Development of Human Factors Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO): Integration of ATIS and Crash Avoidance In-Vehicle Information: Preliminary Simulator Study

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FOREWORD

This report is one of a series of reports produced as part of a contract designed to develop precise, detailed human factors design guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO). During the analytic phase of the project, research issues were identified and rated by 8 human factors experts along 14 separate criteria. The goal of the experimental phase was to examine the highest rated research issues that can be addressed within the scope of the project. The 14 experiments produced in that phase reflect the results of those ratings.

This report documents a study that was performed to investigate the following issues: (1) the influence of an ATIS on driver performance in reduced visibility conditions, (2) the influence of an ATIS on drivers' reactions to unexpected roadway events, and (3) the interaction of an ATIS with a Collision Avoidance System (CAS).

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Director, Office of Safety
Research and Development

NOTICE

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16. Abstract:

This study investigated three issues relevant to Advanced Traveler Information System (ATIS) design: (1) the influence of an ATIS on driver performance in reduced visibility conditions, (2) the influence of an ATIS on drivers' reactions to unexpected roadway events, and (3) the interaction of an ATIS with a Collision Avoidance System (CAS). The study was conducted in two phases, combining a very efficient confounded experimental design used in Phase I with a traditional orthogonal design used in Phase II. Both experiments were conducted in a high-fidelity driving simulator. A total of 20 drivers was tested: 8 in Phase I and 12 in Phase II. In both phases, subjects completed several driving scenarios, during which they received roadway-relevant information via an in-vehicle ATIS and variable message signs (VMS) posted on the roadway. Subjects also experienced several unexpected roadway events, some of which triggered a CAS alert. Results showed that mean speed was lower in the ATIS condition than in the control condition, while out-of-vehicle VMS messages did not alter speed. Contrary to our expectations, effects of ATIS and VMS messages upon driving performance did not depend upon visibility conditions. Drivers in clear and fog visibility performed consistently. The results also showed that an ATIS message interfered with the driver's ability to react to a pedestrian road incursion. However, an ATIS message did not interfere with a CAS warning. The present results need to be expanded before design guidelines, especially for integration of in-vehicle systems, can be written with great confidence. However, these results do indicate that the simulator can provide a reasonable test bed for future evaluation of system interactions.

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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 yards	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

Symbol	When You Know	Multiply By	To Find	Symbol
		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)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°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 TO 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	35.71	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)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°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 September 1993)

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LIST OF ABBREVIATIONS

ANCOVA . . . . Analysis of covariance
ANOVA . . . . Analysis of variance
ATIS . . . . Advanced Traveler Information Systems
BMDP . . . . Bio-Medical Data Processing
CAS . . . . Collision Avoidance System
CVO . . . . Commercial Vehicle Operations
FHWA . . . . Federal Highway Administration
ITS . . . . Intelligent Transportation Systems
m/sec . . . . meters per second
ms . . . . milliseconds
RANCOVA . . . . Repeated measures analysis of covariance
RANOVA . . . . Repeated measures analysis of variance
VMS . . . . Variable message signs

EXECUTIVE SUMMARY

Battelle's Human Factors Transportation Center (HFTC) is carrying out a study for the U.S. Federal Highway Administration (FHWA) to develop human factors design guidelines for the ATIS and Commercial Vehicle Operations (CVO) components of the Intelligent Transportation Systems (ITS). These systems are intended to provide a wealth of real-time information to the driver, including route guidance to avoid congestion and minimize travel time, safety and warning notices, and identification of desired motorist services, such as how to get to the nearest service station. While ATIS and CVO systems offer great potential benefits, their effectiveness depends on driver acceptance of the new technology, the ability of the system to integrate with other driving tasks, and the extent to which the systems conform to driver physical and cognitive capabilities and limitations.

This study investigated three issues relevant to ATIS design: (1) the influence of an ATIS on driver performance in reduced visibility conditions, (2) the influence of an ATIS on drivers' reactions to unexpected roadway events, and (3) the interaction of an ATIS with a Collision Avoidance System (CAS).

To investigate these issues, this research used a two-phase experimental design, combining a very efficient confounded experimental design used in Phase I with a traditional orthogonal design used in Phase II. Both experiments were conducted in a high-fidelity driving simulator. A total of 20 drivers was tested: 8 in Phase I and 12 in Phase II. In both phases, drivers completed several driving scenarios, during which they received roadway-relevant information via variable message signs (VMS) posted on the roadway and via an in-vehicle ATIS. Drivers also experienced several unexpected roadway events, some of which triggered a CAS alert.

The goal of Phase I was to build an initial driving performance model using a fractional-factorial design. Key independent variables of interest were information location (in-vehicle ATIS vs. roadway VMS) and visibility (clear vs. fog). Several other variables were included in the experimental design of this phase in order to represent a range of workload conditions, including roadway curvature, traffic density, speed limit, and road type. The resulting performance model accounted for 84 percent of total variance in speed.

Building upon the results of Phase I, an unambiguous final model was developed in Phase II using a standard full-factorial experimental design. Results of Phase II showed that mean speed was lower in the ATIS condition that in the control condition, while out-of-vehicle VMS messages did not alter speed. Standard deviation of speed and standard deviation of lane position were not influenced by either message type. Contrary to our expectations, effects of ATIS and VMS messages upon driving performance did not depend upon visibility conditions. Drivers in clear and fog visibility performed consistently. However, this result needs to be replicated on the road before it can form a basis for guideline development.

From the viewpoint of information integration, the most important parts of these experiments investigated how ATIS and CAS operate jointly. Experiment 1 (Phase I) suggested that intermediate levels of urgency are the locus of greatest interaction effects: when a collision event is either very urgent or not urgent, response time to the CAS event is not improved by having a CAS warning. In the most urgent collision situation an ATIS event did not prevent the fastest driver response time. However, the very small number of drivers tested in experiment 1 did not provide the statistical power to confirm these results. Experiment 2 (Phase II) did demonstrate conclusively that an ATIS message interfered with the driver's ability to react to a pedestrian road incursion. However, an ATIS message did not interfere with a CAS warning.

These results suggest both benefits and costs to in-vehicle messages. The good news is that CAS warnings are sufficiently robust so that ATIS messages do not appear to interfere with the driver's ability to process CAS information, perhaps in part because both kinds of message occur within the vehicle, avoiding the need to shift attention from the roadway. The bad news is that there appears to be an attentional cost to ATIS messages relative to processing external roadway events, such as pedestrians.

The present results from preliminary simulator experiments need to be expanded before design guidelines, especially for integration of in-vehicle systems, can be written with great confidence. However, these results do indicate that the simulator can provide a reasonable test bed for future evaluation of system interactions.

CHAPTER 1. INTRODUCTION

BACKGROUND

Recent advances in electronics and microcomputing have led to the feasibility of functionally-powerful, computer-based Advanced Traveler Information Systems (ATIS) as part of the automotive environment. Although these systems range in functionality, they all have the goal of acquiring, analyzing, communicating, and presenting information to assist travelers in moving from a starting location to a desired destination. While systems under development or in production promise to improve travel safety, efficiency, and comfort, they represent a new frontier in ground transportation. If not carefully developed, such systems could result in misapplied and unusable technology. In particular, there is a growing information gap between the advanced and diverse status of ATIS devices and the availability of human factors design criteria that can be used during the ATIS design process.

Battelle’s Human Factors Transportation Center (HFTC) is carrying out a study for the U.S. Federal Highway Administration (FHWA) to develop human factors design guidelines for the ATIS and Commercial Vehicle Operations (CVO) components of the Intelligent Transportation Systems (ITS). These systems are intended to provide a wealth of real-time information to the driver, including route guidance to avoid congestion and minimize travel time, safety and warning notices, and identification of desired motorist services, such as how to get to the nearest service station. While ATIS and CVO systems offer great potential benefits, their effectiveness depends on driver acceptance of the new technology, the ability of the system to integrate with other driving tasks, and the extent to which the systems conform to driver physical and cognitive capabilities and limitations. The guidelines that result from this effort will help designers produce ATIS and CVO systems that conform to human capabilities and limitations, enhance driver acceptance, and promote highway safety.

There are three technical phases associated with this project: (1) an analytical phase, (2) an empirical phase, and (3) an integrative phase. In this report, we summarize the rationale, methods, and results of part of the empirical phase of this effort. The research areas investigated include influence of an ATIS on driver performance in reduced visibility conditions and on drivers’ reactions to unexpected roadway events, and interaction of an ATIS with a Collision Avoidance System (CAS).

RATIONALE FOR THE STUDY

In a previous project task, *Definition and prioritization of research studies* (Kantowitz, Lee, and Kantowitz, 1997), a total of 91 research issues was rated by eight human factors experts along 14 separate criteria. Among the 20 highest-rated issues resulting from this effort were issue E14: *Examine how in-vehicle road sign information (e.g., ISIS) affects workload especially under nighttime, poor-weather, and other reduced visibility conditions*, and issue F2: *Examine how route guidance systems might adversely influence driver detection and recognition of unusual roadway events.*

An issue that has not been included in the original rating concerns the interaction of CAS with ATIS. Although there has been considerable research on how ATIS influences driving performance, it is not known how an ATIS will interact with other systems in a car, such as a CAS. It is of concern how drivers will react when these two separate systems present simultaneous, and sometimes conflicting, information. One possibility is that CAS information will have priority due to the rare and urgent nature of the alert, suppressing ATIS information. It is also possible that ATIS will reduce mental resources available for CAS, to a degree that would influence the ability of the driver to respond promptly to the collision warning.

OBJECTIVES AND HYPOTHESES

This study aims to answer the following questions:

1) How do ATIS and Variable Message Signs (VMS) affect driving performance in low visibility conditions?
2) Is a driver's ability to detect unusual roadway events impaired by having an ATIS?
3) How does a CAS interact with an ATIS?

An ATIS diverts the driver's attention away from the roadway and, therefore, is expected to somewhat negatively influence driving behavior. This influence is expected to be greater in reduced visibility conditions than in clear weather, as the driving task requires more attention when visibility is reduced. These considerations are reflected in the following hypotheses that guided our analysis:

Driving Performance

- Driving performance will be worse in the ATIS condition than in the VMS condition under both clear weather and low visibility conditions.
- Low visibility will have a negative influence on driving performance in both ATIS and VMS conditions; however, this influence will be greater in the ATIS condition than in the VMS condition.

Detection of Unusual Roadway Events

- Response time to unusual roadway events will be longer when the event takes place during message presentation than when no ATIS messages are present.

Reactions to CAS Alerts

- Response time to CAS alerts will be longer in the presence of an ATIS message than when no ATIS messages are present.

METHODOLOGY

The study was conducted in two data collection phases. In the first phase, we employed a fractional-factorial design with respect to continuously measured dependent variables (e.g., speed), but less than fractional for other types (not present on all sample conditions). We employed a fractional approach in order to comprehensively address the three objectives within time and other resources available typically for attacking human factors engineering design problems (vs. years for full-factorial approaches). It should also be noted that event variables often do not readily fit into full factorial structures (e.g., when *qualitatively* changed in nature by the settings of their occurances). Of course, fractional designs are not unambiguous as their main effects and interactions are systematically confounded (Cochran and Cox, 1957; Winer, Brown, and Michels, 1991). To logically unconfound some of these, we used information-processing theory later in our analysis (Kantowitz, 1992). To further clarify relationships, we have also conducted further data collection during a second data collection phase using a full-factorial design. In short, the purpose of the first phase was to identify an initial performance model and to identify variables requiring amplification during the second phase. The purpose of the second phase was to develop an unambiguous final model building upon the results of the first phase.

CHAPTER 2. PHASE I

INTRODUCTION

The driving task requires varying levels of attentional demand as some driving conditions require more attention than others. For example, two-lane streets require more attention than interstates; curved roads require more attention than straight roads; heavy traffic requires more attention than light traffic (Hulse and Dingus, 1989). It is also known that road geometry (radius of curvature) interacts with traffic density to influence driver workload (Kantowitz, 1995). Other factors that are likely to influence driver workload are speed and time allowed to make a decision about diverting from a planned route. All of these variables were incorporated in Phase I experimental design in order to represent a wide range of driving conditions in our initial investigation.

Besides attention demands required by the driving task, the size of the vehicle and corresponding dynamics are also believed to influence driver performance. Vehicle dynamics (e.g., engine horsepower and braking ability) could be changed in the driving simulator used in this study; consequently, we incorporated vehicle size as a variable in our experimental design.

METHOD

Subjects

Four male and four female subjects, with ages ranging from 19 to 30 (mean = 23, standard deviation = 3.78) were recruited from the University of Washington. All subjects had normal or corrected-to-normal vision, had been holding an active driver's license for more than 1 year, drove at least twice per week, and reported no problems with motion sickness. Subjects were paid $10 per hour for their participation, for approximately 3 hours of research time.

Apparatus

Driver behavior was investigated using the University of Washington High-Fidelity Driving Simulator, seven driving scenarios, a choice reaction time test, and an adaptive tracking test. Each of these is explained in detail below.

University of Washington High-Fidelity Driving Simulator

This simulator is housed within a mobile trailer and incorporates a 1994 Saturn sedan, mounted on a "road feel" motion platform. The 180 degrees horizontal by 45 degrees vertical forward scene, and the 60 degrees by 45 degrees vertical scene are controlled by a Silicon Graphics Onyx Rack System with Reality Engine II graphics that generates textured surfaces with flicker-free motion. A five-channel directional sound system provides realistic engine, road, and other-vehicle noises with appropriate direction cues, intensity levels, and Doppler shift. All sounds are consistent with vehicle states, changes in road surfaces, and the location and distance of external sound sources. The motion platform imparts high frequency movements that are correlated with the visual and auditory cues. The result is a realistic environment that has only one major limitation in the absence of the vestibular cues to motion.

The outside visual scene provides the driver with a high-fidelity representation of the real world, presenting multi-lane highways, two-lane rural roads, residential areas, and downtown core roads with representative roadway features and changes in elevation and terrain, as well as homes and commercial buildings, functional traffic control devices, pedestrians, and a range of other vehicles. The simulator also provides full control over ambient conditions, such as time of day and weather conditions.

The simulator is controlled from a single operator workstation. The operator monitors the progress of the driver through a plan view display of the visual database and a three-camera video system, and communicates with the driver through a two-way audio communication system. Data collected during the simulation include the locations and states of the simulator vehicle and other autonomous objects within the database. All inputs to the steering wheel, accelerator, brake, and vehicle secondary controls (e.g., gear shift, headlights) are also recorded. Acceleration rate is measured by a linear potentiometer; braking behavior is measured by a strain gauge. Inputs into these devices are translated into a percentage of throttle and brake pressure.

Driving Scenarios

Subjects completed seven driving scenarios. The first three of these were 3-5 min practice scenarios; the remaining four were experimental scenarios that took approximately 14 min to complete at the posted speed limits. In all scenarios, time of day was set at 12:00 pm, and the only sound source was the driver’s vehicle (68 dB(A) SPL).

The purpose of the practice scenarios was to help subjects to become familiar with the steering, accelerator, and brake characteristics of the simulator, and to get accustomed to the simulated environment. They consisted of rural driving under bright skies, with a limited number of traffic control devices and other vehicles encountered along the route. The roadway included both straight and curved sections surrounded by trees, hills, and grass.

The experimental scenarios took place on two-lane rural roads and a multi-lane highway that simulates a part of Washington State Highway 520. The same visual database was used in all four scenarios; the database was traversed twice in the eastbound direction, and twice in the westbound direction. One trip in each direction took place in clear weather while the other one took place in fog (with 100 meters of visibility).

During both practice and experimental scenarios, drivers received roadway-relevant information through VMS posted on the roadway and an in-vehicle ATIS. Roadway signs presented text messages on a 2.6 × 8.6 m display area on top of the driver's lane, 3.3 m above the roadway. Messages were printed with uppercase characters, approximately 0.9 m tall, in bright yellow on a black background. The signs displayed a message when the drivers were 50 m away from the sign; the message was visible until the driver passed the sign. ATIS messages were displayed on a Sharp 5.4-in diagonal color display located on the dashboard, 82.3 cm to the right of the steering wheel. The ATIS displayed visual text messages that were accompanied by an auditory tone (79db(A), 1500 ms). Messages were printed in uppercase characters in bright green on a black background. Messages remained on the display for 8 s or until the driver reached the roadway event the message referred to. All messages presented to the drivers are listed in appendix A.

Besides presentation of VMS and ATIS messages, experimental scenarios also included unexpected roadway events that required the driver to take immediate action in order to avoid a collision. Examples of such events are a vehicle rapidly decelerating in front of the driver and a pedestrian crossing the street without paying attention to the traffic. Subjects experienced a total of 10 unexpected events; these are described in table 1. Four of the unexpected events were associated with a CAS alert; the drivers heard an auditory collision alert (80 dB(A) SPL) as these events took place if they were driving in the CAS On condition. The collision alert was considered to be a highly critical alarm requiring immediate attention, and was easily distinguished from the tone that accompanied ATIS messages. If the drivers were driving in the CAS OFF condition, the events took place, but the drivers did not hear a CAS alert. The four unexpected roadway events that activated the CAS will be referred to as *CAS events*. CAS events took place while the driver was responding to an ATIS or VMS message or while no messages were being presented. The other six unexpected events took place immediately following message presentation; they did not trigger collision warnings.

Table 1. Unexpected events.

EVENT REFERENCE*	SCENARIO	EVENT DESCRIPTION	TIMING	CAS ALERT?
Event 1	2	A pedestrian walks into the roadway.	Immediately following a VMS message	No
Event 2	2	On a two-lane road, a vehicle in the opposing lane invades the driver's lane while performing a passing maneuver.	Immediately following a VMS message	No
Event 3	3	A car parked on the shoulder cuts through the driver's lane to merge into the left-hand lane.	Immediately following a VMS message	No
Event 4	4	A motorcycle merges into the driver's lane from the left-hand shoulder.	Immediately following an ATIS message	No
Event 5	4	A vehicle cuts into the driver's lane and comes to a stop on the shoulder.	Immediately following an ATIS message	No
Event 6	1	A vehicle overtakes the driver and rapidly slows down.	Immediately following an ATIS message	No
CAS+ATIS	1	On a two-lane rural roadway, the driver receives the ATIS message: "Pass on left, chemical spill ahead." While the driver is switching lanes, a vehicle parked on the side of the road begins to move toward the driver.	While the driver is responding to an ATIS message	If the driver is driving in the "CAS ON" condition
CAS+VMS	3	On a four-lane highway, the driver is presented the message: "Merge left, construction ahead." When the driver begins to switch lanes, a vehicle behind the driver in the left-hand lane accelerates, not allowing the driver to merge into the lane.	While the driver is responding to a VMS message	If the driver is driving in the "CAS ON" condition
CAS 1	2	Lead vehicle rapidly decelerates.	No accompanying ATIS/VMS message	If the driver is driving in the "CAS ON" condition
CAS 2	4	Lead vehicle rapidly decelerates. (Less urgent than a CAS1 event)	No accompanying ATIS/VMS message	If the driver is driving in the "CAS ON" condition

* This is how the events will be referenced later on in the report.

Choice Reaction Time Test

Choice reaction and tracking tests were included to use as covariates in subsequent analyses. Choice reaction time test measured the speed of manual choice response to a visual stimulus. The stimulus (the character ‘X’) was presented on a computer screen, randomly on either of two fixed locations: one on the left side of the screen and another one on the right. Subjects were instructed to place the tip of their left index finger on the ‘Z’ key, and the tip of their right index finger on the ‘/’ key, and press the ‘Z’ key if the stimulus appears on the left and ‘/’ key if on the right. Inter-stimulus time was 1 s. The stimulus remained on the screen until the correct response was given, for a maximum of 750 ms. The test was administered on a lap-top computer with a Pentium processor. Practice tests included 25 trials, while experimental tests included 50 trials.

