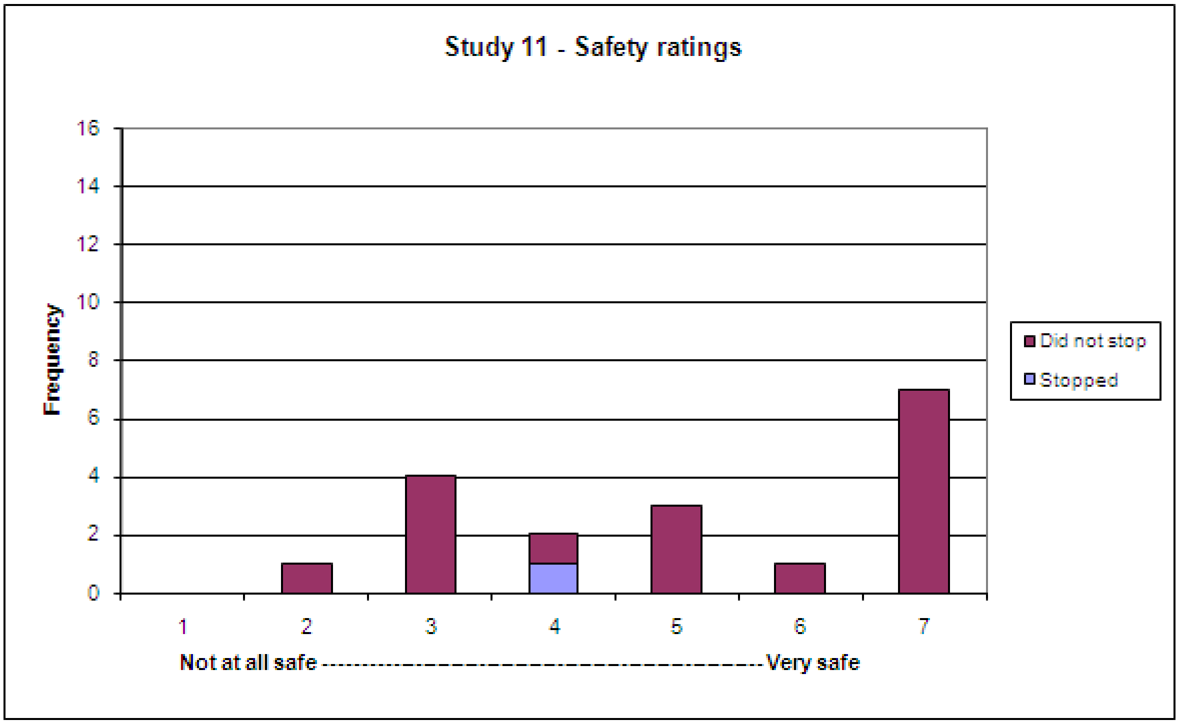

Figure 68 Safety ratings for Study 11.

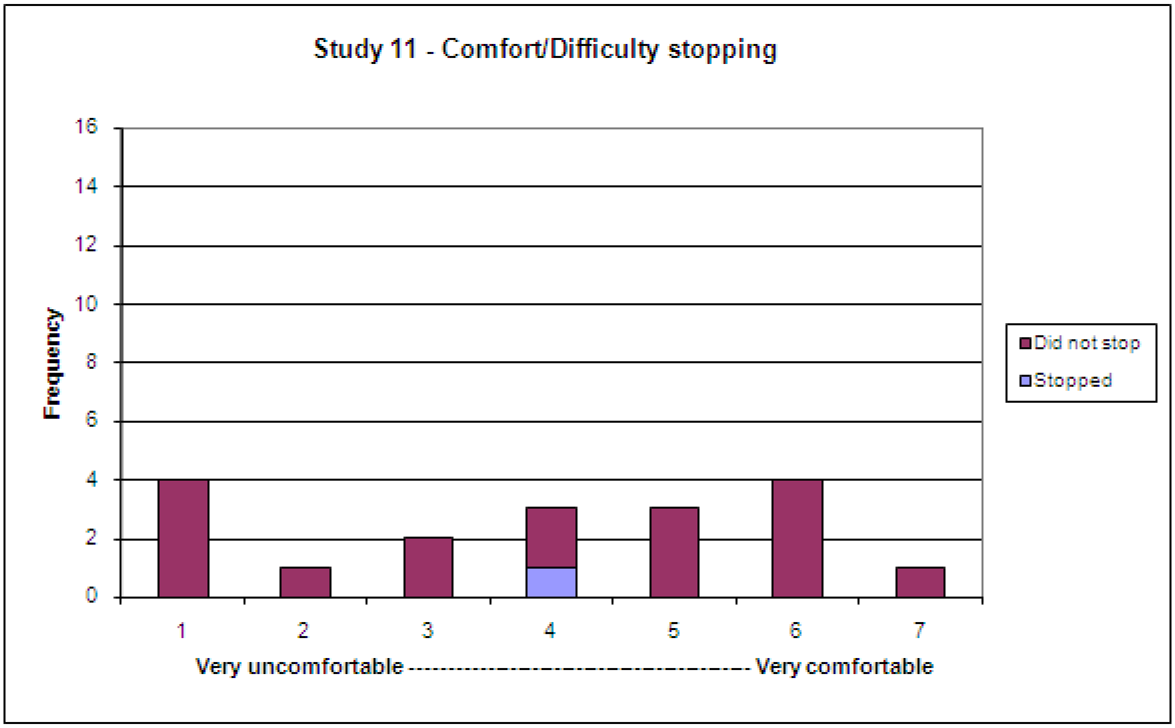

Figure 69 Rating comfort and difficulty stopping for Study 11.