Adaptive Tracking Test

This test of perceptual-motor skill measured adaptive manual tracking of a visual target. The subject was shown a circular target that moved back and forth horizontally across a computer screen. The subject manually controlled a smaller target with a joystick positioned on the table in front of the screen, and was instructed to track the moving target by keeping the smaller target on top of the irregularly moving larger target. The motion of the target was randomly determined using multiple combinations of sinusoidal wave forms. The target’s speed depended on the accuracy of the subject, slowing down when the subject was not doing well, and speeding up as the subject increased in accuracy. A practice session of 20 s was followed by 120 s of testing. This test was administered on the same computer as the choice reaction time test.

Experimental Design

Independent Variables

Table 2 shows the independent variables examined in this experiment. Between-subject variables included CAS status, car size, and decision time. Within-subject variables included information location, visibility, road type, speed limit, road curvature, traffic density, message type, unexpected event, and window.

Table 2. Independent variables for phase I.

VARIABLE TYPE	VARIABLE NAME	VARIABLE LEVELS
Between-Subject	CAS Status	On Off
	Car Size	Small Big
	Decision Time	Near Far
Within-Subject, Between-Scenario	Information Location	ATIS (in vehicle) VMS (on the roadway)
	Visibility	Clear Fog (100 meters visibility)
Within-Subject, Within-Scenario	Road Type	Four-lane road Two-lane road
	Speed Limit	30 mi/h 60 mi/h
	Road Curvature	Straight Curve
	Traffic Density	Low (0-1 other vehicles) High (3-5 other vehicles)
	Message Type	Slow down Change lanes Neutral
	Unexpected Event	Present Not present
	Window	Before-message During-message After-message

CAS Status was either on or off. If the subjects were driving in the CAS on condition, they received collision alerts as certain unexpected events took place (i.e., CAS events in table 1). In the CAS off condition, no alerts were provided for CAS events.

Car Size had two levels, (1) small and (2) big. The two vehicles differed in engine displacement, engine inertia, engine vibration frequency, and other vehicle constants.

Decision Time related to the distance (at message onset) between the driver's vehicle and the roadway event referred to by the message. This variable had two levels, (1) near and (2) far, which were determined by the design guideline provided in Campbell, Carney, and Kantowitz (1998) for *timing of auditory navigation information*. Preferred minimum distance and preferred maximum distance suggested by the guideline were used for the near and far levels of this variable. These are determined by the following equations:

Preferred minimum distance (meters) = speed (km/h) x 1.637 + 14.799

Preferred maximum distance (meters) = speed (km/h) x 2.222 + 37.144

Both distances are functions of vehicle speed; they were calculated with the assumption that the subjects would drive at the speed limit.

Information Location and Visibility were within-subject, between-scenario variables; their values remained the same within a driving scenario. Four orthogonal conditions of these variables defined the four scenarios that the subjects were required to complete, as shown in table 3. Information Location referred to how messages were presented to the driver, and had two levels, (1) VMS and (2) ATIS. In the VMS condition, messages were displayed on message signs posted on the roadway. In the ATIS condition, messages were presented inside the vehicle. Visibility also had two levels, (1) clear weather and (2) fog with 100 meters of visibility.

Table 3. Experimental design: Within-subjects, between scenario variables.

DRIVING SCENARIO	INFORMATIONA LOCATION	VISIBILITY
1	ATIS	Clear
2	VMS	Fog
3	VMS	Clear
4	ATIS	Fog

Other within-subject variables, road type, speed limit, road curvature, traffic density, message type, unexpected event, and window, were varied within a scenario. There were two levels of road type, (1) two-lane roads and (2) four-lane roads; two levels of speed limit, (1) 30 mi/h and (2) 60 mi/h; two levels of road curvature, (1) straight and (2) curve, and two levels of unexpected event, (1) present and (2) not present. There were also two levels of traffic density: (1) low and (2) high. In low traffic density, there was at most one other vehicle in the vicinity of the driver; in high traffic density there were three to five other vehicles.

Message type was determined by message content and the action required from the driver. This variable had three levels:

1. Slow Down (i.e., slow down, pedestrian crossing ahead),
2. Change Lanes (i.e., change lanes, accident in lane ahead), and
3. Neutral (i.e., road closed for paving tomorrow).

Window referred to the position of the data-collection windows and had three levels: (1) before-message window, (2) during-message window, and (3) after-message window. All windows were of equal duration. During-message window started with message presentation and ended when the driver reached the relevant roadway event (or, in the case of neutral messages, where the event would have been placed had there been a relevant roadway event). During-message window was immediately preceded by the before-message window, and immediately followed the after-message window.

From the 16 unique combinations of the within-scenario variables road type, speed limit, curvature, and traffic density, 6 were chosen to represent a range of workload conditions. In each driving scenario, a scenario incident was placed at locations corresponding to each of the six combinations. Table 4 displays the incidents in each of the four experimental scenarios, as well as the corresponding roadway characteristics (i.e., road type, speed limit, curvature, and traffic density). An incident consisted of a VMS/ATIS message, an unexpected event, or both. Each experimental scenario included six incidents: one CAS event, two slow-down messages, two change-lane messages, and one neutral message. Two of the messages in each scenario were paired with an unexpected event.

Table 4. Scenario incidents.

ROAD TYPE	SPEED LIMIT	CURVATURE	TRAFFIC DEMAND	SCENARIO 1 [CLEAR] [ATIS]	SCENARIO 2 [FOG] [VMS]	SCENARIO 3 [CLEAR] [VMS]	SCENARIO 4 [FOG] [ATIS]
Four-lane	30	Curve	Low	Slow Down Event 6	Change Lanes	CAS+VMS	Slow Down
Four-lane	60	Straight	High	Change Lanes	CAS 1	Slow Down Event 3	Change Lanes
Two-lane	30	Straight	Low	CAS+ATIS	Slow Down	Change Lanes	Neutral Event 4
Two-lane	30	Curve	High	Slow Down	Change Lanes Event 2	Neutral	Change Lanes
Two-lane	60	Straight	Low	Change Lanes	Neutral Event 1	Slow Down	Slow Down
Two-lane	60	Curve	High	Neutral	Slow Down	Change Lanes	CAS 2

Each of the eight subjects received a unique combination of the between-subject variables, as shown in table 5. A balanced Latin square design, replicated twice, was used to determine the scenario order.

Table 5. Experimental design: Between-subject variables.

SUBJECT ID	DECISION TIME	CAS STATUS	ENGINE SIZE	SCENARIO ORDER
1	Near	Off	Small	1 2 4 3
2	Near	Off	Big	2 3 1 4
3	Near	On	Small	3 4 2 1
4	Near	On	Big	4 1 3 2
5	Far	Off	Small	1 2 4 3
6	Far	Off	Big	2 3 1 4
7	Far	On	Small	3 4 2 1
8	Far	On	Big	4 1 3 2

Dependent Variables

Three types of dependent variables were collected: (1) measures of driving performance, (2) response time to roadway events, and (3) measures of reaction time and tracking ability. They are explained below.

Driving Performance Measures. Of particular interest in driving performance data were measures of speed maintenance and measures of steering wheel movements.

Under conditions of increased attentional demand, the driver often reduces vehicle speed (Tijerina, Kiger, Rockwell, and Wierwille, 1996). Research has also found velocity maintenance to be a sensitive measure to changes in the amount of attention demands by secondary driving tasks (Monty, 1984). Vehicle speed can be considered a vehicle state that has to be held constant in most circumstances. Therefore, variations in velocity are used to evaluate performance. Drivers are required to make continuous adjustments in pedal displacement to maintain correct speed. When driver attention is drawn away from the driving task, there is a tendency to maintain the foot in the same position. When the drivers realize they are going too slowly, the accelerator is depressed to a greater degree than is normal for a continuous adjustment, resulting in a higher variation in speed.

Research has shown that changes in driving steering behavior occur when driver attention changes (Wierwille and Gutman, 1978). In normal, low attention circumstances, drivers make continuous, smaller steering corrections to make up for roadway variance and driving conditions. These corrections are typically within the range of 2 to 6 degrees. As attention is drawn away from the task of driving, the frequency of steering corrections tends to decrease. Since the small centering corrections decrease, the vehicle tends to drift farther away from the lane center, and a larger steering input is required to correct the position. These larger steering inputs generally exceed 6 degrees and are referred to as large steering reversals. An increase in the rate of large steering reversals, therefore, indicates high attention or workload requirements and a reduction in driving performance.

Response Times to Roadway Events. Response times to the unexpected events were determined by looking at drivers' steering and breaking behavior. Response time was equal to the time from event onset to when the pressure on the break pedal exceeded 2 percent or the angular velocity of the steering wheel exceeded 105 degrees/s.

Measures of Reaction Time and Tracking Ability. Performance measure on the reaction time test was correct-response latency. The harmonic mean of correct-response latencies in a block provided a summary score for that block. Performance on the adaptive tracking test was measured with the percentage of time on target starting at 30 s into the test.

Procedure

Potential subjects were screened through a Subject Selection Phone Questionnaire (appendix B) and a Driver Demographic Characteristics Questionnaire (appendix C). To be able to participate, subjects were required to be over 18 years of age, have been holding an active driver's license for more than a year, and drive in Seattle at least twice a week. Individuals who experienced motion sickness, frequent migraines, serious heart condition, were pregnant, suffered any medical condition, or took any medications that predisposed them to nausea, blurred vision, or drowsiness were omitted from the study to minimize the risk of simulator sickness.

Upon arriving at the simulator, subjects were asked to read the FHWA Research Participation Information Summary (appendix D) and to sign the associated consent form (appendix E). The symptoms and possibility of simulator sickness were also explained to them at this time.

After the consent form had been signed, a Subject Comfort Assessment Questionnaire (appendix F) was administered to record the driver's state of well-being before the experiment. This was used as a pre-screening tool; the drivers were not permitted to enter the simulation room if their score on the comfort assessment did not meet a pre-determined criterion. If they did meet the criterion, a postural disequilibrium test was administered next. This test required the drivers to balance on one foot with their eyes closed and their arms folded across their chest. The experimenter recorded the length of the time, up to 30 s, that the drivers could keep their position without moving or opening their eyes. The test was repeated three times. The mean score was calculated and kept to be compared with the post-test results.

The drivers then completed two blocks of the adaptive tracking and choice reaction time tests. Following that, they were escorted to the vehicle and were encouraged to adjust the seat and mirrors to a comfortable position. The vehicle's controls were shown to the drivers, and the presence of a microphone and video cameras was noted. The drivers were told that their primary task throughout the experiment was to safely operate the vehicle as if they were driving their own vehicle in the real world. They were instructed to drive at the posted speed limits, and to stay in the right hand lane when not passing.

After the drivers felt comfortable inside the vehicle, and were able to repeat the instructions to the experimenter, they completed the three practice scenarios. The practice scenarios enabled the drivers to get used to the feel of the simulator, and to get adjusted to the simulated environment. After the practice trials were completed, the drivers were asked to complete the four experimental scenarios in a pre-determined order. During the simulation, the experimenter monitored the drivers' speed and verbally reminded them to slow down or speed up if they deviated too far from the posted speed limits.

After the completion of each driving scenario, the drivers took a 3-10 min break. During this time, the Subject Comfort Assessment Questionnaire was administered again to make sure that the drivers were not experiencing any adverse effects of the simulation. After two experimental scenarios were driven, the drivers also completed the choice reaction time and adaptive tracking tests.

After all driving was complete, drivers repeated the choice reaction time and adaptive tracking tests. The Postural Disequilibrium Test and the Subject Comfort Assessment Questionnaire were also administered one more time. If the differences between pre-test and post-test scores failed to meet pre-determined criteria, the driver was encouraged to remain at the experiment site and rest for 30 min, and the tests were administered again after that time. If drivers met the criteria after the second post-test administration, they were permitted to drive home, otherwise they were sent home in a taxi. Before leaving the simulator, the drivers were paid and a record of payment form was completed and signed.

RESULTS AND DISCUSSION

The results will be described in three sections: (1) performance on the choice reaction time and adaptive tracking tests, (2) driving performance, and (3) responses to unexpected roadway events. Data analyses were conducted using Bio-Medical Data Processing (BMDP) Version 7.0 software package. An alpha level of 0.05 was selected as the criterion for statistical significance.

Performance on Choice Reaction Time and Adaptive Tracking Tests

Figures 1 and 2 display the mean scores obtained on the choice reaction and adaptive tracking tests. Tracking data for one subject during two blocks were missing; they were replaced by the scores of the preceding block.

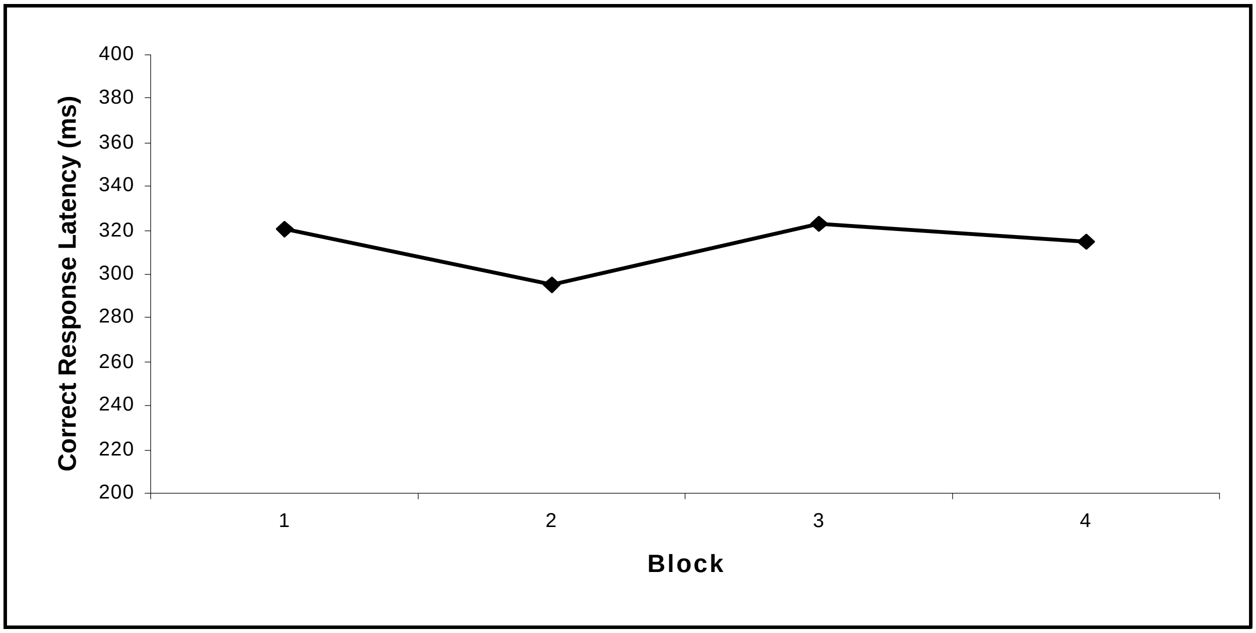

Figure 1. Mean reaction time scores (averaged over all subjects).

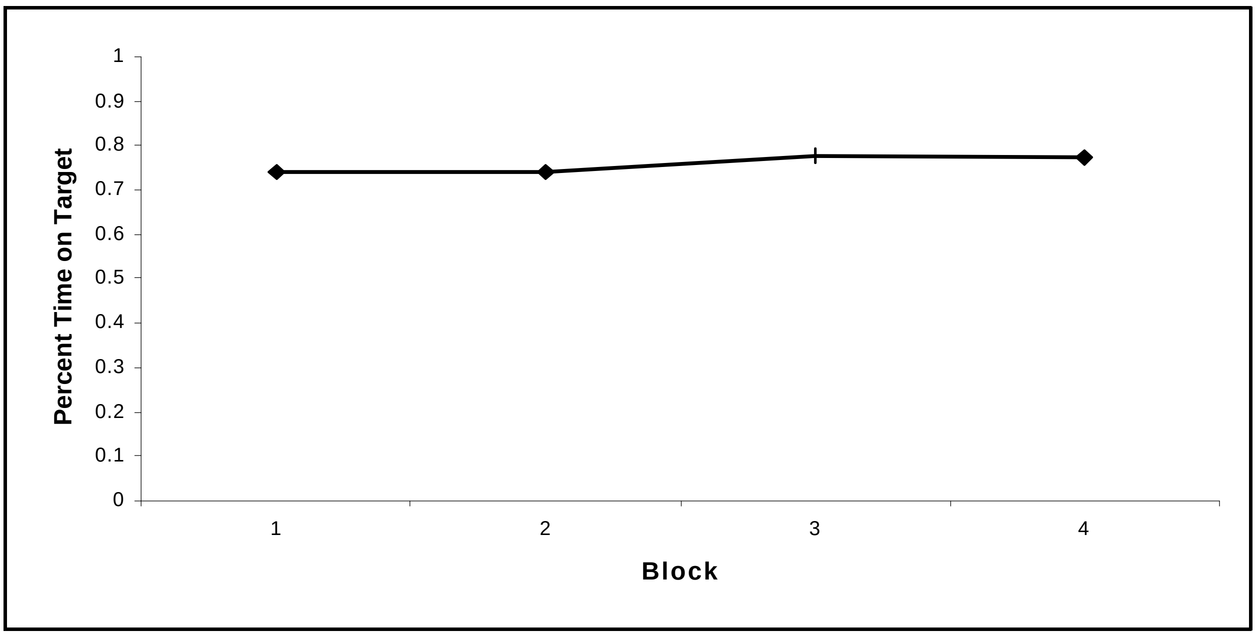

Figure 2. Mean tracking scores (averaged over all subjects).

Driving Performance

A repeated measures analysis of covariance (RANCOVA) was used to investigate the influence of various independent variables on mean speed, using reaction time and tracking scores as covariates. Of note, reaction time covariate for a driver was the arithmetic mean of the reaction time scores in all four blocks; tracking covariate was the arithmetic mean of the tracking scores of the last two blocks. Excluded in the ANCOVA were cases with unexpected events and cases where the driver had a collision.

The fractional design used in this experiment did not allow all the interactions to be statistically included in the analysis. In keeping with Kantowitz (1992), this was addressed by investigating alternative theory-based models that included different combinations of possible interactions. Theory-based restrictions, e.g., either monotonic or no decrease in speed with increasing load, served to effectively decrease confounding as described elsewhere (Bittner, Bramwell, Morrissey, and Winn, 1998; Bittner, 1974; Scheffe, 1959). In our approach, we did not formally apply logical constraints as Bittner et al. (1998) did; rather, we used them in selecting the final model. Of course, there was some potential for a less-than-ideal model selection using our approach; however, an unambiguous resolution was the objective of Phase II, so an approximate model was adequate for the purposes of Phase I. This is the advantage of our iterative-phased experimental approach.

Based on magnitude of explained variance and robustness, as well as logical consistency, a final model was selected for predicting speed as a function of the independent variables. The selected model explained 84 percent of total variance in speed. This analysis can be seen in appendix G.

Figure 3 shows predicted mean speed as a function of window and information location. There was a significant window × information location interaction, $F(2, 184) = 6.94$, $p < 0.005$. While there were no differences with respect to information location in the pre-message window, mean speed in the during window was lower in the VMS condition than in the ATIS condition. Two possibilities may account for this finding: (1) reading VMS messages required more attention than reading ATIS messages, or (2) subjects reduced their speed in the VMS condition to have more time to read the roadway message.

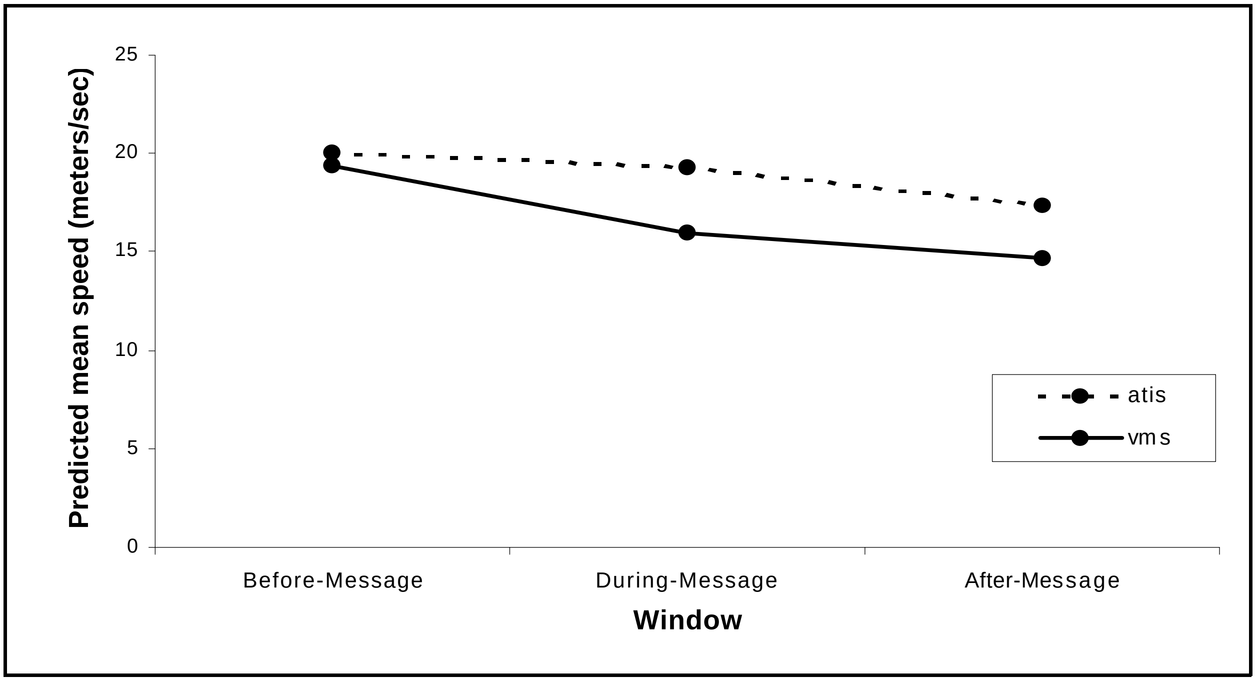

Figure 3. Predicted mean speed as a function of window and information location.

Figure 4 shows predicted speed as a function of window and curvature. The window × curvature interaction was significant, $F(2, 184) = 7.97$, $p < 0.001$. Mean speed in the during-message window was lower on curves than on straight sections; there were no differences in the pre-message window.

Figure 5 shows predicted mean speed as a function of window and road type. There was a significant window × road type interaction, $F(2, 184) = 10.19$, $p < 0.001$. Mean speed in the during-message window was lower on two-lane roads than on four-lane roads; there were no differences with respect to road type in the pre-message window.

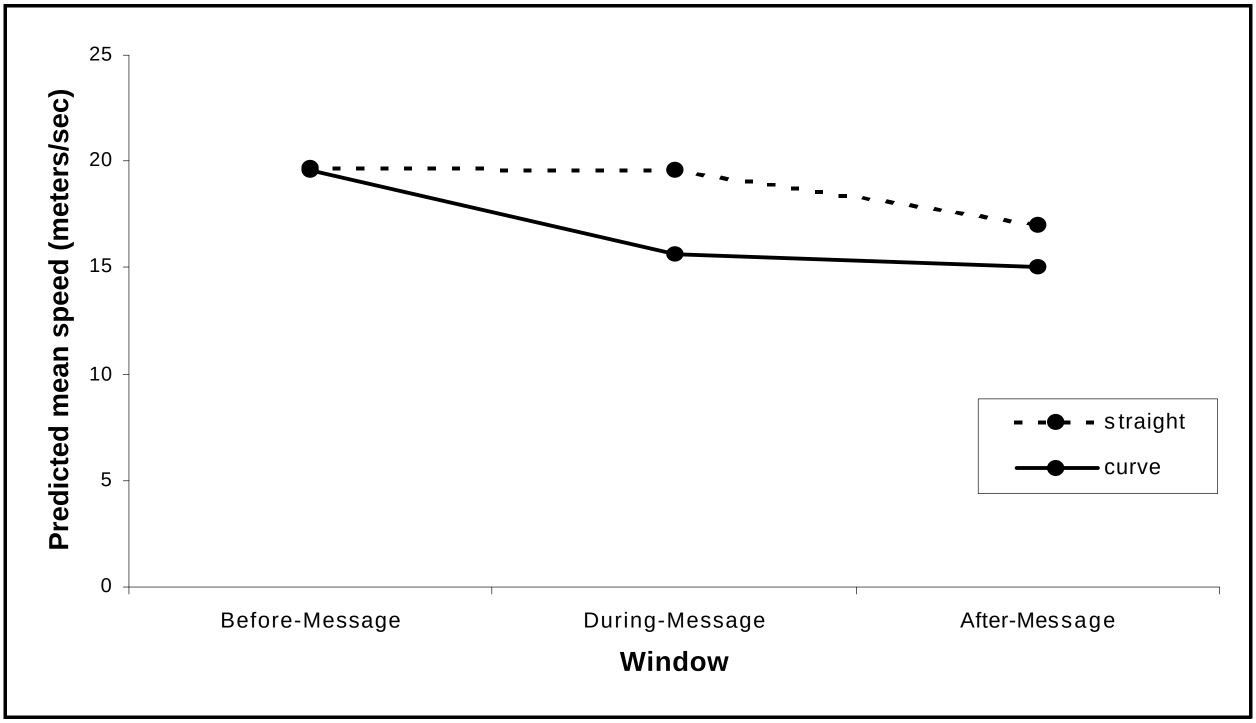

Figure 4. Predicted mean speed as a function of window and curvature.

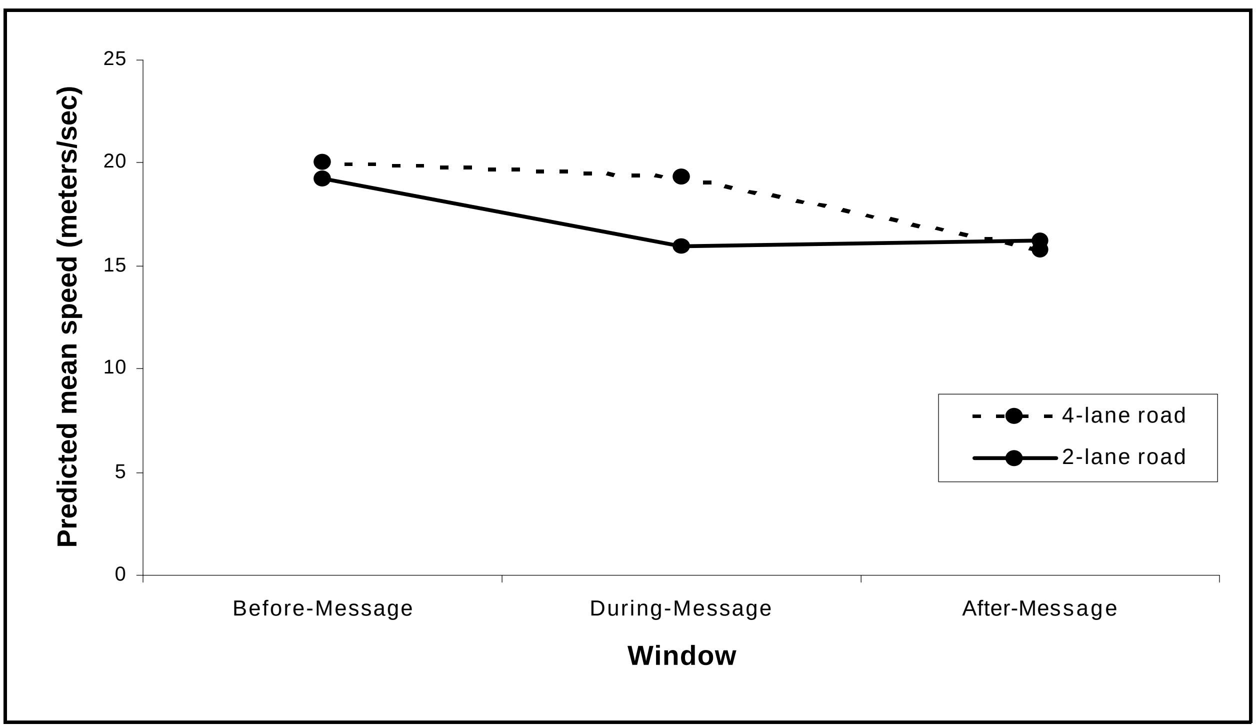

Figure 5. Predicted mean speed as a function of window and road type.

Figure 6 shows predicted mean speed as a function of window, message type, and speed limit. The window × message type × speed limit interaction was significant, $F(4, 184) = 22.03$, $p<0.005$. In the 60 mi/h condition, all message types caused a significant decrease in speed. In the 30 mi/h condition, slow-down messages caused a decrease in speed, change-lane messages did not influence speed, and neutral messages caused an increase in speed.

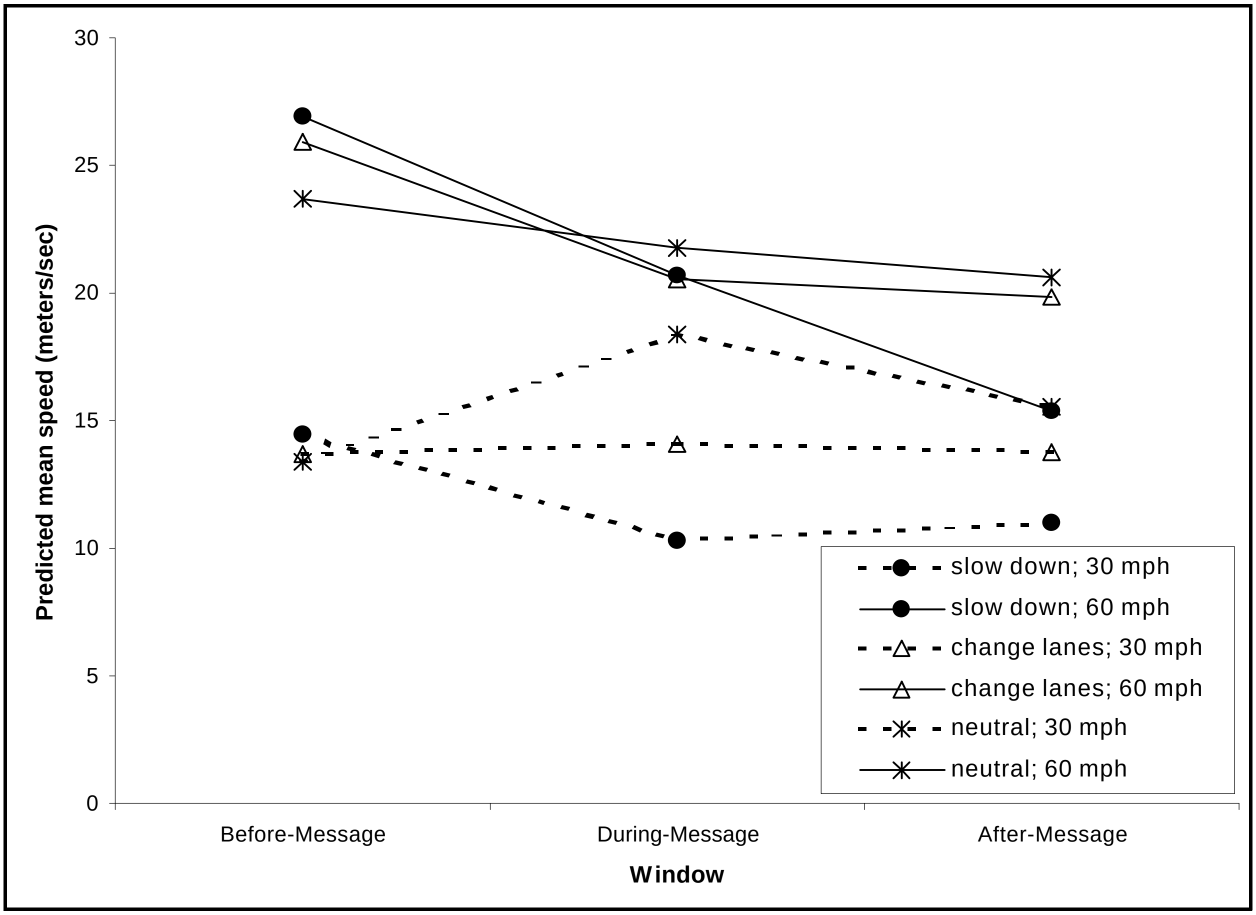

Figure 6. Predicted mean speed as a function of window, message type, and speed limit.

Contrary to our expectations, main effect of visibility, $F(1, 90) = 1.48$), $p > 0.05$, and the window × visibility interaction, $F(2, 184) = 1.36$, $p > 0.05$, did not reach the 0.05 significance level.

Standard deviation of speed, although a useful measure when drivers maintain a constant speed, was not found useful in this case, as drivers did not maintain constant speed. Rate of large steering wheel reversals, another independent variable that was available, was not examined because, in addition to its sparse probabilistic nature, it was confounded by road curvature.

Unexpected Roadway Events

To investigate the influence of various independent variables on response times to unexpected events, two analyses of variance (ANOVA) were conducted. The analyses were performed on response times that were less than 4 s. After 4 s of uninterrupted driving, the driver would be beyond the unexpected event, and any steering or braking inputs would not be in response to that event. There were missing data for all unexpected events. CAS+VMS event was entirely omitted from the analysis because drivers either did not see the car approaching from behind, or did not associate it with the collision alert. (This outcome did not occur with the CAS + ATIS event where the approaching vehicle came from in front of the driver's vehicle. Comparison of front- and rear-warning CAS is beyond the scope of the present experiment.) CAS events and other unexpected events will be discussed separately.

CAS Events. Figure 7 shows the mean response time to CAS events in the presence and absence of a collision alert. The events are ordered in increasing urgency. CAS+ATIS event was the most urgent CAS event; it required an immediate response as another vehicle was coming toward the driver in the same lane. CAS2 was the least urgent; it involved a lead vehicle that abruptly reduced its speed. CAS1 was similar; however, the driver had less time to react in this case (the lead car was closer to the driver, and its goal speed was lower). Figure 7 shows an interesting finding. In the extreme cases of urgency, mean response times in the presence and absence of a collision alert are approximately equal. In between the extreme cases, drivers who received an alert reacted faster than those who did not receive an alert. However, an analysis of covariance did not detect an event × CAS Status interaction, $F(2, 13)=2.39$, $p>0.05$, or a CAS Status main effect, $F(1,13)=0.94$, $p>0.1$.

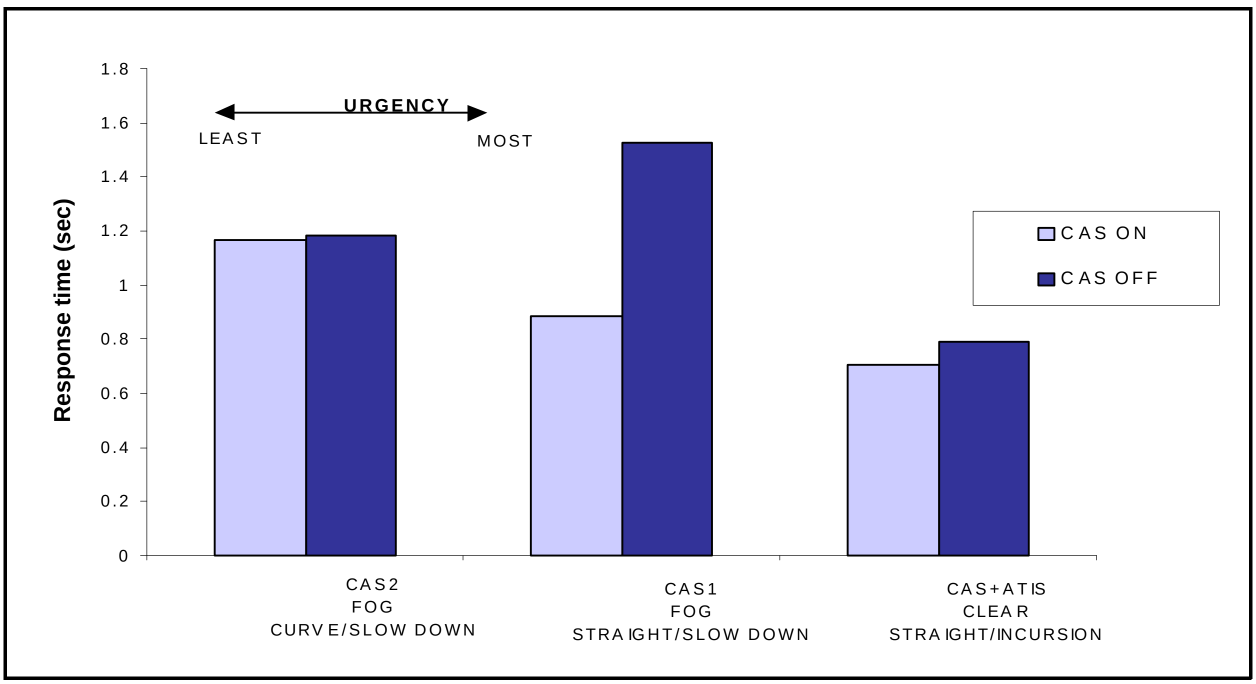

Figure 7. Influence of CAS status on response times to CAS events.

Other Unexpected Events. Figure 8 shows the influence of information location and visibility on response times to unexpected events. Mean response time in the ATIS-clear condition was lower than in the other three conditions; however, an analysis of covariance did not detect any statistical differences between groups, $F(1,24)=1.27$, $p > 0.1$. It should be noted that the ATIS-clear condition had only one valid data point.

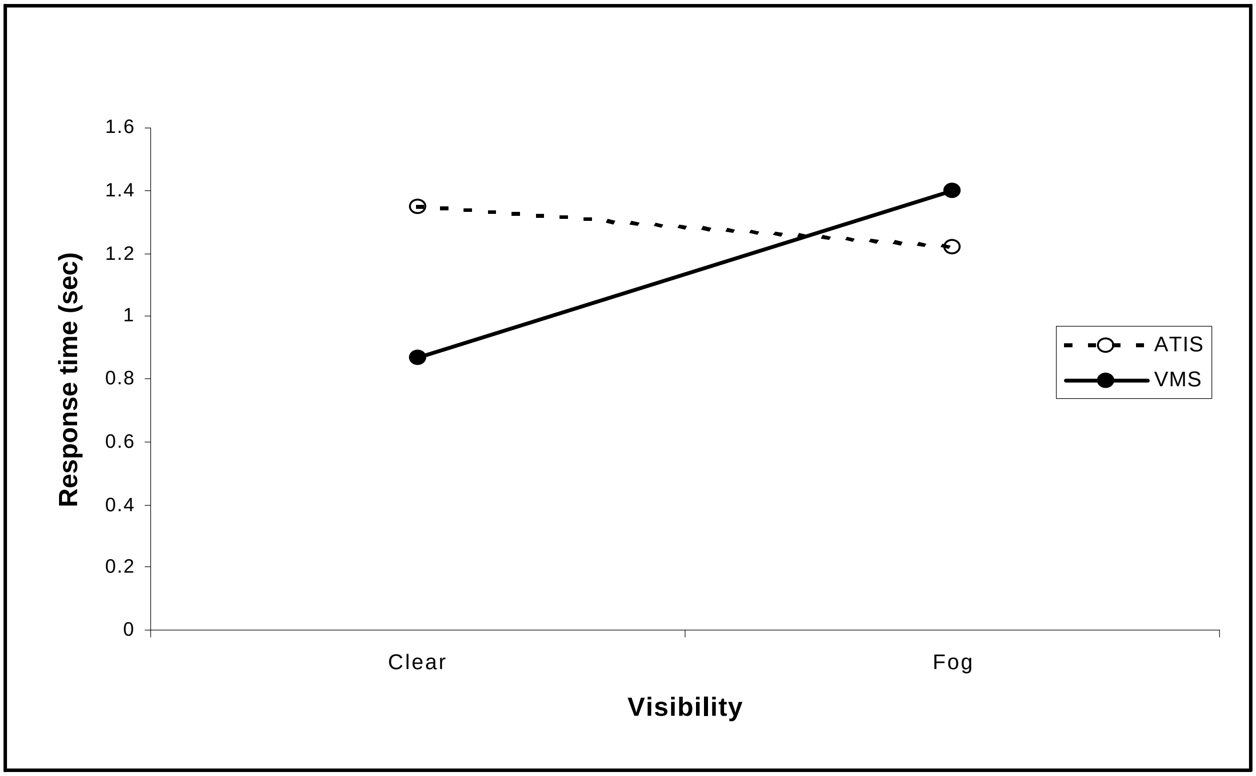

Figure 8. Influence of visibility and display location on response time to unexpected roadway events.