6.10 Appendix J: Descriptive Statistics for PBA Additional Trials

Table 22 Low sensitivity PBA means and standard deviations.

Variable (N)	Overall (17)	PBA Active (4)
Distance from stop bar (m)	3.93 (11.09)	10.59 (14.16)
Peak deceleration (g)	0.98 (0.18)	1.22 (0.12)
Constant deceleration (g)	0.6 (0.11)	0.72 (0.25)
RDP from warning onset to stop bar (g)	0.41 (0.03)	0.4 (0.03)
RDP from braking onset to stop bar (g)	0.57 (0.08)	0.6 (0.05)
RDP from warning onset to collision zone (g)	0.31 (0.03)	0.31 (0.02)
RDP from braking onset to collision zone (g)	0.39 (0.05)	0.41 (0.02)
Time to peak deceleration (s)	1.64 (0.41)	1.14 (0.28)
Time from brake to peak deceleration (s)	1.17 (0.4)	0.6 (0.04)
Maximum brake velocity (% s)	3.92 (1.37)	5.44 (0.66)

Table 23 Low-medium sensitivity PBA means and standard deviations.

Variable (N)	Overall (12)	PBA Active (4)
Distance from stop bar (m)	2.2 (11.46)	12.84 (2.82)
Peak deceleration (g)	0.97 (0.20)	1.2 (0.12)
Constant deceleration (g)	0.58 (0.12)	0.71 (0.08)
RDP from warning onset to stop bar (g)	0.45 (0.03)	0.46 (0.03)
RDP from braking onset to stop bar (g)	0.55 (0.1)	0.58 (0.04)
RDP from warning onset to collision zone (g)	0.33 (0.03)	0.34 (0.03)
RDP from braking onset to collision zone (g)	0.38 (0.06)	0.4 (0.03)
Time to peak deceleration (s)	1.47 (0.45)	1.08 (0.27)
Time from brake to peak deceleration (s)	1.16 (0.46)	0.77 (0.34)
Maximum brake velocity (% s)	4.21 (1.39)	5.59 (1.33)

Table 24 Medium sensitivity PBA means and standard deviations.

Variable (N)	Overall (22)	PBA Active (6)
Distance from stop bar (m)	7.0 (14.79)	21.5 (11.16)
Peak deceleration (g)	0.92 (0.22)	1.21 (0.02)
Constant deceleration (g)	0.58 (0.12)	0.74 (0.08)
RDP from warning onset to stop bar (g)	0.4 (0.02)	0.4 (0.01)
RDP from braking onset to stop bar (g)	0.51 (0.05)	0.52 (0.05)
RDP from warning onset to collision zone (g)	0.3 (0.02)	0.3 (0.01)
RDP from braking onset to collision zone (g)	0.36 (0.03)	0.37 (0.02)
Time to peak deceleration (s)	1.66 (0.5)	1.32 (0.34)
Time from brake to peak deceleration (s)	1.23 (0.47)	0.88 (0.42)
Maximum brake velocity (% s)	3.71 (1.41)	4.84 (1.54)

Table 25 Medium-high sensitivity PBA means and standard deviations.

Variable (N)	Overall (23)	PBA Active (6)
Distance from stop bar (m)	4.25 (11.96)	15.5 (5.77)
Peak deceleration (g)	0.94 (0.21)	1.24 (0.02)
Constant deceleration (g)	0.59 (0.13)	0.77 (0.07)
RDP from warning onset to stop bar (g)	0.4 (0.02)	0.41 (0.03)
RDP from braking onset to stop bar (g)	0.54 (0.07)	0.59 (0.07)
RDP from warning onset to collision zone (g)	0.3 (0.02)	0.31 (0.02)
RDP from braking onset to collision zone (g)	0.38 (0.04)	0.4 (0.04)
Time to peak deceleration (s)	1.78 (0.47)	1.24 (0.33)
Time from brake to peak deceleration (s)	1.34 (0.47)	0.79 (0.36)
Maximum brake velocity (% s)	3.63 (1.66)	5.42 (1.15)

Table 26 High sensitivity PBA means and standard deviations.

Variable (N)	Overall (13)	PBA Active (7)
Distance from stop bar (m)	4.48 (18.94)	15.94 (17.38)
Peak deceleration (g)	1.02 (0.27)	1.25 (0.04)
Constant deceleration (g)	0.6 (0.15)	0.71 (0.11)
RDP from warning onset to stop bar (g)	0.44 (0.03)	0.45 (0.03)
RDP from braking onset to stop bar (g)	0.54 (0.08)	0.55 (0.07)
RDP from warning onset to collision zone (g)	0.33 (0.03)	0.34 (0.02)
RDP from braking onset to collision zone (g)	0.38 (0.05)	0.39 (0.05)
Time to peak deceleration (s)	1.3 (0.49)	0.92 (0.16)
Time from brake to peak deceleration (s)	1.03 (0.46)	0.67 (0.13)
Maximum brake velocity (% s)	3.32 (1.61)	4.14 (1.71)

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