CHAPTER 3. PHASE II

INTRODUCTION

The results of the first phase were limited by the fractional factorial approach described earlier. To clarify the earlier results, a completely balanced design was used to investigate the subset of variables found most influential in Phase I. The independent variables included visibility and display location, while the dependent variables included speed and lane deviation measures. The design structure provided for a repeated measures analysis of variance (RANOVA). Method, Results, and Discussion follow.

METHOD

Subjects

Six male and six female drivers, ranging in age from 18 to 30 years old (mean = 20.75, standard deviation = 3.41), were tested. All drivers had normal or corrected-to-normal vision, had been holding an active driver's license for more than 1 year, drove at least twice per week, and reported no problems with motion sickness. The drivers were recruited from the University of Washington, and were paid $10 per hour for their participation.

Apparatus

Driver behavior was investigated using the University of Washington High-Fidelity Driving Simulator, which was also used in Phase I of this study. The driving scenarios are explained below.

Driving Scenarios

Drivers completed three practice and four experimental driving scenarios, as outlined in table 6. All scenarios took place during daytime, on a rural two-lane highway with straight sections and easy curves (radius > 800 m), with occasional traffic in the opposing direction. The sound from the driver's vehicle was set to 68 db(A). Posted speed limit was 45 mi/h in all scenarios; drivers were instructed to drive at the speed limit.

During the simulation, drivers received roadway-relevant information through roadway VMS and in-vehicle ATIS. The messages were similar in format and style to the ones presented in Phase I. Some of the in-vehicle and VMS messages informed the driver of a vehicle or an object blocking the roadway. When this was the case, the message was presented 450 m before the blocking vehicle or object. ATIS messages remained on the display for 4 s.

Table 6. Driving scenarios.

SCENARIO	VISIBILITY	LENGTH (M)	SCENARIO EVENTS
Practice Scenario 1	Clear	3008	None
Practice Scenario 2	Clear	3724	Pedestrian event ATIS message: "Road closed for paving tomorrow" VMS message: "Axle weight limit: 5 tons"
Practice Scenario 3	Clear	5575	VMS message: "Bicycles use shoulder only" ATIS message: "Temperature: 56 degrees"
Experimental Scenario 1	Clear	3935	Pedestrian event CAS event
Experimental Scenario 2	Fog	10925	VMS message: "Tune to 92.5 for traffic updates" ATIS message: "Accident ahead, use left lane" ATIS message: "Gas station in vicinity" VMS message: "Truck overturned ahead, use shoulder"
Experimental Scenario 3	Clear	12138	VMS message: "Bicycles use shoulder only" ATIS message: "Stopped vehicle ahead, pass on left" ATIS message: "Expect traffic delays in 10 miles" VMS message: "Lane closed for construction, pass on right"
Experimental Scenario 4	Clear	7750	ATIS message: "Disabled vehicle ahead, pass on left" ATIS message: "Lane blocked ahead, pass on right" + Pedestrian Event ATIS message: "Chemical spill ahead, use shoulder" + CAS Event

Also present in the scenarios were several pedestrians standing on the right side of the roadway, ready to cross the street. As the driver was approaching them, some of these pedestrians crossed the street at a speed of 6 km/h. The movement of the pedestrian started 5 s before the driver would reach the pedestrian at a speed of 45 mi/h (the posted speed limit). The drivers were told to beep the horn if they see a pedestrian crossing the street; however, they were not in danger of hitting the pedestrian if they were driving at 45 mi/h as the pedestrian moved out of the driver's lane before the driver reached him.

In addition to the *pedestrian event* described above, the scenarios also included a *CAS event*. Unlike the pedestrian event, the CAS event required the driver to react in order to avoid a collision. This event involved a vehicle stopped at the right side of an intersection. As the driver was approaching the intersection, this vehicle accelerated and stopped in the middle of the driver's lane. When the vehicle crossed the boundary of the driver's lane, the driver heard a loud auditory collision alert [80 db(A)]. (Unlike experiment 1 where only half the drivers received CAS warnings, in this experiment all drivers heard a CAS alert as this event was taking place.) The collision alert was considered to be a highly critical alarm requiring immediate attention, and was easily distinguished from the tone that accompanied ATIS messages. The stopped vehicle began its movement 2.5 s before the driver would reach the intersection at a speed of 45 mi/h. The driver did not see the blocking vehicle until it invaded the driver's lane, as the vehicle was hidden behind a building.

The three practice scenarios consisted of a total of 10 min of driving in clear weather. The drivers saw two message signs on the roadway, and received two in-vehicle messages. They saw one pedestrian crossing the street, in addition to eight pedestrians standing on the side of the roadway.

In scenario 1, the drivers saw a pedestrian crossing the street and experienced a CAS event. They also saw four stationary pedestrians. This scenario took place in clear weather, and took 3.5 min to complete at the posted speed limit.

In scenario 4, the drivers received three in-vehicle messages. A pedestrian started to cross the street 0.8 s after the presentation of the second message. The CAS event took place 0.8 s after the presentation of the third message. This scenario took place in clear weather, and took 6.5 min to complete at the posted speed limit.

In each of scenarios 2 and 3, drivers received two in-vehicle and two roadway messages. They also saw three stationary pedestrians. Scenario 2 took place in fog (with 100 m visibility) while scenario 3 took place in clear weather. Both scenarios took approximately 10 min to complete at the posted speed limit.

Experimental Design

Independent Variables

Table 7 provides a description of the independent variables that were investigated in this experiment. Between-subject variables included gender and scenario order. Within-subject variables included visibility, display location, message type, window, and event condition.

Visibility had two levels: clear weather and fog with 100 m visibility. Display location also had two levels: ATIS and VMS. Two types of messages were presented: neutral and change-lane. Change-lane messages informed the driver of an object blocking the driver's lane. Neutral messages presented general information that did not require any steering or braking action from the driver.

Window referred to the position of the data collection windows and had two levels: before-message window and during-message window. Both windows were of equal duration. The instant that a message was presented marked the end of the before-message window and the beginning of the during-message window. Analyses were performed with window durations of 4 s and 8 s.

Table 7. Independent variables for Phase II.

VARIABLE NAME	VARIABLE TYPE	VARIABLE LEVELS
Display Location	Within-subjects	ATIS VMS
Visibility	Within-subjects	Clear Fog (100 m visibility)
Message Type	Within-subjects	Neutral Change Lanes
Window	Within-subjects	Before-Message Window During-Message Window
Event Condition	Within-subjects	Event Only Following an ATIS Message
Scenario Order	Between-subjects	1-2-3-4 1-3-2-4
Gender	Between-subjects	Male Female

Event condition had two levels: event only and following an ATIS message. In the event-only condition, no messages were present when the roadway event (i.e., CAS event or pedestrian event) took place. In the following-an-ATIS-message condition, the roadway event took place 0.8 s after the driver received an ATIS message. It would also be desirable to have a following-a-VMS-message condition; however, limited resources did not allow us to do this within the framework of an orthogonal design.

Scenario order, which was a between-subjects variable, had two levels. Drivers drove the experimental scenarios either in the order 1-2-3-4 or in the order 1-3-2-4. Gender was another between-subjects variable.

A total of 12 drivers was tested. Three drivers were randomly assigned to each of the four combinations of two levels of gender and two levels of scenario order.

Tables 8 and 9 show the experimental design. Scenarios 1 and 4 were designed to investigate research questions that involved unexpected roadway events. In these scenarios, drivers experienced one pedestrian event and one CAS event. Both events took place in the event-only condition in scenario 1, and in the following-an-ATIS-message condition in scenario 4. Scenarios 2 and 3, on the other hand, were designed to investigate the influence of ATIS and VMS on driving performance in reduced visibility conditions. In each of these scenarios, drivers received two ATIS messages and two VMS messages. One message in each display location was neutral; the other one was a change-lane message. Scenario 2 was driven in fog with 100 m visibility; scenario 3 was driven in clear weather.

All else being the same, response times are expected to be faster the second time an event takes place. Therefore, having the drivers experience the events first in the event-only condition and then in the following-an-ATIS-condition biased the experiment against any effects of an ATIS message on response times. To keep this bias at a minimum, scenarios 1 and 4 were placed as far away from each other as possible, which dictated scenario 1 to be driven first and scenario 4 to be driven last.

Table 8. Experimental design—scenarios 1 and 4.

SCENARIO	EVENT	EVENT CONDITION
1	Pedestrian Event CAS Event	Event Only Event Only
4	Pedestrian Event CAS Event	Following an ATIS Message Following an ATIS Message

Table 9. Experimental design—scenarios 2 and 3.

SCENARIO	VISIBILITY	DISPLAY LOCATION	MESSAGE TYPE
2	Fog	VMS ATIS ATIS VMS	Neutral Change Lanes Neutral Change Lanes
3	Clear	VMS ATIS ATIS VMS	Neutral Change Lanes Neutral Change Lanes

Table 10 shows the number of pedestrians, stationary and moving, in all driving scenarios. Stationary pedestrians were included in order to keep the probability of a given pedestrian crossing the street low.

Table 10. Number of pedestrians in scenarios.

	NUMBER OF PEDESTRIANS	
SCENARIO	STATIONARY	MOVING
Practice Scenario 1	3	0
Practice Scenario 2	2	1
Practice Scenario 3	3	0
Experimental Scenario 1	4	1
Experimental Scenario 2	3	0
Experimental Scenario 3	3	0
Experimental Scenario 4	2	1
Total	20	3

Dependent Variables

Dependent variables of interest included measures of driving performance and measures of responses to roadway events (i.e., pedestrian and CAS events); these are listed in table 11. Driving performance measures included mean speed, standard deviation of speed, mean lane position, and standard deviation of lane position. Roadway-event measures included brake reaction time, steering reaction time, and horn-button press latency.

Under conditions of increased attentional demand, the driver often reduces vehicle speed (Tijerina et al., 1996). Research has also found velocity maintenance to be a sensitive measure to changes in the amount of attention demanded by secondary driving tasks (Monty, 1984). Vehicle speed can be considered a vehicle state that has to be held constant in most circumstances. Therefore, variations in velocity are used to evaluate performance. Drivers are required to make continuous adjustments in pedal displacement to maintain correct speed. When driver attention is drawn away from the driving task, there is a tendency to maintain the foot in the same position. When the drivers realize they are going too slowly, the accelerator is depressed to a greater degree than is normal for a continuous adjustment, resulting in higher variation in speed.

While no driver maintains the vehicle perfectly at a selected lateral position in the lane, normally the attentive driver makes continuous, smaller steering corrections that yield a certain variability in lane position. With increased attention to in-vehicle tasks (or other distractions), the frequency of steering corrections per unit time tends to decrease. Since small steering corrections decrease, the vehicle tends to drift farther from the selected lane position and this requires a larger corrective steering input subsequently. If this pattern of behavior is exhibited, lane position variance (or standard deviation) might be expected to increase with increased attentional demand (Tijerina et al., 1996).

Table 11. Dependent variables for Phase II.

VARIABLE	UNITS AND DESCRIPTION
Mean speed	meters/second; mean vehicle speed within a given data collection window
Standard deviation of speed	meters/second; standard deviation of vehicle speed within a given data collection window
Mean lane position	meters; mean displacement from lane center within a given data collection window
Standard deviation of lane position	meters; standard deviation of displacement from lane center within a given data collection window
Brake reaction time	seconds; length of time from the moment the collision alert is activated until the pressure on the brake pedal exceeds 2%
Steering reaction time	seconds; length of time from the moment the collision alert is activated until steering wheel velocity exceeds 105 degrees/second
Horn-button press latency	seconds; length of time from the moment a pedestrian begins to cross the street until the horn-button is pressed

Procedure

Potential drivers were screened through a Subject Selection Phone Questionnaire (appendix B) and a Driver Demographic Characteristics Questionnaire (appendix C). To be able to participate, drivers were required to be over 18 years of age, hold an active driver's license for more than 1 year, and drive at least twice a week. Individuals who experienced motion sickness, frequent migraines, serious heart condition, were pregnant, suffered any medical condition, or took any medications that predisposed them to nausea, blurred vision, or drowsiness were omitted from the study to minimize the risk of simulator sickness.

Upon arriving at the simulator, drivers were asked to read the FHWA Research Participation Information Summary (appendix D) and to sign the associated consent form (appendix E). The symptoms and possibility of simulator sickness were also explained to them at this time.

After the consent form had been signed, a Subject Comfort Assessment Questionnaire (appendix F) was administered to record the driver's state of well-being before the experiment. This was used as a pre-screening tool; the drivers were not tested if their score on the comfort assessment test did not meet pre-determined criteria. If they did meet the criteria, a postural disequilibrium test was administered next. This test required the subject to balance on one foot, eyes closed and arms folded across the chest. The experimenter recorded the length of time, up to 30 s, the drivers could keep their position without moving or opening their eyes. The test was repeated three times. The mean score was calculated and kept to be compared with the post-test results.

After a brief description of the simulator, the subject was seated inside the vehicle and was encouraged to adjust the seat and mirrors to a comfortable position. The vehicle's controls were shown to the driver, and the presence of a microphone and video cameras was noted. The drivers were told that their primary task throughout the experiment was to safely operate the vehicle as if they were driving their own vehicle in the real world. They were instructed to drive at the posted speed limits, keep both hands on the steering wheel, and beep the horn if they see a pedestrian crossing the street.

After the drivers felt comfortable inside the vehicle, and were able to repeat the instructions to the experimenter, they completed three practice scenarios. The purpose of the practice scenarios was to enable the drivers to get used to the feel of the simulator, and to get adjusted to the simulated environment. After the practice trials were completed, the drivers were asked to complete the four experimental scenarios in a pre-determined order. During the simulation, the experimenter monitored the drivers' speed and verbally reminded them to slow down or speed up if they deviated too far from the posted speed limit.

After each driving scenario, the drivers took a 5 min break. When all the driving was completed, Postural Disequilibrium and Subject Comfort Assessment tests were administered again. If the differences between the drivers' pre-test and post-test scores did not reach pre-determined criteria, the drivers were encouraged to remain at the experiment site and rest for 30 min. After 30 min, the tests were administered again. If the drivers met the criteria after the second administration, they were permitted to drive home; otherwise, they were sent home in a taxi. Before leaving the simulator, the drivers were paid and a record of payment form was completed and signed.

RESULTS AND DISCUSSION

The results will be described in two sections: (1) driving performance, (2) response times to roadway events. Data analyses were conducted using the Bio-Medical Data Processing (BMDP) Version 7.0 software package. An alpha level of 0.05 was selected as the criterion for statistical significance. Due to a mechanical failure during testing, data from one subject were not usable. The analyses were conducted using the data from the remaining 11 subjects.

Driving Performance

Three repeated measures analyses of variance (ANOVA) were conducted to evaluate the influence of display location and visibility on mean speed, standard deviation of speed, and standard deviation of lane position. Each analysis included the independent variables of visibility, display location, window, scenario order, and gender. The analyses were performed on neutral messages only. In the analyses that are reported, a window length of 4 s was used. Analyses were repeated with a window length of 8 s, and similar results were obtained. Complete ANOVA tables can be seen in appendix I.

Figure 9 shows mean speed as a function of window, display location, and visibility. There was a significant window × display location interaction, $F(1, 7) = 28.76$, $p = 0.001$. Simple effect tests showed that, for VMS messages, there was no significant difference between the before- and during-message windows, $F(1,7)=0.17$, $p > 0.5$. However, for ATIS messages, mean speed was significantly lower in the during-message window than in the before-message window, $F(1,7)=5.61$, $p < 0.05$. Contrary to our expectations, visibility × display location × window interaction did not reach the 0.05 level of significance, $F(1,7)=4.76$, $p > 0.05$. Thus, the window × display location interaction was the same for both levels of visibility.

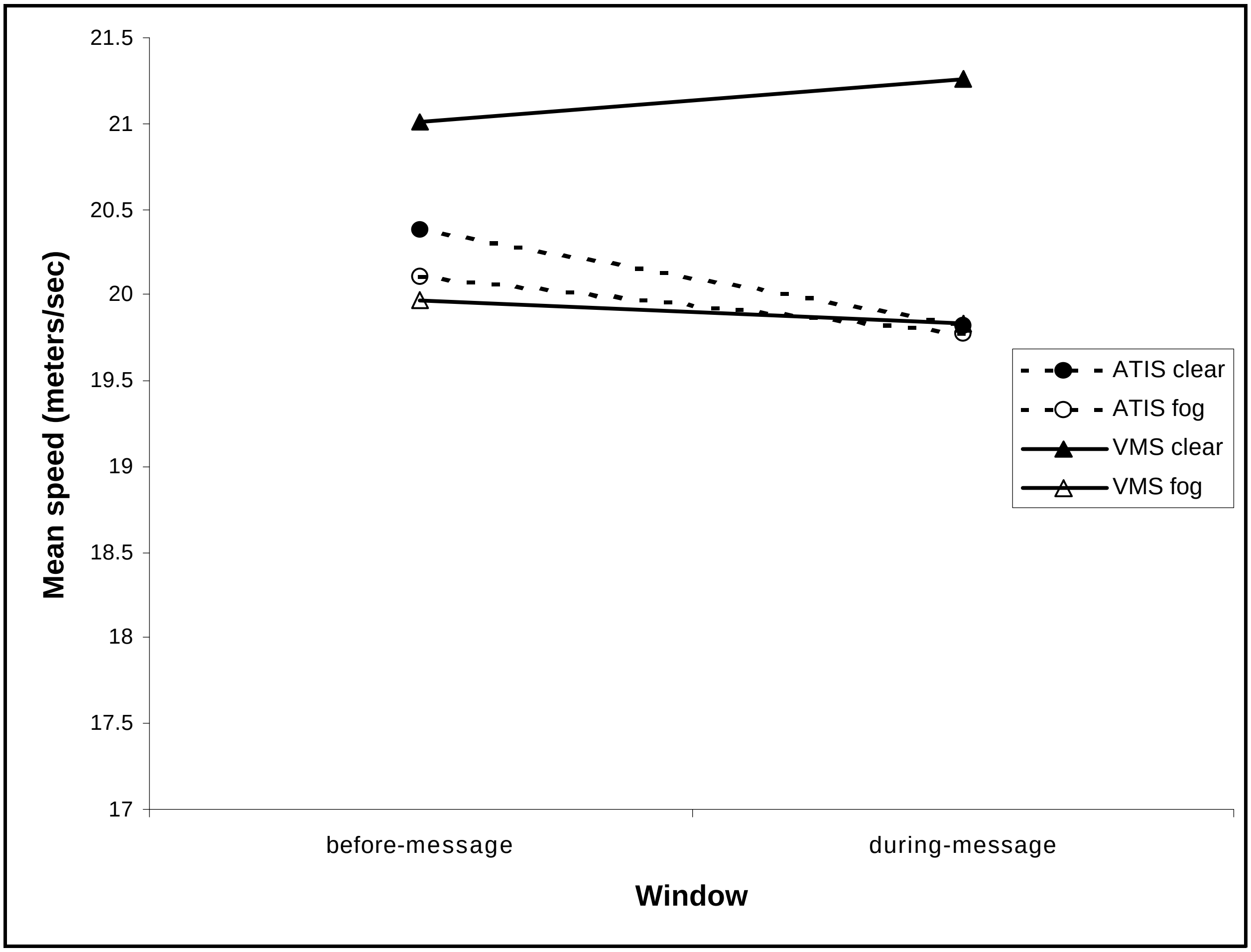

Figure 9. Mean speed as a function of window, display location, and visibility.

Figure 10 shows the influence of window, display location, and visibility on standard deviation of speed. In the during-message window, standard deviation of speed was higher in the ATIS-fog condition than in the other conditions; however, the difference was not significant, $F(1,7)=0.17$, $p > 0.5$. None of the main effects or two-way interactions of visibility, display location, and window reached statistical significance.

Figure 11 shows standard deviation of lane position as a function of window, display location, and visibility. None of the main effects or interactions of visibility, display location, and window reached statistical significance. SD of lane position was slightly higher in fog than in clear weather; however, the difference was not significant, $F(1, 7) = 4.05$, $p > 0.05$.

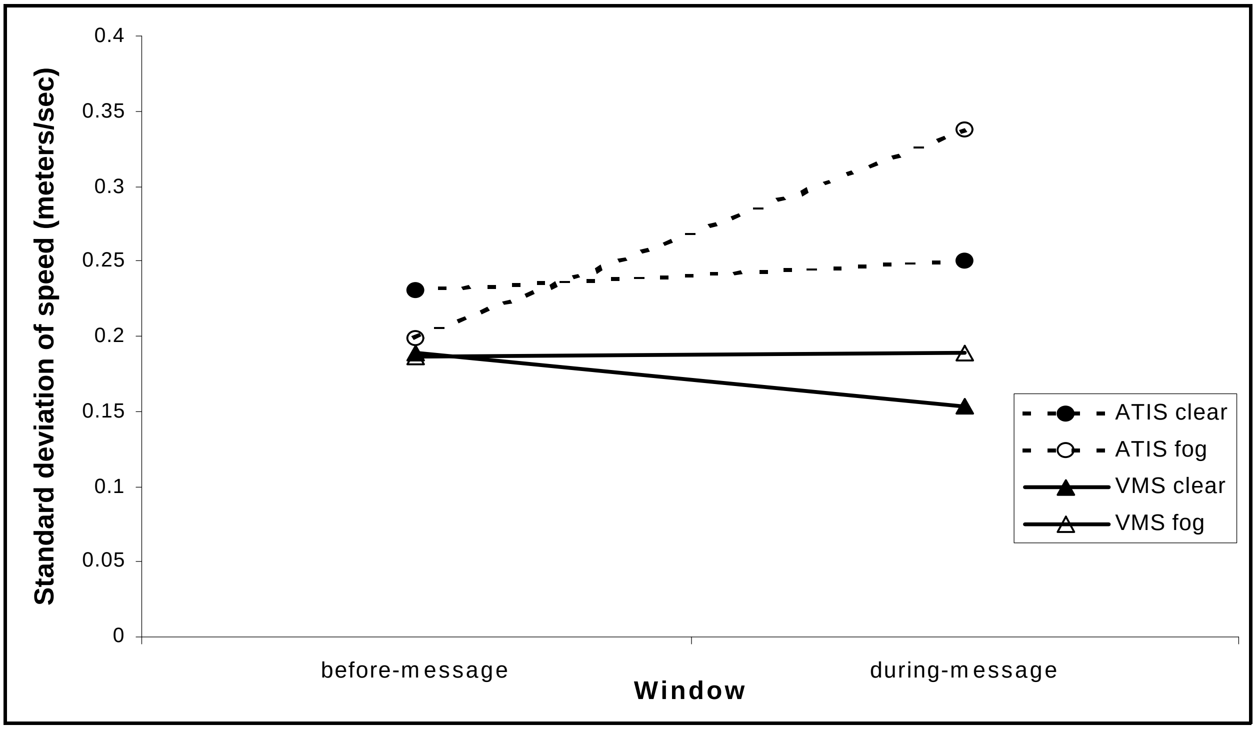

Figure 10. Influence of window, display location, and visibility on standard deviation of speed.

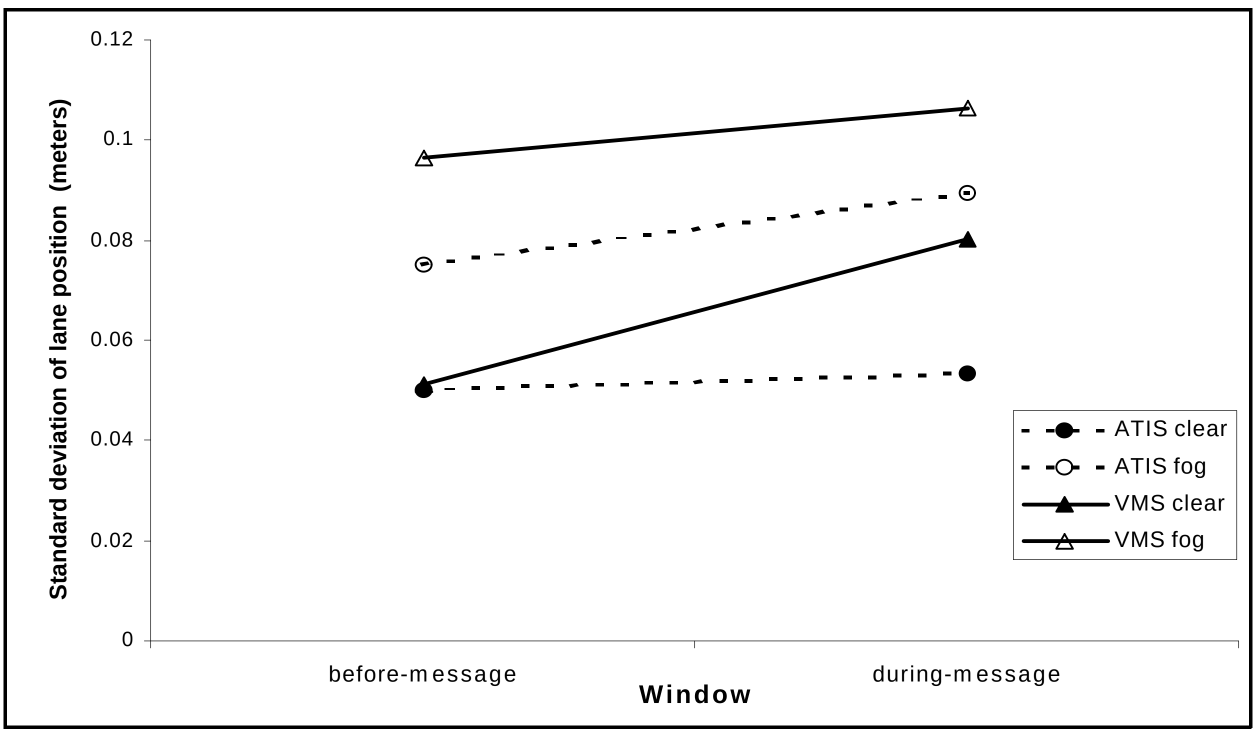

Figure 11. Influence of window, display location and visibility on standard deviation of lane position.

In summary, VMS messages did not influence the driving performance measures of mean speed, standard deviation of speed, or standard deviation of lane position. ATIS messages, on the other hand, caused a reduction in mean speed, but did not influence standard deviation of speed or standard deviation of lane position. The influence of ATIS and VMS on driving performance was consistent across two levels of visibility.

Response Times to Roadway Events

Two repeated measures analyses of variance were conducted to evaluate the influence of ATIS on drivers' responses to roadway events. The first analysis was performed on horn-button press latencies following the pedestrian events. The second analysis was performed on brake reaction times following the CAS events. Both analyses included the independent variables of gender and scenario order. In the CAS event, steering reaction times were also collected; however, all drivers reacted to this event by first pressing the brake pedal. Therefore, only the brake reaction times were analyzed.

Inspection of the data revealed that there were two outliers in the pedestrian event and one outlier in the CAS event that were more than two standard deviations away from the mean. The analyses were conducted excluding these outliers. All data, including the outliers, are presented in appendix H. Complete ANOVA tables can be seen in appendix I.

Figure 12 shows mean response times to the roadway events as a function of event condition. In the pedestrian event, horn-button press latency was significantly longer in the following-an-ATIS-message condition (M=1.63) than in the event-only condition (M=1.21), $F(1,5) = 16.82$, $p<0.01$. In the CAS event, brake response time in the following-an-ATIS-message condition (M=0.84) was not significantly different than in the event-only condition, (M=0.94), $F(1,7)=4.63$, $p>0.05$. These results indicate that drivers' recognition of unexpected roadway messages was negatively influenced by ATIS, but their response time to a CAS alert was not.

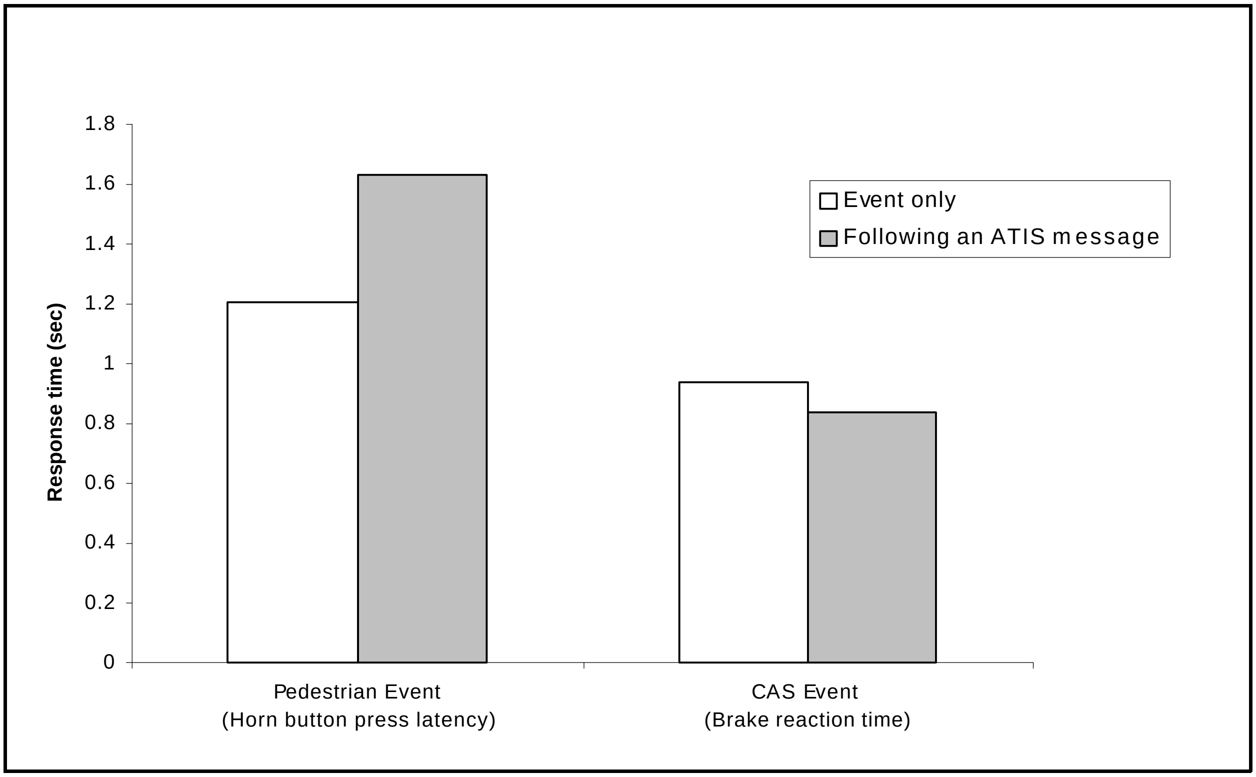

Figure 12. Response times to the pedestrian and CAS events as a function of event condition.

CHAPTER 4. CONCLUSIONS

This research combined a very efficient confounded experimental design used in experiment 1 (Phase I) with a traditional orthogonal design used in experiment 2 (Phase II). The goal of the first experiment was to quickly identify key independent variables that could be later studied in depth. While the efficient statistical model used in experiment 1 was successful, accounting for 84 percent of total variance in speed, this model must be used with great caution because of potential unknown higher-order confoundings. While such confounding is necessary to obtain an efficient design, it mandates careful interpretation. Appendix J contains a traditional statistical analysis for experiment 1, to the extent that this is possible given the intentional confoundings.

In general, conflicting results between experiments 1 and 2 should be resolved by favoring experiment 2, the full orthogonal statistical design. When we compare the effects of in-vehicle messages upon vehicle speed we note such a conflict. In experiment 1 (figure 3), mean speed was lower in the VMS condition. However, in experiment 2 (figure 9) mean speed was lower in the ATIS condition, and out-of-vehicle VMS messages did not alter speed. While reasonable interpretations can be given to either outcome, we believe that ATIS messages require more driver attention than VMS messages because of the requirement to shift attention from the roadway to inside the vehicle. Hence, we conclude that ATIS messages alter driving performance while VMS messages do not. In another Battelle simulator study (Kantowitz, Hanowski, and Garness, 1999) auditory and visual in-vehicle messages were accompanied by slight increases in vehicle speed and slight decreases in speed standard deviation. Again, in-vehicle messages affected driver performance. It seems reasonable to expect that, as the message set presented inside the vehicle expands as more in-vehicle devices are added, effects of message presentation will continue to alter driving performance.

Contrary to our expectations, effects of ATIS and VMS messages upon driving performance did not depend upon visibility conditions. Drivers in both clear and fog visibility performed consistently. However, this result needs to be replicated on the road before it can form a basis for guideline development.

From the viewpoint of information integration, the most important parts of these experiments investigated how ATIS and CAS operate jointly. Experiment 1 suggested (figure 7) that intermediate levels of urgency are the locus of greatest interaction effects; whether a collision event is either very urgent or not urgent, response time to the CAS event is not improved by having a CAS warning. In the most urgent collision situation an ATIS event did not prevent the fastest driver response time. However, the very small number of drivers tested in experiment 1 did not provide the statistical power to confirm these results.

Experiment 2 (figure 12) did demonstrate conclusively that an ATIS message interfered with the driver's ability to react to a pedestrian road incursion. However, an ATIS message did not interfere with a CAS warning.

These results suggest both benefits and costs to in-vehicle messages. The good news is that CAS warnings are sufficiently robust so that ATIS messages do not appear to interfere with the driver's ability to process CAS information, perhaps in part because both kinds of message occur within the vehicle avoiding the need to shift attention from the roadway. The bad news is that there appears to be an attentional cost to ATIS messages relative to processing external roadway events, such as pedestrians.

The present results from preliminary simulator experiments need to be expanded before design guidelines, especially for integration of in-vehicle systems, can be written with great confidence. However, these results do indicate that the simulator can provide a reasonable test bed for future evaluation of system interactions.

APPENDIX A: MESSAGES PRESENTED TO DRIVERS IN PHASE I

Table 12. Messages presented to drivers in phase I.

SCENARIO	INFORMATION LOCATION	MESSAGES PRESENTED
Practice 1		None
Practice 2	VMS	Axle weight limit: 5 tons Arboretum open dawn to dusk
Practice 3	ATIS	Snow storm expected tonight Oil change needed in 300 miles
Experimental scenario 1	ATIS	Slow down, construction ahead Merge left, right lane ends Use shoulder, rocks in lane Temperature: 56 degrees Slow down, slow vehicle ahead Pass on left, chemical spill ahead
Experimental scenario 2	VMS	Use left lane, slow vehicle ahead Tune to 92.5 for traffic updates Slow down, pedestrian crossing ahead Use shoulder, lane blocked ahead Slow down, road maintenance ahead
Experimental scenario 3	VMS	Use shoulder, road repair ahead Bicycles, use shoulder only Move right, accident ahead Slow down, school zone ahead Merge left, construction ahead Slow down, workers on bridge
Experimental scenario 4	ATIS	Road closed for paving tomorrow Use shoulder, road narrows ahead Pass with caution, accident ahead Slow down, new speed limit ahead Merge left, right lane closed

APPENDIX B: SUBJECT SELECTION PHONE QUESTIONNAIRE

Subject Name ______________________________ **Phone Number _________**

Age _______ **Gender ______ (1=M, 0=F)**

1) Do you have an active driver's license? _____Yes (1) _____ No (2)
[Exclude subject if answer is NO]

2) How many times per week do you drive in Seattle?
_____< 1X (1) _____1X (2) _____2 or more (3)
[Exclude subject if answer is “Once or less”.]

3) Do you ever experience motion sickness while driving or riding in a vehicle (e.g., car, bus, train, plane, boat)?
_____Never (1) _____Sometimes (2) _____ Often (3)

[If answer is “Sometimes or Often,” inform subject of the following:
“One potential risk with any simulator study is the possibility of “simulator sickness.” Simulator sickness is similar to the motion sickness that some people experience when traveling in a vehicle. Because you often experience motion sickness, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies which do not involve the simulator, if you wish.”]

4) Past research has suggested that this type of simulator research may not be suitable for individuals who experience migraine or tension headaches? Do you experience either of those?

_____ No (1) _____Yes (2)

[If answer is Yes, question the subject further. If they have experienced a migraine recently, or experience migraines frequently, inform subject of the following.
“One potential risk with any simulator study is the possibility of “simulator sickness.” Simulator sickness is similar to the motion sickness that some people experience when traveling in a vehicle. Research shows that people who experience migraines or tension headaches may be more susceptible to simulator sickness. Because you often experience migraines, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies which do not involve the simulator, if you wish.”]

5) Also, this type of simulator research may not be suitable for individuals who suffer from a serious heart condition. Do you suffer from a heart condition ?

_____No (1) **_____Yes (2)**

[If yes, inform the subject of the following:
"Due to your heart condition, we must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies which do not involve the simulator, if you wish."]

6) If female: Also, simulator research may not be suitable for women that are pregnant. Are you pregnant?

_____No (1) **_____Yes (2)**

[If yes, inform the subject of the following:
"One potential risk with any simulator study is the possibility of "simulator sickness." Simulator sickness is similar to the motion sickness that some people experience when traveling in a vehicle. Because you are pregnant, and therefore prone to nausea, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies which do not involve the simulator, if you wish."]

7) Do you suffer from any condition or take any medications that predispose you to nausea, blurred vision, or drowsiness?

_____No (1) **_____Yes (2)**

[If yes, inform the subject of the following
"One potential risk with any simulator study is the possibility of "simulator sickness." Simulator sickness is similar to the motion sickness that some people experience when traveling in a vehicle. Because of your condition/medication, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies which do not involve the simulator, if you wish."]

APPENDIX C: DRIVER DEMOGRAPHIC CHARACTERISTICS QUESTIONNAIRE

Subject ID: __________

1. Age: _____

2. Number of years as a licensed driver: _____

3. Number of years driving in Seattle: _____

4. Number of years lived in Seattle _____

4. Town of residence: _________________________ Zipcode _______________

5. Gender: G Male G Female

6. What is the average number of miles you drive annually?

G less than 5,000
G 5,000 - 9,999
G 10,000 - 19,999
G 20,000 - 39,999
G 40,000 - 69,999
G 70,000 - 99,999
G more than 100,000

7. Where did you learn about this research? ___________________________________

APPENDIX D: RESEARCH PARTICIPATION INFORMATION SUMMARY

The purpose of this experiment is to discover your reactions to new technology that will soon be available for passenger automobiles. This technology presents messages, either inside the vehicle or on external message signs, that inform you about current highway conditions. This experiment uses a driving simulator to study how people react to these messages. Our goal is to make driving safer and more pleasant by using new technology.

If you agree to participate in this study, you will be asked to complete a short practice session to familiarize yourself with the simulator. The practice session will be followed by several driving sessions. The entire study should take no more than 3 hours to complete. You will receive $10 an hour for your participation.

You should know that a small number of people experience something similar to motion sickness when operating simulators. The effects are typically slight and usually consist of an odd feeling or warmth. If you feel uncomfortable, you may ask to quit at any time. Most people enjoy driving the simulator and do not experience any discomfort.

All data obtained are for research purposes only and will remain confidential. Names will not be associated with the questionnaires in any way and no data will be reported to licensing authorities or insurance companies. The information will be reviewed by both Battelle and Federal Highway Administration (FHWA) scientists, and the data will remain with Battelle and the FHWA. It is your privilege to withdraw from this study at any time. If you withdraw, you will be paid for the time that you have participated without the loss of any benefits.

APPENDIX E: CONSENT FORM.

I have read the attached statement and agree to permit the use of my responses for research purposes.

______________________	____________	____________
Signature of Participant	Date of Birth	Today's Date
______________________	____________________	
Please Print Name	Social Security Number	

Permanent Mailing Address: ________________________________

____

______________________	____________
Signature of Experimenter	Today's Date

Record of Payment:

One session @ $10.00 per hour Amt. Paid ____________

______________________	____________
Signature of Participant	Today's Date
______________________	____________
Signature of Experimenter	Today's Date

APPENDIX F: SUBJECT COMFORT ASSESSMENT QUESTIONNAIRE

Subject #__________

Directions: Please indicate whether your symptoms are none (0), slight (1), moderate (2), or severe (3).

Symptom:	**Pre-test**	**Pract 1**	**Pract 2**	**Pract 3**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**
General discomfort								
Drowsiness								
Headache								
Sweating								
Nausea								
Blurred vision								
Dizziness when eyes are open								
Dizziness when eyes are closed								
Faintness								
Stomach discomfort								

APPENDIX G. PHASE I ANALYSIS OF COVARIANCE TABLES

Table 13. Analysis of covariance for mean speed.

SOURCE	df	MS	F	p	GREENHOUSE-GEISSER	HUYNH-FELDT	REGRESSION COEFFICIENT
Information Location (I)	**1**	**257.65**	**23.52**	**0.0000**			
Message Type (M)	**2**	**77.40**	**7.07**	**0.0014**			
Speed (S)	**1**	**2719.26**	**248.27**	**0.0000**			
Visibility (V)	1	16.21	1.48	0.2270			
Curvature (B)	**1**	**122.85**	**11.22**	**0.0012**			
Traffic Density (T)	1	4.33	0.40	0.5309			
Car Size	1	32.10	2.93	0.0904			
Decision Time (D)	1	15.20	1.39	0.2420			
Road Type (R)	**1**	**58.74**	**5.36**	**0.0228**			
M × S	2	24.47	2.23	0.1130			
Reaction Time Covariate	1	9.07	0.83	0.3652			0.0048
Tracking Covariate	1	16.66	1.52	0.2207			-12.0367
All covariates	2	24.97	2.28	0.1082			
ERROR	90	10.95					
Window (W)	**2**	**135.60**	**28.56**	**0.0000**	**0.0000**	**0.0000**	
W × I	**2**	**32.94**	**6.94**	**0.0012**	**0.0020**	**0.0012**	
W × M	**4**	**67.39**	**14.19**	**0.0000**	**0.0000**	**0.0000**	
W × S	**2**	**168.98**	**35.59**	**0.0000**	**0.0000**	**0.0000**	
W × V	2	6.44	1.36	0.2600	0.2595	0.2600	
W × B	**2**	**37.84**	**7.97**	**0.0005**	**0.0008**	**0.0005**	
W × T	2	3.51	0.74	0.4793	0.4642	0.4793	
W × E	2	5.19	1.09	0.3373	0.3317	0.3373	
W × D	2	4.33	0.91	0.4033	0.3932	0.4033	
W × R	**2**	**48.38**	**10.19**	**0.0001**	**0.0001**	**0.0001**	
W × M × S	**4**	**22.03**	**4.64**	**0.0014**	**0.0022**	**0.0014**	
ERROR	184	4.75					

Table 14. Analysis of covariance for response times to unexpected events.

SOURCE	df	MS	F	p	REGRESSION COEFFICIENT
Car Size	1	0.23528	1.55	0.2245	
Information Location (I)	1	0.00364	0.02	0.878	
Visibility (V)	1	0.03446	0.23	0.6376	
I × V	1	0.19227	1.27	0.2708	
Reaction Time Covariate	**1**	**0.82451**	**5.45**	**0.0283**	**0.004**
ERROR	24	0.15133			

Table 15. Analysis of covariance for response times to CAS events.

SOURCE	df	MS	F	p	REGRESSION COEFFICIENT
CAS Status	1	0.08982	0.94	0.3505	
Car Size	**1**	**0.67888**	**7.09**	**0.0195**	
Event	**2**	**0.56099**	**5.86**	**0.0154**	
CI	2	0.22927	2.39	0.1303	
Reaction Time Covariate	1	0.01398	0.15	0.7086	-0.0008
ERROR	13	0.09577			

APPENDIX H. PHASE II ROADWAY-EVENT DATA

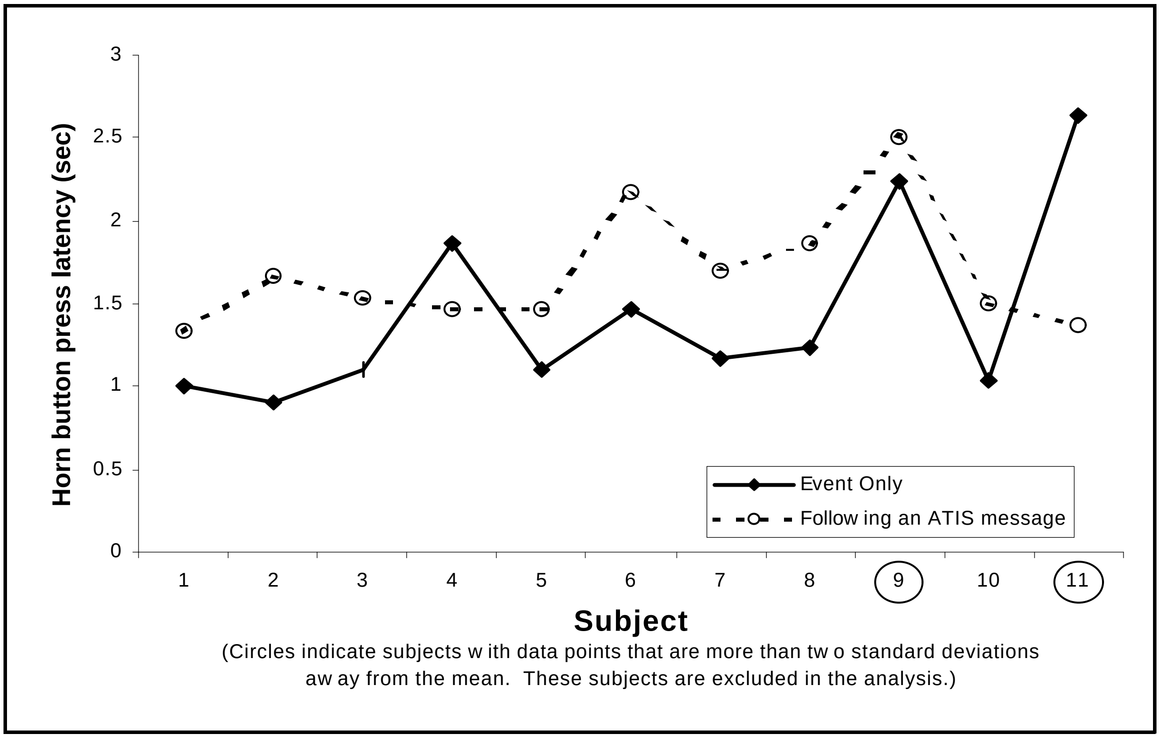

Figure 13. Horn-button press latencies following pedestrian events.

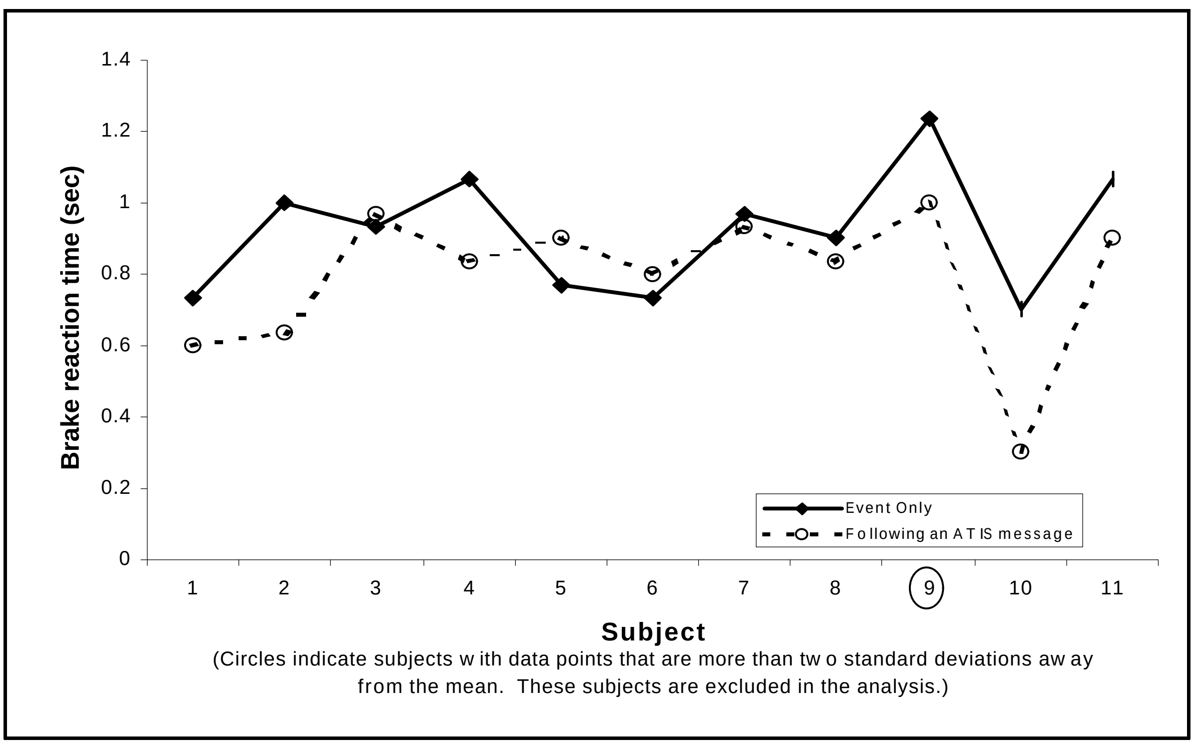

Figure 14. Brake reaction times following a CAS event.

APPENDIX I. PHASE II ANALYSIS OF VARIANCE TABLES

Table 16. Analysis of variance for mean speed.

SOURCE	df	MS	F	p
Scenario Order (S)	1	6.73408	2.52	0.1564
Gender (G)	1	0.67066	0.25	0.6317
S×G	1	1.13735	0.43	0.5349
ERROR	7	2.67119		
Window (W)	1	0.87769	1.57	0.2505
W×S	1	0.02329	0.04	0.8441
W×G	1	0.22566	0.4	0.5454
W×S×G	1	0.4823	0.86	0.3839
ERROR	7	0.55908		
Visibility (V)	1	10.00614	4.75	0.0657
V×S	1	3.00498	1.43	0.2713
V×G	1	1.12873	0.54	0.488
V×S×G	1	6.1979	2.94	0.1301
ERROR	7	2.10716		
W×V	1	0.05386	0.36	0.5683
W×V×S	1	0.12419	0.83	0.3936
W×V×G	1	0.54099	3.6	0.0997
W×V×S×G	1	0.00843	0.06	0.8196
ERROR	7	0.15034		
Information Location (I)	1	6.07163	0.81	0.3982
I×S	1	0.96465	0.13	0.7305
I×G	1	0.04498	0.01	0.9404
I×S×G	1	0.56203	0.07	0.7922
ERROR	7	7.5023		

SOURCE	df	MS	F	p
W×I	**1**	**1.43734**	**28.76**	**0.001**
W×I×S	1	0.09603	1.92	0.2082
W×I×G	1	0.1674	3.35	0.1099
W×I×S×G	**1**	**0.35533**	**7.11**	**0.0322**
ERROR	7	0.04998		
V×I	1	5.24215	3.43	0.1066
V×I×S	1	2.33708	1.53	0.2564
V×I×G	1	0.59978	0.39	0.5511
V×I×S×G	1	1.61139	1.05	0.339
ERROR	7	1.53019		
W×V×I	1	0.56201	4.76	0.0655
W×V×I×S	1	0.43502	3.68	0.0964
W×V×I×G	1	0.08019	0.68	0.4371
W×V×I×S×G	**1**	**0.77393**	**6.55**	**0.0376**
ERROR	7	0.1181		

Table 17. Analysis of variance for standard deviation of speed.

SOURCE	df	MS	F	p
Scenario Order (S)	1	0.01028	0.09	0.7704
Gender (G)	1	0.02687	0.24	0.6388
S×G	1	0.05909	0.53	0.4906
ERROR	7	0.1117		
Window (W)	1	0.01502	0.44	0.5297
W×S	1	0.00106	0.03	0.8654
W×G	1	0.02658	0.77	0.4083
W×S×G	1	0.00282	0.08	0.7828
ERROR	7	0.03436		

SOURCE	df	MS	F	p
Visibility (V)	1	0.00539	0.3	0.6008
V×S	1	0.03744	2.09	0.1917
V×G	1	0.00134	0.07	0.7924
V×S×G	**1**	**0.22129**	**12.34**	**0.0098**
ERROR	7	0.01794		
W×V	1	0.02851	2.03	0.1972
W×V×S	1	0.00849	0.6	0.4623
W×V×G	1	0.00443	0.32	0.592
W×V×S×G	1	0.00143	0.1	0.7591
ERROR	7	0.01405		
Information Location (I)	1	0.1288	3.5	0.1037
I×S	1	0.00109	0.03	0.8685
I×G	1	0.04639	1.26	0.2988
I×S×G	1	0.10459	2.84	0.1359
ERROR	7	0.03685		
W×I	1	0.04273	2.17	0.1841
W×I×S	1	0.01192	0.61	0.4618
W×I×G	1	0.0547	2.78	0.1394
W×I×S×G	1	0.00144	0.07	0.7945
ERROR	7	0.01968		
V×I	1	0.00276	0.15	0.7123
V×I×S	1	0.0766	4.09	0.0828
V×I×G	1	0.02321	1.24	0.3024
V×I×S×G	1	0.01241	0.66	0.4425
ERROR	7	0.01873		

SOURCE	df	MS	F	p
W×V×I	1	0.00604	0.17	0.6932
W×V×I×S	1	0.01271	0.36	0.5696
W×V×I×G	1	0.01036	0.29	0.6068
W×V×I×S×G	1	0.02949	0.83	0.3938
ERROR	7	0.03572		

Table 18. Analysis of variance for standard deviation of lane position.

SOURCE	df	MS	F	p
Scenario Order (S)	1	0.00353	1.13	0.3234
Gender (G)	1	0.0004	0.13	0.7317
S×G	**1**	**0.01846**	**5.89**	**0.0456**
ERROR	7	0.00313		
Window (W)	1	0.00648	3.4	0.1078
W×S	1	0.00227	1.19	0.3112
W×G	1	0.00623	3.27	0.1136
W×S×G	1	0.00158	0.83	0.3933
ERROR	7	0.00191		
Visibility (V)	1	0.02203	4.05	0.0842
V×S	1	0.00946	1.74	0.2288
V×G	1	0.00002	0	0.9561
V×S×G	1	0.00152	0.28	0.6133
ERROR	7	0.00544		
W×V	1	0.00023	0.25	0.6353
W×V×S	1	0.00058	0.63	0.4539
W×V×G	1	0.00161	1.75	0.2279
W×V×S×G	1	0	0	0.959
ERROR	7	0.00092		

SOURCE	df	MS	F	p
Information Location (I)	1	0.00958	2.99	0.1275
I×S	1	0.00891	2.78	0.1394
I×G	1	0.00926	2.89	0.133
I×S×G	1	0.00199	0.62	0.4564
ERROR	7	0.00321		
W×I	1	0.00092	0.36	0.569
W×I×S	1	0.00182	0.7	0.4292
W×I×G	1	0.00239	0.93	0.3681
W×I×S×G	1	0.00267	1.04	0.3424
ERROR	7	0.00258		
V×I	1	0.00063	0.19	0.6725
V×I×S	1	0.00185	0.57	0.475
V×I×G	1	0.00301	0.93	0.3678
V×I×S×G	1	0.00191	0.59	0.4683
ERROR	7	0.00325		
W×V×I	1	0.00189	0.93	0.3658
W×V×I×S	1	0.00034	0.17	0.6952
W×V×I×G	1	0.00011	0.05	0.8251
W×V×I×S×G	1	0.00488	2.41	0.1642
ERROR	7	0.00202		

Table 19. Analysis of variance for horn-button press latency following the pedestrian events.

SOURCE	df	MS	F	p
Gender (G)	1	0.16279	1.59	0.2624
Scenario Order (S)	1	0.06677	0.65	0.4555
G×S	1	0.02367	0.23	0.6505
ERROR	5	0.10212		
Condition (C)	**1**	**0.93432**	**16.82**	**0.0093**
C×G	1	0.06374	1.15	0.333
C×S	1	0.04741	0.85	0.398
C×G×S	1	0.04738	0.85	0.3981
ERROR	5	0.05555		

Table 20. Analysis of variance for brake reaction time following the CAS events.

SOURCE	df	MS	F	p
Scenario Order (S)	1	0.03797	1.28	0.3008
Gender (G)	1	0.05932	2.00	0.2068
S×G	1	0.03117	1.05	0.3445
ERROR	6	0.02962		
Condition (C)	1	0.0593	4.63	0.075
C×S	1	0.01635	1.28	0.3018
C×G	1	0.00301	0.24	0.6449
C×S×G	1	0.01481	1.16	0.3237
ERROR	6	0.01282		

APPENDIX J. TRADITIONAL STATISTICAL ANALYSIS FOR PHASE I

This section summarizes the traditional statistical analyses conducted in Phase I. Of main interest were effects of information location, and interaction of information location with visibility, road type, curvature, and traffic density. Speed limit and message type were confounding factors for all analysis variables. Sample size limitations did not allow for analyses with speed limit as an additional factor. Instead, analyses were performed separately for speed limits of 30 mi/h and 60 mi/h. Message type was included in the analyses as a separate factor; this was made possible by combining neutral and change-lane messages, creating two message types, (1) slow-down, and (2) other.

Cases with unexpected events and collisions were excluded. Remaining data were then averaged for the dependent variable (mean speed) over irrelevant factors for the eight sampled individuals. When possible, analyses were completed using Repeated Measures Analysis of Variance. All reports of significance are based on an alpha level of 0.05. Due to the extremely small sample size, non-random sampling procedure, and missing data, we suggest directing attention to patterns that can be seen in the plots, while using the formal analysis as a guide to large differences. In many cases, small sample sizes precluded the implementation of Repeated Measures. In these cases, only plots of sample means are provided.

Figures 15 and 16 show the influence of information location on mean speed, controlling for speed limit and message type. At 30 mi/h, there is no significant difference in average speed between ATIS use and VMS use for "Slow Down" as well as for other message types. This is illustrated in table 21, which shows a Repeated Measures Analysis of Variance on mean speed in the 30 mi/h condition.

At 60 mi/h, controlling for message type, average speed is significantly different between VMS and ATIS conditions, where VMS is associated with a larger decrease in mean speed from the before-message window to the during-message window. The relevant analysis can be seen in table 22. One outlier greatly affecting the pre-window average speed (average speed = 8.09) was excluded in the analyses.

Figures 17 through 24 show the interaction of information location with each of the additional independent variables: visibility, road type, traffic density, and curvature. It was not possible to conduct Repeated Measures analyses including information location, message type, and an additional factor. This was due to the minimal or no sample data points in a number of cells.

This analysis shows that at 60 mi/h, VMS use is associated with a greater decrease in mean speed than ATIS use. Our results show that both the speed limit and the message type displayed via ATIS or VMS have a great impact on mean speed. With respect to the message type variable, when measuring average speed, the "Slow Down" message particularly affects the outcome. Once these variables are controlled for, then small sample sizes and empty cells preclude formal analyses. However, this study does point to a possible relationship between information location and the performance measure of mean speed. The results point to relevant confounders and sample size restrictions that will have to be addressed in a larger study that may shed further light on the subject.

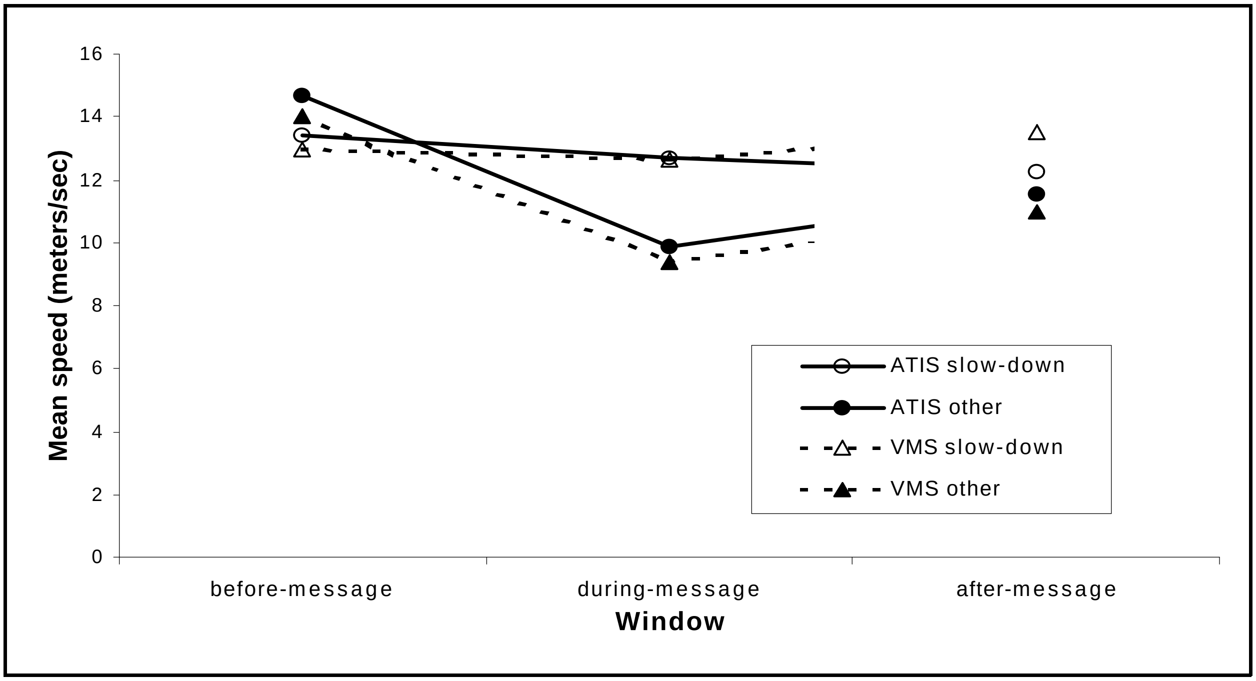

Figure 15. Mean speed in the 30 mph condition as a function of message type and information location (averaged over all other factors).

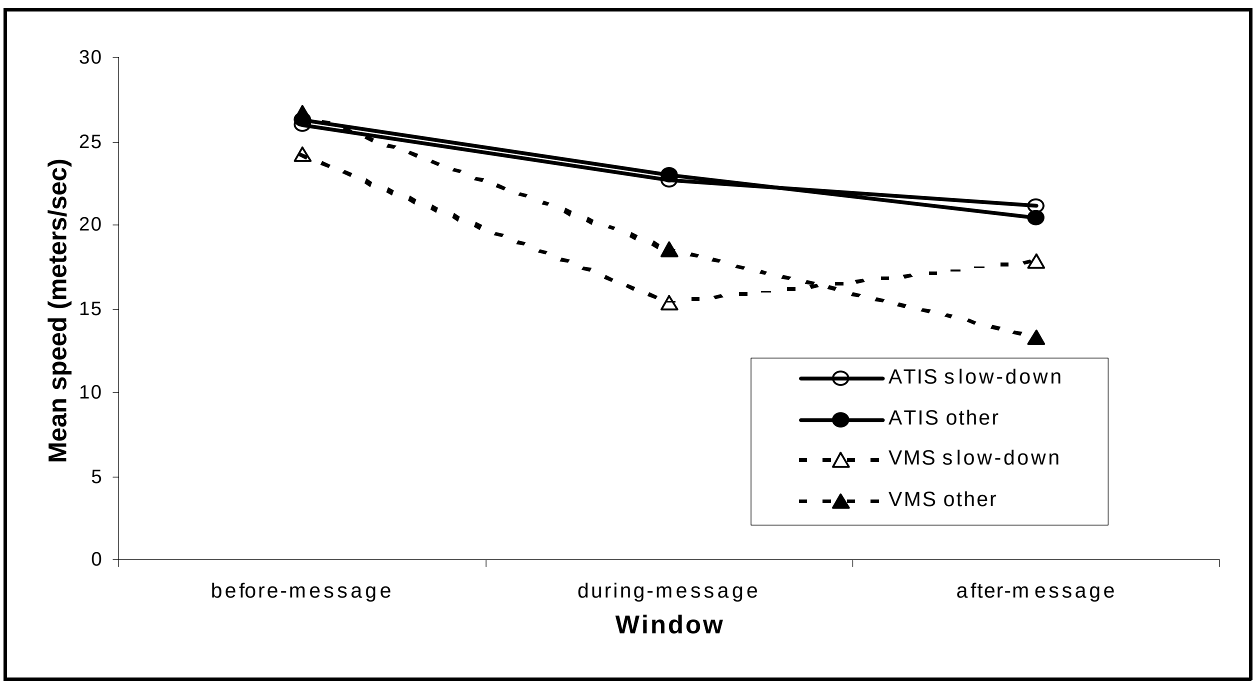

Figure 16. Mean speed in the 60 mph condition as a function of message type and information location (averaged over all other factors).

Table 21. Repeated measures analysis of variance for mean speed in the 30 mi/h condition.

SOURCE	df	MS	F	p
Information Location (I)	1	0.574	0.128	0.733
ERROR	6	4.482		
Message Type (M)	**1**	**28.740**	**6.659**	**0.042**
ERROR	6	4.316		
Window (W)	**2**	**49.183**	**29.241**	**0.000**
ERROR	12	1.682		
I×M	1	3.468	2.572	0.160
ERROR	6	1.348		
I×W	2	1.518	1.071	0.373
ERROR	12	1.418		
M×W	**2**	**31.543**	**16.444**	**0.000**
ERROR	12	1.918		
I×M×W	2	1.298	2.040	0.173
ERROR	12	0.636		

Table 22. Repeated measures analysis of variance for mean speed in the 60 mi/h condition.

SOURCE	df	MS	F	p
Information Location (I)	**1**	**364.788**	**69.946**	**0.000**
ERROR	7	5.215		
Message Type (M)	1	0.838	0.143	0.716
ERROR	7	5.855		
Window (W)	**2**	**512.397**	**73.340**	**0.000**
ERROR	14	6.987		
I×M	1	0.980	0.114	0.745
ERROR	7	8.589		
I×W	**2**	**65.281**	**17.721**	**0.000**
ERROR	14	3.684		
M×W	**2**	**47.777**	**7.530**	**0.006**
ERROR	14	6.345		
I×M×W	**2**	**27.060**	**12.261**	**0.001**
ERROR	14	2.207		

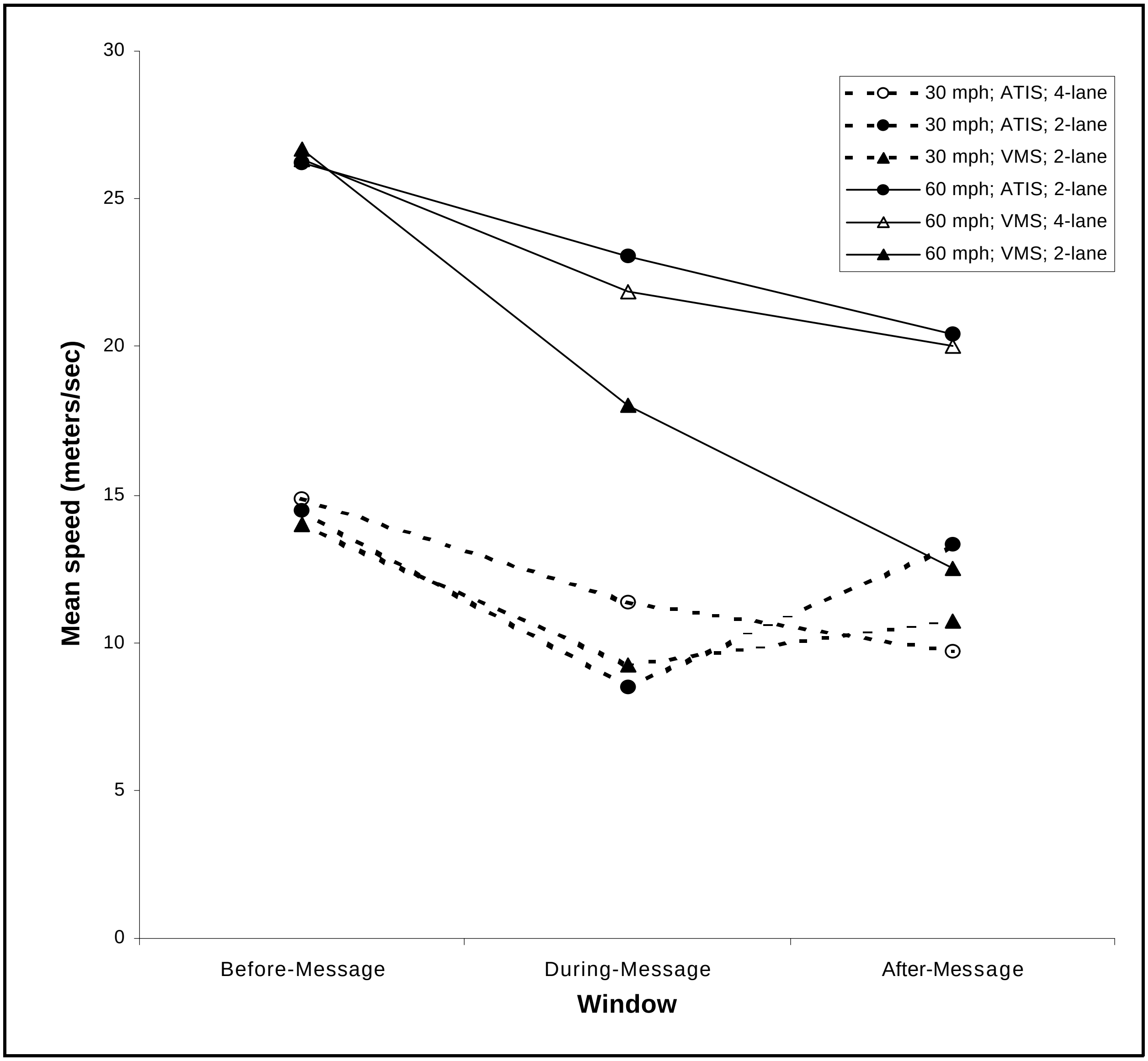

Figure 17. Information location × road type × speed limit × window interaction for slow-down messages (averaged over all other factors).

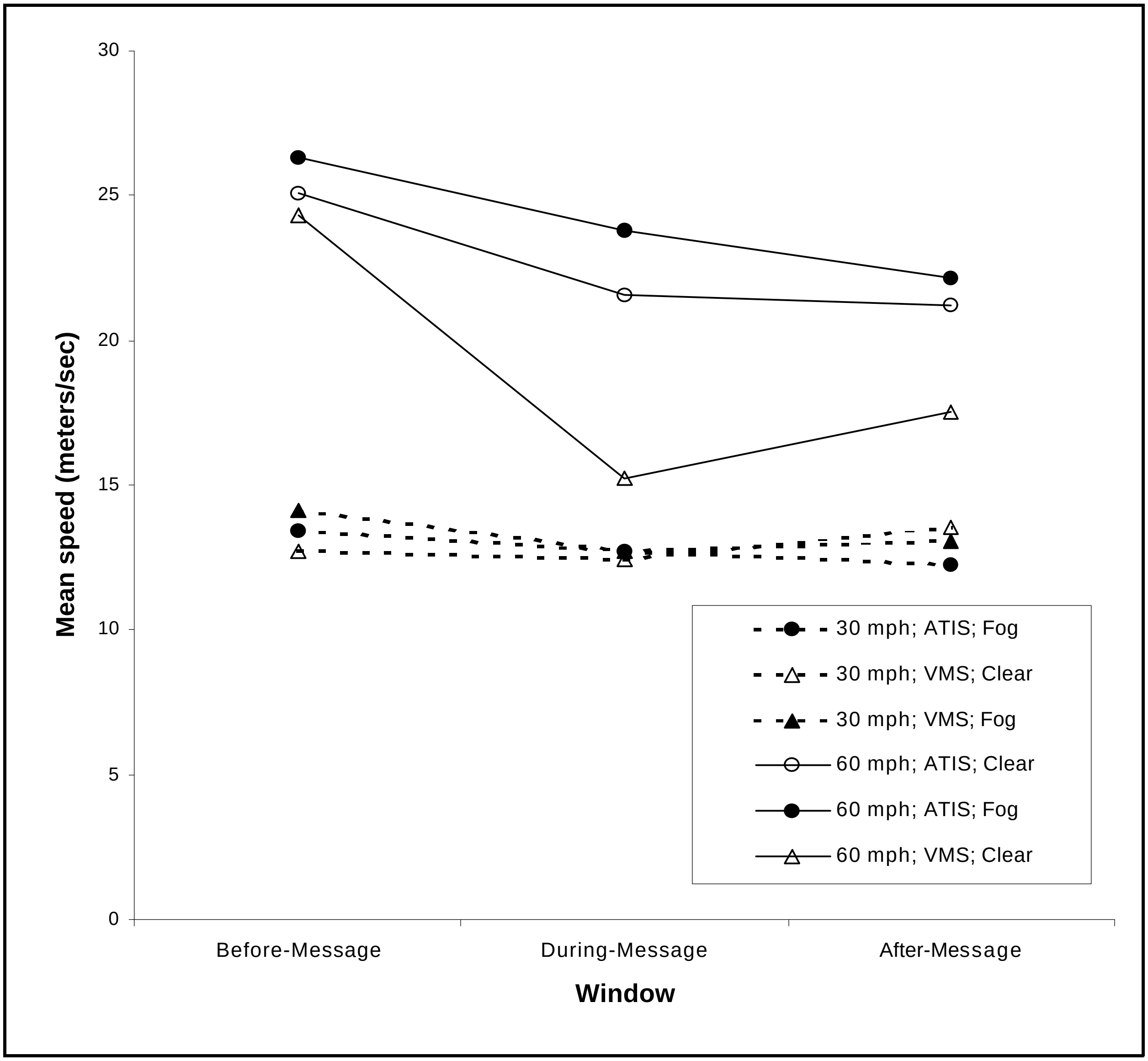

Figure 18. Information location × visibility × speed limit × window interaction for other messages (averaged over all other factors).

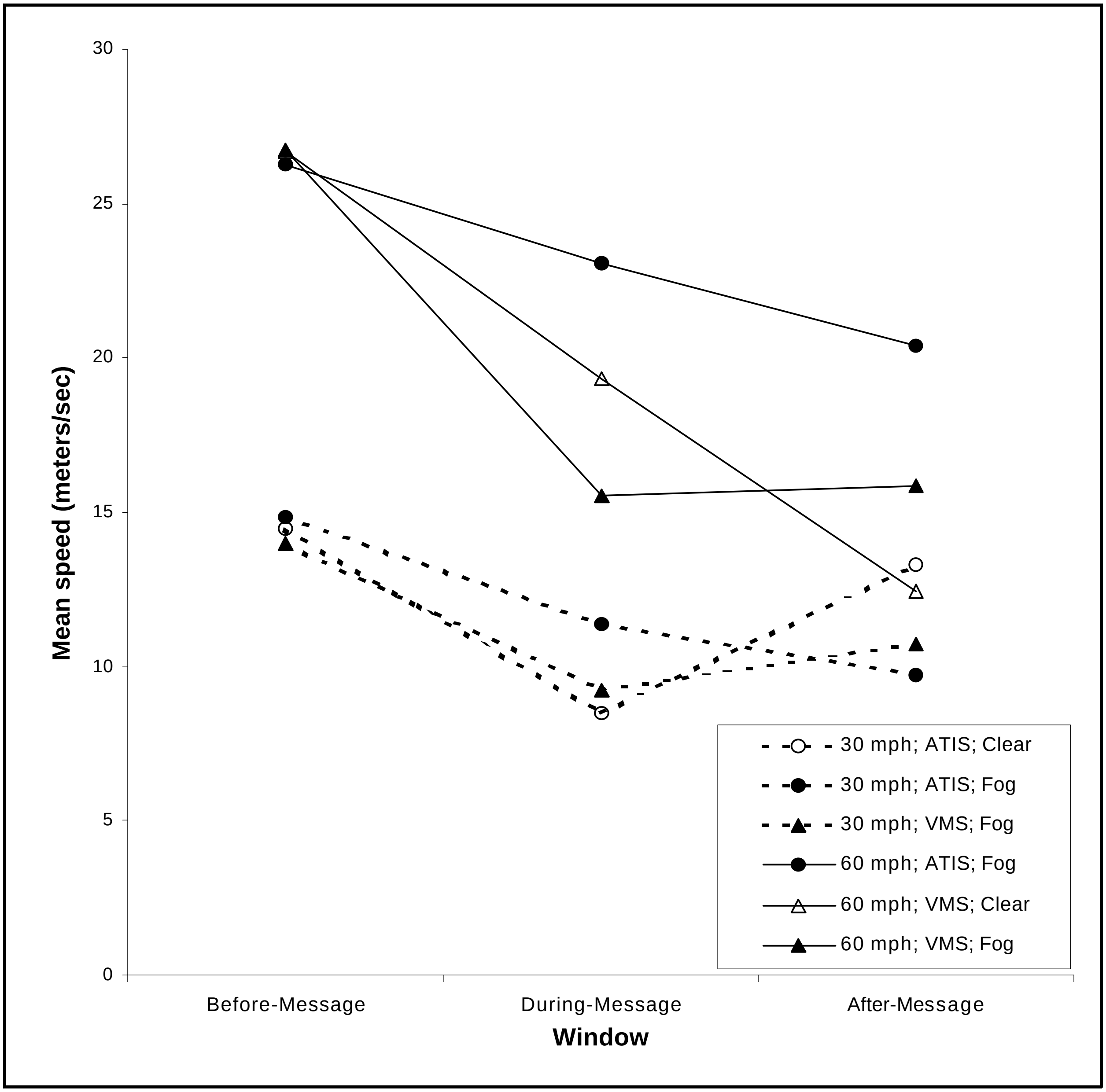

Figure 19. Information location × visibility × speed limit × window interaction for slow-down messages (averaged over all other factors).

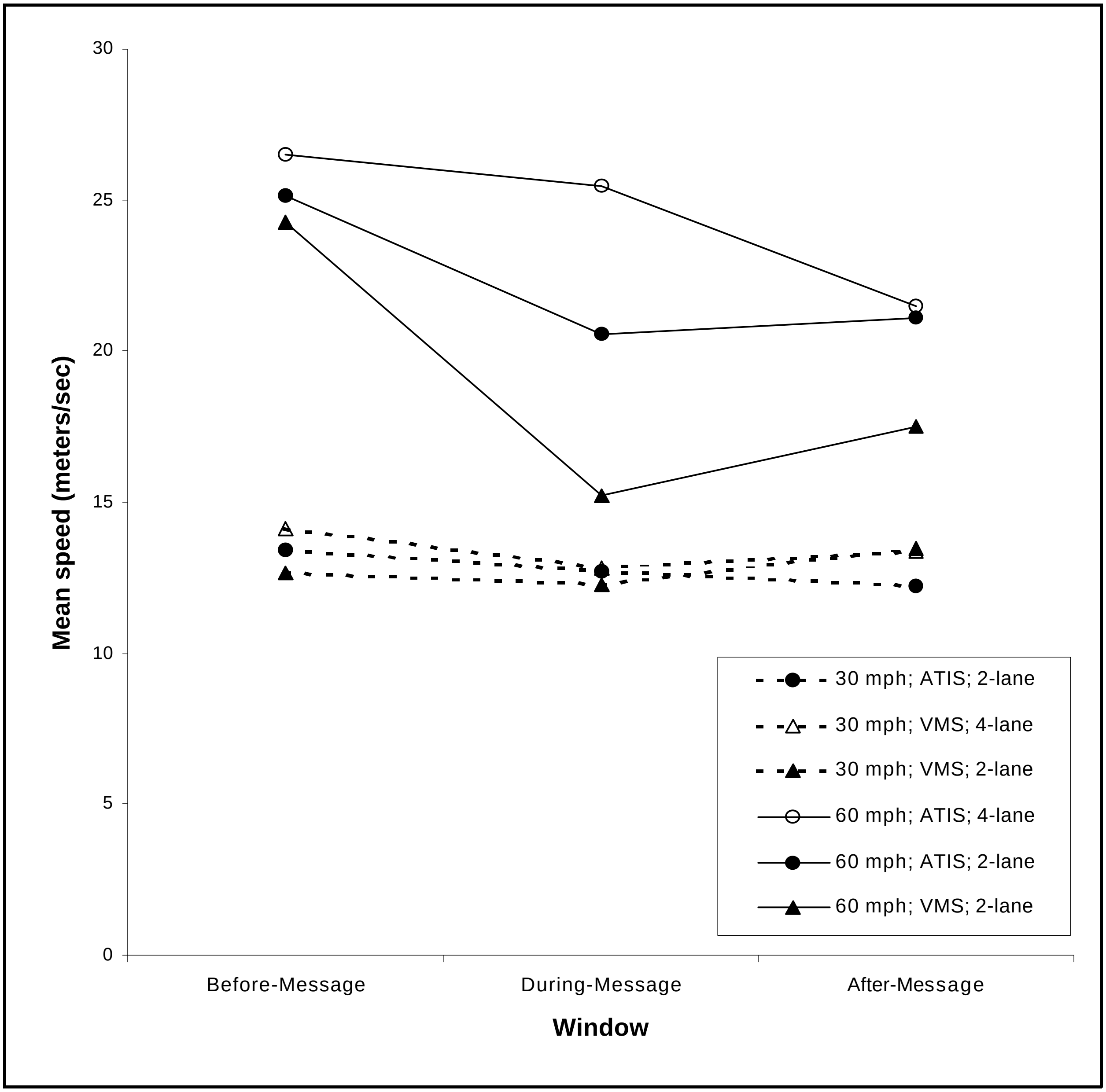

Figure 20. Information location × road type × speed limit × window interaction for other messages (averaged over all other factors).

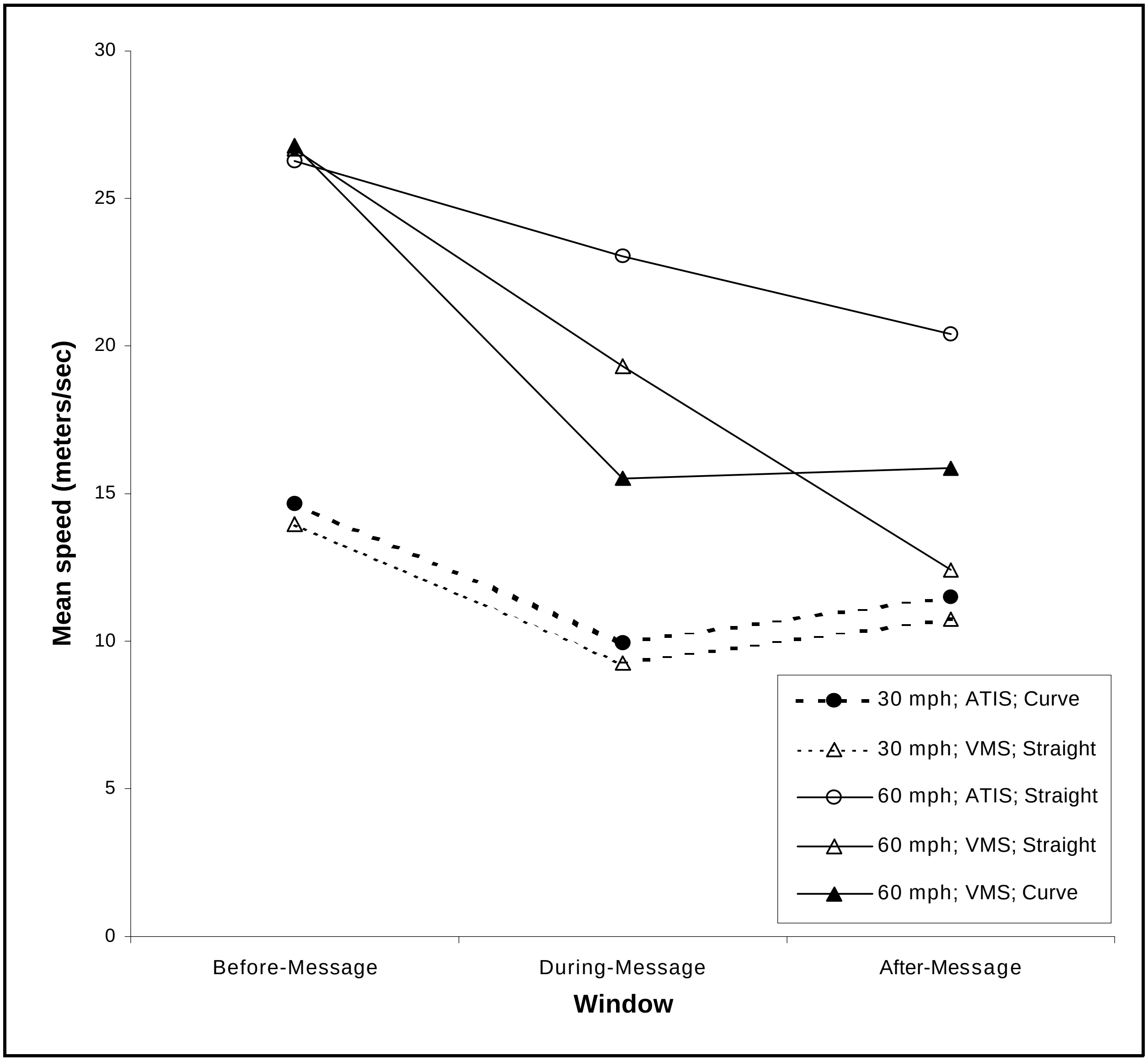

Figure 21. Information location × speed limit × curvature × window interaction for slow-down messages (averaged over all other factors).

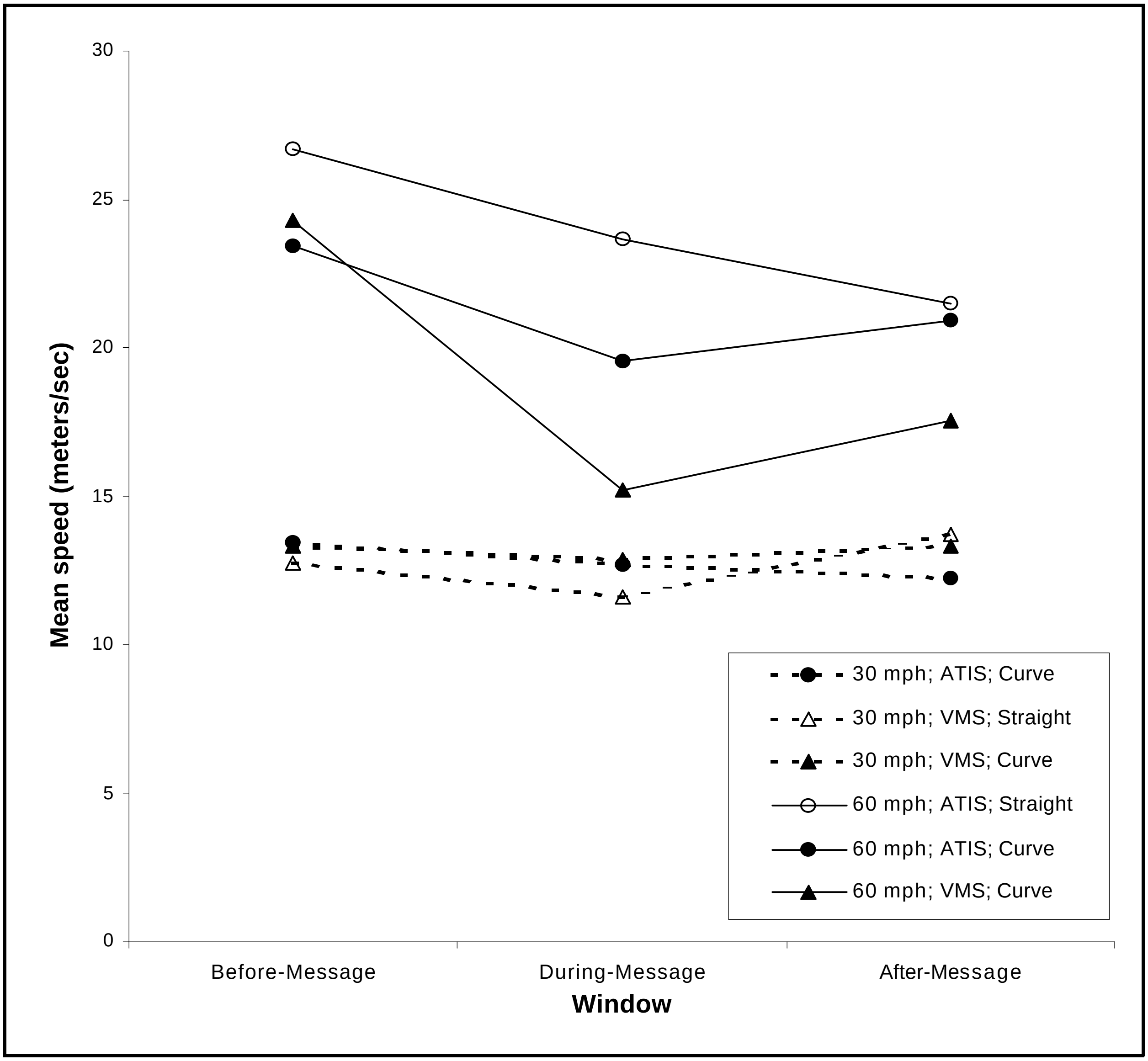

Figure 22. Information location × speed limit × curvature × window interaction for other messages (averaged over all other factors).

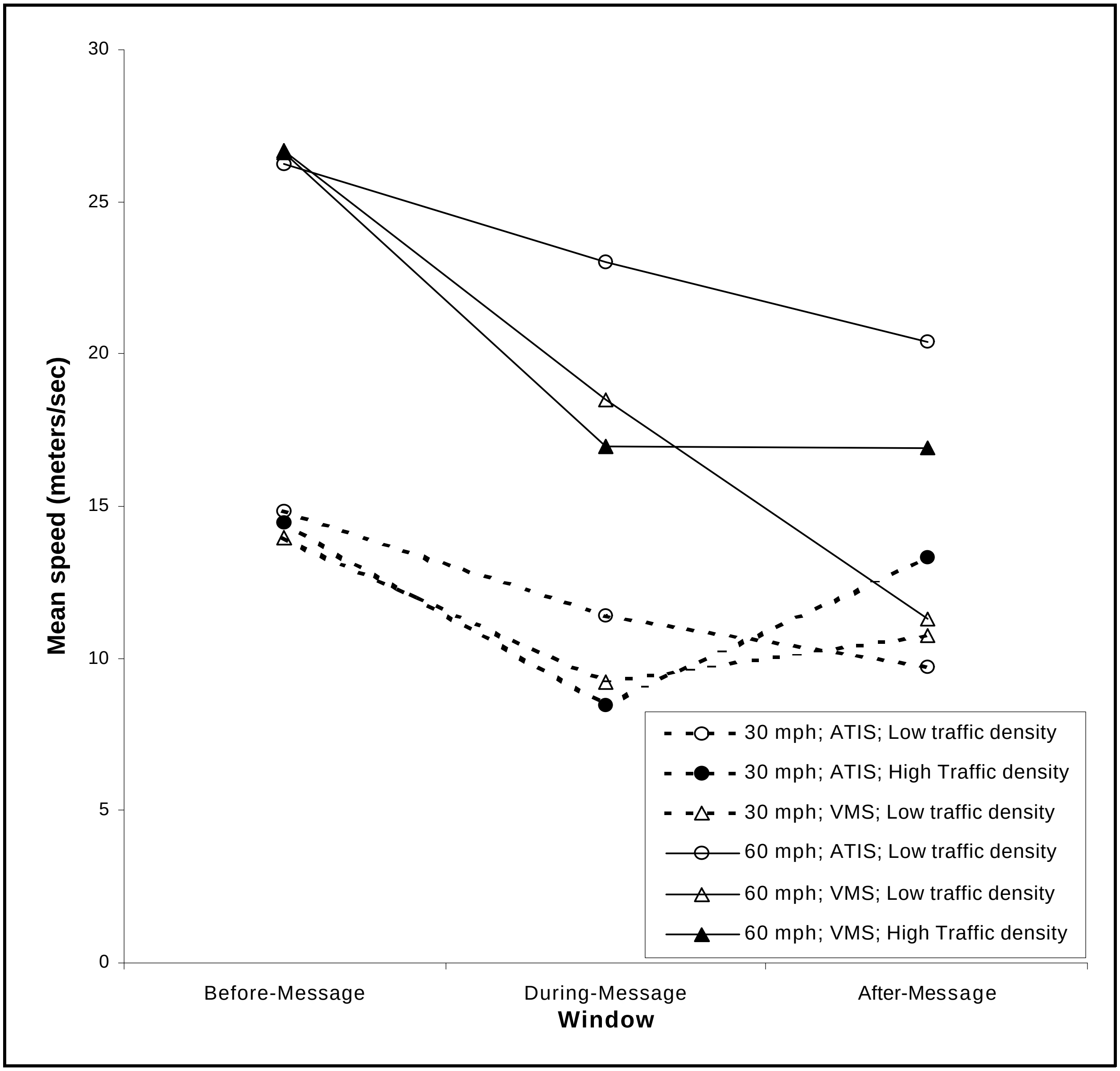

Figure 23. Information location × speed limit × traffic density × window interaction for slow-down messages (averaged over all other factors).

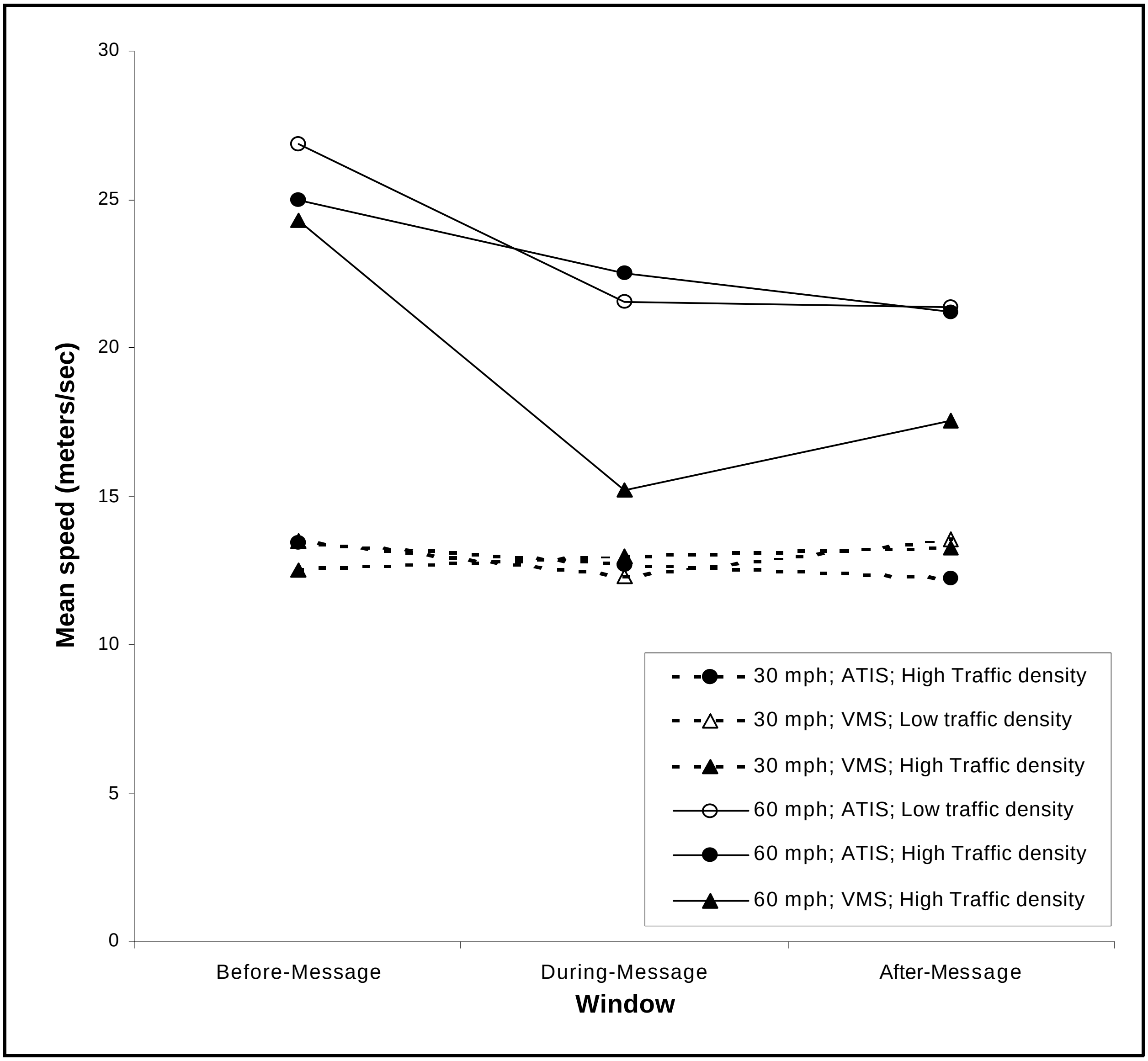

Figure 24. Information location × speed limit × traffic density × window interaction for other messages (averaged over all other factors).

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